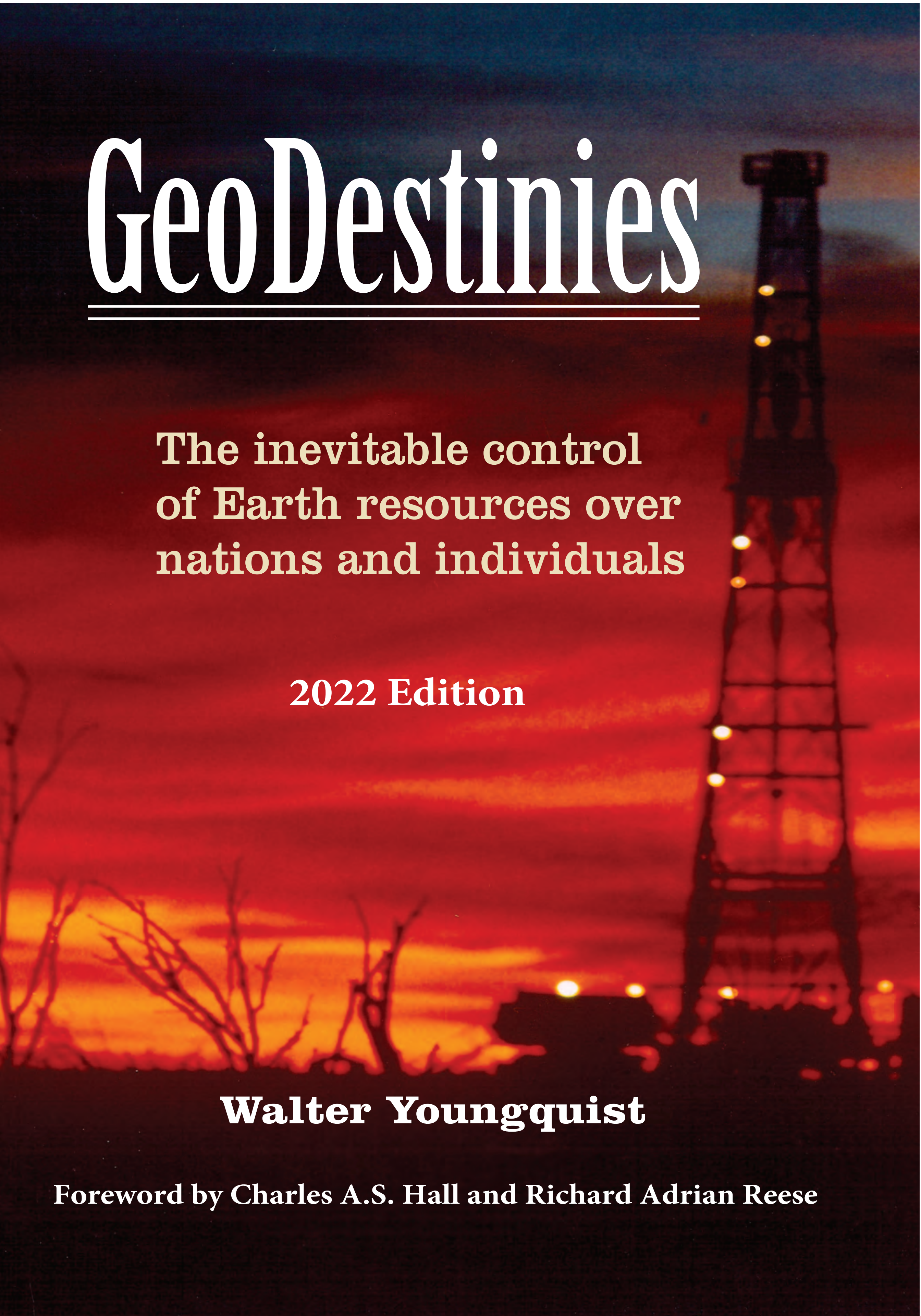

GeoDestinies

The inevitable control of Earth resources over nations and individuals

2022 Edition

Walter Youngquist

Foreword by Charles A.S. Hall and Richard Adrian Reese

GeoDestinies

Note to the 2022 Edition of *Geodestinies*, by Walter Youngquist

The original edition of Walter Youngquist's classic exposé of how minerals and nonrenewable resources underpin the history of humankind and control our destiny even today, in spite of all our vaunted technological advances, was published in 1997. The tumultuous events of the following decade and a half – including terrorist attacks, wars, and advancing resource depletion – convinced Walter that a new and updated edition of *Geodestinies: The inevitable control of Earth resources over nations and individuals* was in order.

After the first printing of *GeoDestinies* sold out, many urged him to print more. Unfortunately, the global resource story was a fast-moving target. Walter wanted to update the text before the next printing, but he couldn't write as fast as the issue was unfolding. An updated manuscript was finally completed in April 2012 – two months after his 92nd birthday. The publication process hit some curves, and it's now ten years later. **The copyediting process was not quite finished when the publisher went out of existence.** Walter Youngquist died in 2018 at the age of 96. We are honored to be among those whose efforts have ensured that his great work is available once again, albeit posthumously.

This orphaned work then languished for several years more until we decided that its message and content were too important to abandon unseen. If no longer quite so timely or fresh, the new edition of *Geodestinies* had a certain, underlying timelessness or "evergreen" quality that warranted its publication online in PDF format, to make it as widely and freely available as possible. We enlisted the distinguished authors Charles Hall and Richard Adrian Reese to write a new foreword to *Geodestinies*, edited by Connie Barlow.

Dr. Youngquist's astonishing career – spanning many decades and many countries – as an exploration geologist and scholar, gave him unmatched insights into how humanity's dependence on Earth resources, far from diminishing as some errant economists maintained, has only intensified. The implications of this reality are inescapable. Read Walter and discover how.

– Leon Kolankiewicz and Michael Dowd, March 2022

GeoDestinies

Foreword to the 2022 Edition by Charles A. S. Hall and Richard Adrian Reese

The events unfolding as we write this foreword involving the international fallout from the Russian invasion of Ukraine have shown the world how vulnerable much of modern society is to energy and food disruptions and import restrictions. Europe as a whole must now import about two thirds of the energy it uses as the North Sea petroleum resources, which gave the U.K. and Europe a breather, are depleted and as nuclear plants are closed in response to real or perceived environmental concerns. Likewise fracking, which gave the U.S. a respite in the depletion of its own oil fields, appears to be reaching its own limits as the "sweet spots" are becoming fully exploited. The United States imports about one third of the crude oil it refines. A recent study not yet published in which Hall is involved concludes that there is but half as much real oil left in the world as the official estimates say. There are many good reasons to develop renewables, but the path will be extremely difficult and energy-intensive.

Paul Ehrlich, one of our great thinkers on the environment, wrote:

"*The sad facts are that even in the greatest of research universities, students often graduate or even get a doctorate and remain profoundly ignorant of how the world works. At Stanford it is possible to complete an education and know essentially nothing about science (which along with technology is at least half of our culture) — to say nothing of environmental science.*" *

Unfortunately this is true for most of our universities. Although universities and colleges do offer courses on the environment, they are rarely required. Even when offered, environment courses pay little or no attention to the importance of the resource requirements for modern living, to the availability and limits of those resources, or to the impact of resources on history and economics. They do, not inappropriately, tend to focus on environmental impacts and sometimes promote approaches to "greening" our civilization, usually without explicit energy or other resource analysis. Meanwhile the average grade of copper mined in the United States has fallen from as much as 40 percent in 1890 at the beginning of the boom in Butte, Montana, to 4 percent in 1910, to 0.3 percent today. Most of the oil extracted in the world today comes from fields discovered before 1970. The energy cost of getting a barrel of oil out of even the largest fields, which provide more than half of the oil used globally, has increased by 1 to 2 percent per year since the initiation of their exploitation.

There are many other critical resource issues happening quietly now. By some estimates the U.S. has lost half of the soil suitable for farming, and the productivity of the remaining soil is maintained only by using huge amounts of energy intensive (and polluting) fertilizers. Most young people have no clue where their food comes from, how modern industrial agriculture works, or, indeed, how to produce any food for themselves. Few recent college graduates would know these facts.

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*Ehrlich, P. 2011. A personal view: environmental education — its content and delivery. *Environ Stud Sci.* 1:6–13 (and personal communication).

It need not be that way. Walter Youngquist, after a long and successful career as a petroleum geologist and professor, was among the first to understand and proselytize about how we are rapidly approaching limits to the future availability of many critical nonrenewable resources. He was among the core elders of the "Peak Oil" movement. Since 1976, he warned that resource depletion threatens economic growth and that serious trouble lies ahead. He joined others, including geologist M. King Hubbert and the MIT modelers associated with *The Limits to Growth*, to make the case that Peak Oil is physically inevitable. Back then, as now, few wanted to hear this news. Consequently, although Youngquist gave talks far and wide, he was usually not invited back to the same venue.

The lack of attention to Peak Oil was, in fact, a key motivation for his writing the first edition of *GeoDestinies*, published in 1997. The book made small but important waves — mostly among those who already understood the problem or were open to the message. It was cited in a number of important books and websites.

After the first printing of *GeoDestinies* sold out, many urged him to print more. Unfortunately, the global resource story was a fast-moving target. Walter wanted to update the text before the next printing, but he couldn't write as fast as the issue was unfolding. An updated manuscript was finally completed in April 2012 – two months after his 92nd birthday. The publication process hit some curves, and it's now ten years later. Walter Youngquist died in 2018. We are honored to be among those whose efforts have ensured that his great work is available once again, albeit posthumously.

Most of this second edition remains an accurate, compelling, and desperately needed wakeup call. And yet, a great deal has happened between 2012 and today, so this book is not the latest news on every subject. Notably, Walter's 2012 update largely neglects the upstart industries born of new technologies (and an investment frenzy) for tapping unconventional fossil fuels. Time will tell whether this informational gap turns out to be, rather, Walter's prescient sense of an ephemeral (and financially unsupportable) uptick in the otherwise implacable descent of the energy-dense resources upon which industrial civilization utterly depends. The data we have at the moment suggests that this is so. Sadly once excellent governmental data keeping and analysis that allowed one to assess the real delivery of useful energy to society is increasingly hostage to budget cuts and, it would seem, political interference by those who believe that market prices are all that are needed for a proper assessment of resources.

Consider: When Walter Youngquist was born, an average of 30 units of energy could be returned from each unit of energy invested in discovery and extraction. The "Energy Return On Energy Invested" (EROI) of fossil fuels was thus 30:1. Youngquist contrasts this original resource richness with an EROI of oil fracking in the range of just 15:1 (and this is from the limited "sweet spots"). BP (British Petroleum) gave an estimate of remaining global oil reserves at the end of 2017 as 1,700 billion barrels — which would last 50 years at current production rates. But this oil will deliver far less net energy to society as the best fields are drained. Given that there is likely to be considerably less energy from oil, our most important energy source, we appear to have much less than a generation to get our energy act together, if indeed we are able to do that.

Overall, the unprecedented drawdown of Earth's one-time allotment of near-surface energy and other nonrenewable resources has enabled decades of opulent lifestyle for an extraordinary number of individuals alive within a span of time not much greater than Youngquist's 96 years. But the price for this joyride will eventually far exceed the temporary flurry of benefits. Youngquist said it like this: "The twentieth century witnessed the rise of the nonrenewable resource-based industrial economy. In some respects, the twenty-first century will be like the twentieth century in reverse."

Sadly, we agree.

In conclusion, *GeoDestinies* is a treasure. Readers of this second edition, as with the first, are in for a powerful, overwhelming, mind-expanding experience. This book will sharply redefine your perception of reality. It presents an astonishing assortment of fascinating facts and ideas, while dispelling many widely believed illusions. Civilized life as we know it has an expiration date. Walter Youngquist shows us why.

By Charles A.S. Hall and Richard Adrian Reese, March 18, 2022

Charles A.S. Hall is Professor Emeritus at the SUNY College of Environmental Science and Forestry, a long-time researcher on energy-related topics, co-author of Energy and the Wealth of Nations *(Springer, 2018), and a co-founder of the International Society for BioPhysical Economics. Richard Adrian Reese is working on his fourth book on ecological sustainability. His reviews of 201 books are at www.wildancestors.blogspot.com.*

GeoDestinies

The inevitable control of Earth resources over nations and individuals

Walter Youngquist

To the important few who have used their talents
for the study of the limits of Earth
resources and relating sustainable population size
to these boundaries
and
To my Father and Mother—Walter and Selma—
who against many adversities, both physical and financial,
including the Great Depression,
successfully raised a family at the time
when the only helping hand was their own

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ACKNOWLEDGMENTS

The age of communication has reached a new level with global Internet and e-mail now providing instantaneous contact with others literally everywhere. Yet it takes people to bring it to life, and I have been fortunate in the many knowledgeable friends I have acquired over the years who have greatly enlarged my base of information.

Richard Duncan has been a continual rich source of statistical data and encouragement. Many of my students from my academic years have become valuable information sources on a wide variety of petroleum-related topics, and on global geology and oil prospects. They include Arthur Green, recently retired as Chief Geoscientist of ExxonMobil Corporation; Robert Lent, now retired as Vice President of worldwide exploration for Kerr-McGee Oil Corporation; and Leslie Magoon, now retired from the U.S. Geological Survey and co-author of the comprehensive USGS volume on the portion of the coastal section of the Arctic National Wildlife Refuge area designated for oil exploration.

Still drilling wells, another former student, Ted Bezzerides, and long-time friend Louis Bortz, now retired from Amoco, have kept me informed on current activity and developments in the oil fields. Robert Hirsch generously offered use of his studies and graphs and provided me with an update on the value of various engineering advances in oil production. Joseph Riva, now retired from the Congressional Research Service, Library of Congress, authored numerous publications I have used, and by personal contact added to that information. From Lindsey Grant, by correspondence, conversations, books, and articles based on his broad experience in the U.S. Department of State, I have gained a global perspective on environmental and population problems I would not otherwise have.

With the greatly increased interest in biofuels and related environmental problems, David Pimentel and his associate and wife, Marcia, of Cornell University, from their studies of the flow of energy through and from agricultural systems and related environmental concerns, generously and patiently provided me with much useful data. Albert Bartlett has made me aware of the great importance of the exponential function in world population growth and its related demands on Earth resources.

Contacts abroad have enlarged my view of energy and other resource matters, and problems related to population growth. In Canada, these include Andrew Nikiforuk with his comprehensive study of oil sands, David Hughes on fossil fuel resources, and Peter Salonius with data on sustainable forestry and agriculture problems. John Nunn and William Stanton of the United Kingdom, broadened my perspective in such diverse matters as minerals in ancient medicine, and the rapid worldwide rise in human population 1750–2000. Andrew R.B. Ferguson, Research Coordinator, Population Matters (formerly Optimum Population Trust) of the U.K., reports the facts of what alternative energy sources can or cannot do for the future. His wealth of statistics and analyses clearly define the immense problems that lie ahead.

Colin Campbell of Ireland, organizer of, and moving force (now retired) behind the Association for the Study of Peak Oil and Gas (ASPO), has been an invaluable contact for his global perspective on petroleum resources. Jean Laherrere of France, with his extraordinary ability to put into graphic form the trends of the petroleum industry, in particular, the "creaming curve," has been most informative. His extensive numerically-based studies on matters related to gas hydrates and shale oil have been most helpful. Ted Trainer and Brian Fleay of Australia provided valuable insights into petroleum and population/resource matters. From his more than 30 year experience in the region, Liston Hills, retired Chairman of the Board of ARAMCO, provided insights on the history and petroleum development of the Middle East. Phone calls and frequent letters of A. M. Samsam Bakhtiari from Tehran were a great aid to my understanding of current petroleum matters in the Persian Gulf region.

I make special note of the friendships I enjoyed with Garrett Hardin and L. F. (Buzz) Ivanhoe. A vigorous correspondence together with happy times shared at the Hardin home for a personal exchange of views are some of my most treasured memories. Garrett brought an early vital message on resources and population growth through his classic 1968 essay "The Tragedy of the Commons" in the journal *Science*, which was ultimately translated into 27 languages, and in his several books including *Living Within Limits*, and his last volume, *The Ostrich Factor: Our Population Myopia*. "Buzz" Ivanhoe was one of the early modern geologists to put serious and basic numbers to the discussion of dating peak world oil production. He was consistently ahead of his time, as evidenced by an early chart he sent me showing how, in succession, various priorities would take over for the use of the last significant production of the world's oil.

Matthew Simmons, President of Simmons International, friend and author of the epic study *Twilight in the Desert: The Coming Saudi Oil Shock and the World Economy*, was a great source of useful information otherwise unavailable about the kingdom holding the world's largest oil reserves. I was also fortunate to make the acquaintance of M. King Hubbert, a truly great mind, and to hear his lecture on future domestic and world oil production and its geological limits.

It is grossly unfair to simply list all those who over the many years have faithfully provided me with a great variety of information I would never otherwise have seen, but if given all their due credit, my grateful acknowledgment would be a book in itself. Their consistent contributions with our exchange of ideas over the years have been valuable beyond anything I could have imagined. So, I gratefully acknowledge those who have done so much for me, in effect, all co-authors of this volume. They are: Virginia Abernethy, Francis DeWinter, R. Kirk Dunbar, Alice Friedemann, Robert and Kenneth Gardner, Lee Gerhard, Alfred Henderson, Kendrick Holder, Seppo Korpela, William Leonard, Charles

Maxwell, Alistair McCrone, Daniel Merriam, Richard Pelto, Richard Reese, Charles Swen-ingsen, Ronald Swenson, and John Tanton. My esteemed first Geology Professor, Chester Johnson, was still supplying me with useful comments within two days of his death at age 96. My son John read the entire manuscript and with a sharp eye made numerous useful suggestions and corrections.

I also express my gratitude to my former employers, who gave me the opportunity to study both domestic and international mineral resource economics and supplies. I was also able to view the social, political, and environmental influences of Earth resources as they relate to the world's burgeoning population. These include the U.S. Geological Survey, my consulting clients, Sun Oil Company, Shell Oil Company, Amoco, Humble Oil Company (now part of ExxonMobil), the Minerals Department of Exxon Corporation, and my full-time employer in Peru, International Petroleum Company, Ltd., affiliate of what was then Standard Oil Company (N.J.), later to become ExxonMobil Corporation. Working for ExxonMobil in any of its divisions is an intense and continuing educational experience. A 19-year consulting relationship on geothermal energy for the Eugene Water & Electric Board gave me reason to study that interesting energy source, both here and abroad. Allen Prigge, a longtime friend (and cellmate from the time he and I and 18 other journalists and scientists were thrown into jail in Moscow over a visa error) has generously shared his Internet help over the years.

By far, the most valuable pay I have received from my research and writing endeavors has been to make new friends around the world, and to be allowed to draw on their talents and insights. These and many other contacts and friendships have shown me the great wealth the world has in good, caring, thoughtful, and knowledgeable people everywhere. In these people, and many others unknown to me, lie the hopes for the future. Throughout history, only a small percentage of the population has carried the world forward to better things. We need them now to help us intelligently adjust to the post-fossil fuel paradigm of living on the daily income from truly renewable natural capital, and preserving it for all generations to come. I am privileged to have known some of them.

INTRODUCTORY OVERVIEW

THE DESTINIES OF ALL NATIONS and all people are in many ways bound up with the mineral and energy mineral resources of the Earth. Events of the geologic past have richly endowed some nations with valuable resources, whereas others have very few. The result is markedly different destinies for different nations. How these resources have affected the peoples of the past, how they influence our lives now, and how they will determine our futures is the study of GeoDestinies.

Humans are relative latecomers on the Earth. It existed very well for several billion years without us. Since our arrival and development of cultures into the present technological age, we have, in a very brief time, had an impact on the Earth far greater than any other organism. This has been largely due to the discovery, exploitation, and greatly expanded use of energy from fossil fuels. M. King Hubbert, in 1971, made this cautionary observation: "It is difficult for people living now, who have become accustomed to steady exponential growth in consumption of energy from fossil fuels, to realize how transitory the fossil-fuel epoch will eventually prove to be when it is viewed over a longer span of human history."

Some of us have been very fortunate to live in these times of major technological and medical advances, and with relatively inexpensive and abundant fossil fuels, especially oil, providing us with a lifestyle totally unimaginable 200 years ago. But, we are now living at a great turning point in Earth and human history, which, if not clear now, will be clear when viewed in retrospect.

It is apparent that current political, economic, and social efforts are to keep things as they are — to resist change. People generally do not like change in their lifestyles and their economic situations if they believe they are presently good. But changes come and are unavoidable. Climate is nearly always in a state of flux. Sea level and its related shorelines change. Lifestyles change largely due to changes in the environment, which includes climate and the availability and costs of resources to support them.

Advances in technology and the way energy is used determine lifestyle and culture. When I was born, cars were a rarity, and paved roads outside cities were hardly known.

Lindbergh had not yet flown across the Atlantic, and I never heard the words "jet airplane" or "television." The United States had only about 100 million people (now 313 million and growing). World population was about two billion. Electric refrigerators were unknown. In the Minnesota winters, ice blocks were cut from local lakes and stored in big bins in sawdust to be delivered to iceboxes at each house. Milk and bread were delivered to individual homes by horse and wagon, and coal and wood used as the main home heating sources. "Going to the moon" was a description for something impossible. The matter of population growth was never considered. The world then had less than one-third the people it has now. I visualized the future as more of the same. Obviously, it turned out much differently just within my lifetime. Men have walked on the Moon. We have paved highways across much of the world, some spanning continents. Milk and bread are now only delivered to supermarkets and neighborhood grocery stores.

Just as the world changed remarkably within my lifetime, the world of most of those reading this book will surely also change. Successfully adjusting to a future different in terms of basic resources and lifestyle is the immediate challenge for all of us, especially the young. As future generations look back upon us, will we be remembered as those who intelligently made necessary adjustments to assure a successful future? Will we be known as conscientious caretakers of the renewable resources needed for the future, particularly soil and fresh water?

From the past several billion years of Earth history and myriad geological processes, humans inherited a great storehouse of mineral and energy resources. We have also benefitted from a wealth of diverse biological resources. In earlier centuries, with many fewer people, these Earth resources were exploited slowly and in minor amounts. But within the past few hundred years, the industrial age and advancing technologies greatly increased the rate and volume of resource exploitation while we learned how to utilize these resources in myriad ways. It has been the use of these Earth resources during about 300 years that is the base of our present civilization. President John F. Kennedy (February 23, 1961) said, "Our entire society rests upon — is dependent upon — our water, our land, our forests, and our minerals."

Oil use and depletion

The change in world lifestyles and economies brought about by the use of oil cannot be overstated. Oil permeates human existence as no other substance ever has or probably will, creating a truly unique time in human history. Oil powers world economies. Almost everything produced or consumed in industrial economies has an input of oil somewhere in its production cycle. The range of products made from oil or that contain oil includes tires, golf balls, ice cream, vanilla flavoring, hair dye, toothpaste, and many medicines. What other material can pave our roads, or be part of our cosmetics, an engine coolant (propylene glycol), a pain reliever, or the polyester clothing we wear?

Oil is a nonrenewable resource, and its world production may have already peaked. Production decline and ultimate depletion will cause many changes in economies and lifestyles just as it has since early discovery and development. A number of studies of the amount of oil and timeframes for extraction have calculated ultimate decline. Exact dates for depletion are slightly variable, but there is general agreement that this century will see it arrive. All oil derived products, especially gasoline and diesel, will increase in price. The easy oil has been found and future oil will be more expensive and scarce.

Industrialized societies, and those striving to become more so, tend to lose sight of this basic fact: Earth resources underlie and support our existence. They always have, and always will. Shuffling papers and printing "money" in the world's financial centers are secondary activities to the discovery and use of nonrenewable and renewable resources. Sometimes the paper shuffling and printing of money greatly affects economies, but every economic system is based upon Earth resources, the ultimate source of wealth.

An exponential century that cannot be repeated

The exponential increase in use of Earth resources has led to a huge rise in the standard of living for some segments of the population, chiefly in the industrial world, and the hope for a better standard of living by many others. But the rapid exploitation or resources since the beginning of the Industrial Revolution coupled with continued population increase cannot continue.

The globalization of commerce and trade by use of oil has led to the worldwide exploitation of mineral and energy resources by the industrialized and industrializing countries, in effect, "the tragedy of the commons" (Hardin, 1969) in its ultimate final form. The decline of oil production will in turn result in the return of local economies forced to exist on more locally available resources, as has been the circumstance during much of human history. This will greatly remake our economies and lifestyles from what we know today. This profoundly important fact is discussed again in its various aspects in subsequent chapters.

With the huge population growth made possible by advances in medicine and sanitation, and greatly increased food production largely a benefit of fossil fuels, the finite Earth resources are under unprecedented stress. In 1700, world population is estimated to have been about 610 million. It is now seven billion and increasing every day. This huge increase in population and the related increase in resource consumption are the salient facts of the past three centuries.

Population growth is the force that drives resource consumption. As we view the present and look towards the future, this is the overriding challenge to a sustainable and acceptable future. Due to differences in living standards, some populations (in industrialized countries) use more resources per capita than other populations. In some places local populations are so desperate to survive they destroy the environment with present use and cannot preserve it to sustain future population. In general, population growth and the environment are in direct conflict. In terms of resource use per capita, whether it is large or small, more people use more resources, renewable and nonrenewable.

The twenty-first century will probably see as many changes, but some of them may be in reverse. One inevitable change will be a decline in the amount of oil and gas used. The quadrupling of population since 1900 cannot be repeated and a reduction in population is more likely. The twentieth century was an accelerating century of population growth and resource use. The Earth cannot support two such centuries back to back. Yet, we are trying to do just that. It won't work.

Much more to learn in a short time

The world has become vastly more complex the last hundred years. There is so much more to learn now than a century ago. A basic problem is that a child born today knows no more on the first day of life than a child born a thousand years ago. But, now in just a few decades, a child must learn a tremendous amount to take its place as a productive, knowledgeable part of society and vote intelligently in a democracy. The hallmark of civilization and what is vital to assuring its future is education. For people worldwide, it is vital that education be of the highest priority.

Much of the discussion in the following chapters deals with the effects of the huge, still growing, world population and the great rise in the standard of living for many. Fossil fuels, mined phosphate and potassium mineral fertilizers, ammonia produced from natural gas, and pesticides made from oil have combined to enable us to harvest more from the land than nature would produce. We have, in effect, harvested from "ghost acres of land" that do not really exist, but are provided for us by these resources.

As long as the Earth is viewed as the property of humans to be exploited for their benefit and not shared with all other organisms in the environment, "then we are destined to soon inhabit a biological wasteland" in which humans can no longer be supported (Hedges, 2009). "Thus there is the general moral problem of bequeathing to future generations a negative legacy, an ecologically damaged world" (McMichael, 1993).

Greatly enhanced oil-fueled agricultural production lifted the dawn to dusk, life-shortening, back-breaking task of tilling the soil from many people, allowing them to go to population centers and work at manufacturing and related commerce, which further improved standards of living. Research centers and universities were established and expanded, making advanced education widely available. For the most part, these advantages have been the result of civilization living on a great natural legacy – an inheritance – from ancient sunlight of distant geological ages. The coal, oil, and natural gas we consume are derived from organisms that absorbed that sunlight. In a sense, these fuels are "fossil sunlight." Using these energy resources, we have been able to extract and process mineral resources from the Earth. We have mined metals and nonmetal resources, and smelted, fabricated, processed, and fashioned them into machines and appliances of all kinds and many uses.

But most of these materials, currently important to our lifestyles, can be extracted and used only once, especially our energy resources. These facts of this Earth-related human extractive history can never be repeated. In considering these facts, it is disturbing to see governmental leaders worldwide committed to keeping and expanding the present trends of resource consumption with a comforting claim of "sustainable economic growth." The underlying basic problem of population growth is mostly absent from political agendas that continue to pursue the disastrous illusion of perpetual growth.

"Growth" in terms of non-numerical things such as medical advances or education are qualitative enrichments for humankind and should be pursued. We should spend our natural wealth on ways to "make things better, not bigger" (Fodor, 2001). But growth in terms of volumes and numbers of material goods based on continued exploitation of finite Earth resources is not possible. More and more people using more and more resources do not combine for a successful future. One simple measure of physical standard of living is to divide the available resources by the number of people. When resources are finite, the result is that more and more people mean a lower standard of living for everyone. Inevitably we must adjust to a future of less, living within renewable limits. So the question we confront is: Can we continue to maintain the present high standard of living for those who now enjoy such and hopefully raise the standard of living to a reasonable level for all others using truly renewable Earth resources? Can we live on current resource "income" instead of an inheritance from the past? Time appears to be rapidly running out on making this transition successfully, especially as population continues to grow.

In one of his earlier books, titled *The Twenty-Ninth Day*, Lester Brown (1978) in his subtitle puts the challenge to our future very clearly: *"Accommodating human needs and numbers to the earth's resources."* This challenge, in fact, is already here but not fully recognized. It is the theme of most of the discussion in this volume. The critical importance of matching population size to the overriding control of limited Earth resources must be acknowledged and not ignored through the illusion of "sustainable growth."

While considering the stress on Earth mineral and energy resources and the natural environment resulting from population growth, the discussions following will explore equally important, but hard to measure, social stresses resulting at least in part from depletion of resources such as water supplies and fertile soils. Food shortages and civil unrest have resulted from resource shortages, and population growth in many places is outpacing job growth. These factors of social instability may and do lead to government instabilities.

In some regions and in different times, emigration was the historical outlet for overpopulation. Movement of people to less occupied lands or recently to more affluent lands relieved social stress. But there are no longer empty lands, and many nations resist large immigrations. The world is a "full house" as clearly documented by Brown and Kane in 1994. Forrester (1973) writes, "Relying on technology to solve the problems created by [population] growth is to evade the question of how to slow growth. In the past, technological advance has been used to increase population and demands on the environment...a later advance in technology could be used to increase human well-being rather than human numbers." He concludes, "The optimistic future lies in the direction of first limiting the process of growth and then using technology to raise the standard of living and the quality of life."

Population growth, which increases resource consumption, job competition, various impacts on the environment, and more and more crowding, is now the world's greatest problem. Current population size, and even more so, expected continued population growth underlie nearly all other world problems. One organization states: "*Whatever your cause is, it is lost without population control.*"

Many scientists and others have studied the prospects for the future relative to population size and the probable available resources. One fact is abundantly clear: we have already exceeded the permanent sustainable carrying capacity of the Earth. Our challenge is to reduce population to where it can be supported by sustainable, renewable resources. Such a world economy can only support a smaller population. Everyone now living and under the age of 40 will see the realities of diminished resources and population pressure. And the years go by very swiftly. From experience, I can say that within every person age 70 is a person of 30 who wonders, "What happened?"

The strange silence?

David Attenborough (2011) raises this question concerning the problem of population growth: "I meet no one who privately disagrees that population growth is a problem...So why does hardly anyone say so publicly? There seems to be some bizarre taboo about the subject...this affects the people who claim to care most passionately about a sustainable and prosperous future for our children...their silence implies their admirable goals can be achieved regardless how many people there are in the world, even though they all know they can't."

We must recognize that the great lesson of history is that things "change," and those organisms that adjust survive, and those that do not adjust become extinct. Climate and environment are intimately linked, and these combined with adaptive mutations, have been the moving forces for evolution. The key to survival is not only to adjust to change, but also to preserve the elements in the environment essential to survival. As a "thinking" species, we must put our brains and will to these problems.

Illusion of sustainable economic growth/the reality of "nonrenewable"

The current increasing demand for nonrenewable resources, fossil fuels, metals, and nonmetals, leads us to realize the fallacy of unlimited economic growth. The base for all human economies and societies for provision of material goods whatever they may be is Earth resources. Consuming nonrenewable and finite resources means they *will* be depleted. Increasing demand depletes these resources at a faster rate. Economic growth depends on increasing consumption of everything. The current ideology of economic growth moves us closer and closer to depletion of resources, both renewable and nonrenewable.

"Nonrenewable" means just that, no second helpings. An agrarian economy, based solely on the annual incremental income from renewable resources, can be repeated. The Earth's base of fertile soil, fresh water, and environments that maintain a diverse biological resource must be preserved for future human existence. The industrial civilization with all its benefits that some now enjoy tends to be regarded as the norm of human life, but is far from the norm, which, over the ages, was an agrarian-based existence. Our current intricately developed economic networks with a largely oil-based lifestyle are temporary circumstances making this a truly unique time in human history.

Our modern, developed societies tend to be removed by their present degree of affluence from the environment as the basis of existence. Food comes from the supermarket, clean water comes from the faucet, and electricity comes from the light switch. But, the closer people live to the margins of existence, the more they realize the direct importance of fertile soil, safe drinking water, and natural life-supporting contributions from the environment. Herman Daly has said, "Our economies are wholly owned subsidiaries of the environment."

Change

Human lifetime is so short that the concept of geologic or even historic change is generally beyond experience. But change is part of normal Earth processes and must be anticipated. Over geologic time, great changes are in evidence, such as fossil coral reefs in the Sahara Desert. Sea level fluctuation is one of the most obvious changes as evident from shark teeth I have collected in Montana. More recent change includes the arrival of humans in North America by way of a land bridge from Asia to Alaska during a time of lower sea level when much water was locked in extensive continental glaciers.

Sometimes changes are rapid. Conkling *et al.* (2011), from research in Greenland, note that "...the lessons of the Greenland ice cores are very clear: big widespread abrupt climate changes have happened repeatedly before there were a large number of modern humans on the planet."

Humanity's perfect storm

Present trends are likely to continue. This century will witness a number of disturbing situations and challenges, a collective storm of resource issues.

Grant (2011), in his paper *The Apocalypse Is on Schedule*, notes the convergence of many negative trends this century. These include:

- Decline of oil supplies affecting nearly all aspects of life but especially agricultural productivity, crucial to human survival.
- Declining quality of soils due to erosion, salinization, and loss of organic material necessary for healthy soils.
- Loss of topsoil worldwide ten times as rapidly as it is being formed, from a human perspective a nonrenewable resource.
- Per capita arable acreage declining, in some areas already too small to provide for human survival beyond bare subsistence level, and immediately vulnerable to drought.
- Rising sea level encroaching on coastal agricultural land and flooding human occupation of coastal regions.
- Declining supplies of freshwater for irrigation, due to climate change reducing mountain snowpack to provide needed summer runoff, and aquifers over-pumped worldwide.
- Decline to the point of exhaustion of the high-energy density fossil fuels, and the transition to renewable low-energy density alternative energy sources, which may not be able to power industrial civilization as we know it today.

In the meantime, the freight train trajectory of world population growth continues with its increasing resource demands. The rate at which we are extracting and depleting nonrenewable Earth resources ensures that they will last only a short interval in human history.

The United Nations' Food and Agriculture Organization predicts that the world will need to provide 70 percent more food by 2050 to feed its population. Population now grows faster than food production, and the result is that more than half the world population is currently undernourished. This is the largest number ever in history (Pimentel, 2011). Growth in agricultural production is expected to slow. Achieving any significant growth in agricultural projection will be difficult as the resource base for food production, freshwater and fertile soil declines.

This volume considers the very essence of human nature. We must look to the potential of directing human behavior into consistently constructive channels. Past failures in human relations must be instructive in their negative impacts. As he viewed the destruction at the end of World War II, General Omar Bradley said, "We are technological giants, but moral midgets."

Continual strife, with its immense suffering and loss of life, and in the use of huge amounts of irreplaceable Earth resources, is folly at its utmost.

> War, with its tidal waves of destruction, slaughter and grief, is the answer to no human problem, and an insult to the intelligence that God gave us that we cannot find other answers.
>
> —**Francis Pendleton Gaines**

A re-ordering of national priorities is in order, especially for the United States, now deeply in debt both domestically and internationally. Much treasure has been used for destructive purposes. Charles Osgood in *See You on the Radio*, commented: "War is not the only kind of man-made disaster on this planet, but is one of the most destructive things we can do to each other, which is to say, ourselves....We don't really need to make enemies of one another. Don't we have enemies enough? Common enemies in earthquakes and windstorms and droughts and floods and famines and plagues afflict us all." Many vital elements for our future in a renewable resource world are neglected in order to finance bombs, fighter planes, and other "articles of war." The future depends on our *highest and best* use of all available resources.

Many, if not most people in the developing and developed world are significant consumers in materialistic societies. But, some societies, even now are just as happy not encumbered by so many "things," so a future of less may not mean a change in life satisfaction and would probably be less stressful for many. The value of human intellectual capacity is immense and must be fully applied to the pursuit of truly "sustainable growth." We have an inherent optimism that we can solve problems. This optimism must keep in view the realities of Earth's limited resources determining our physical future.

How we individually live, how we vote, how we conduct ourselves among others are personal choices that will become an aggregate response to the challenges ahead. The h istorically brief, happy time of fossil fuels and its benefits including highly productive agriculture, social and personal mobility, and uncountable consumer products will change and so must we.

I enjoyed the privilege of discussing the probable course of events with my friend, the late Garrett Hardin. Looking at the world as we saw current trends sometimes led us to be somewhat less than optimistic about the future. But as we came to the end of our visit, Garrett would grasp my hand firmly and say, "Yes, but we must try." For all of Garrett's writings about the problems we face, he always thought we might find solutions. It is in that frame of thought this book is written.

The human race is likely to be here for quite some time, but probably in fewer numbers. How we achieve a sustainable resource future, and in what civil condition we survive doing so are not clear. Different lifestyles and economies will exist and will present different challenges and opportunities. The continued growth of population is a demographic freight train moving headlong at least to mid-century against the depletion of nonrenewable and the degradation of many renewable Earth resources.

There are some minor but important positive factors in environmental awareness and protection. Wildlife preserves, marine reserves, and national and local parks and wilderness areas now preserve important natural diversity and some precious irreplaceable terrains. These laudable trends are expanding. Population growth is slowing, but still growing. These gains remain overshadowed by the basic problem of finally stopping and reducing human population numbers to sustainable size in balance with Earth resources. Only the annual increment of renewable resources will be available for all humanity for the *indefinite future*.

This will be the defining century for the lives of all generations to come. Avoiding chaos from the stress of transition to a future of less will require the best of human endeavors. "Accepting the fact that the world available to humans is a limited one will be one of the most difficult tasks ever tackled by our species. The intermediate costs will be high; the ultimate reward will be survival itself" (Hardin, 1999).

Those who will be living at the end of this century will see much of this future come about. Then, as now, Earth resources will continue to be the base of human existence and will inevitably control the destinies of nations and individuals. We are made of Earth materials and its biological products, and on them we survive. "Mother Earth" is not an abstract concept. We must care for the Earth's life-sustaining resources much better than we have. Our destinies depend on it.

History is subject to geology.
—Will and Ariel Durant, *The Lessons of History*

Editorial notes

The term "petroleum" in that industry and as used here, includes both oil and gas. The term "gas" means natural gas, not gasoline (which in common public use has been shortened to "gas"). Also, the fossil fuels of petroleum, coal, shale oil, and oil sands are regarded as minerals like bauxite or hematite, but they are sometimes split off from other minerals by terming them "energy minerals." Also, for the sake of brevity, in some places the term mineral has been used for all energy and other Earth-derived resources. Elements, such as copper, lead, and silver are regarded as minerals as are the ores in which these materials are found. The terms "resources" and "reserves" have different meanings in the strict sense. Resources are all the existing raw materials in the Earth. Reserves are those known portions of the resources that can be produced economically, but as prices change and because technology can change mineral production economics, the distinction between reserves and resources has not been made at all times in this text.

The bibliography lists works that have been consulted. References are listed in the bibliography that express divergent views. Each has been consulted but may not be cited in the text. These are included so that varied opinions may be examined if the reader wishes to pursue the subject.

GeoDestinies considers the global impact of the present huge demand for minerals in its many aspects. It is a multidisciplinary view, which includes national and international economics, politics, technology, demography, history, sociology, engineering, and geology. Issues of ethics must also be a part of this study. Humans live with one another in an increasingly crowded world demanding more and more resources. How are these resources to be divided? Who has the right to use them, and what claims upon them do we recognize for generations yet to come? Do we provide for such claims? If so, how?

—Walter Youngquist
Eugene, Oregon
April 2012

Chapter 1

Minerals Move Civilization

History has quite properly recorded the progress of civilization in terms of various ages, based on what Earth materials in use seemed the most important at the time. These have commonly been designated as the Stone Age, the Copper Age, the Bronze Age, and the Iron Age. These Ages were not mutually exclusive of one another, but each one added to the preceding one. When primitive humans learned to chip or flake some rocks into useful tools the Stone Age was born, but for several millennia thereafter the use of stones did not advance civilization.

When the first metal to be used in a utilitarian fashion (not ornamental as gold and silver were early used), civilization began to move forward, progress that continues to this day. Copper, tin (with copper to make bronze), and iron have been the metals that have had a major role in this movement. The use of minerals has provided the material basis for the development of civilization, and has been a major factor in the rise and fall of communities, empires, and nations from the Stone Age to the present (Park, 1975; Poss, 1975; Raymond, 1986). The Roman Empire in particular depended on bronze and iron for much of its military success.

The Stone Age

A rock thrown at a game animal or bounced off the skull of an enemy was probably the first use of minerals by humans. Eventually the notion occurred to someone to chip a rock into something which could be used as a knife or scraper, and flint, because it can be easily flaked into such tools, became important. Flint occurs geologically in a variety of associations but it is most readily found and extracted as nodules in limestone and shale. In certain regions of France, especially in the La Claise River Valley, flint nodules are present in great abundance for several miles in the bordering limestone cliffs. Here, ancient peoples developed extensive flint workings, chiefly near the present village of Grand Pressigny. These rocks probably made this area the most important economic district in Europe at that time.

During the Stone Age, flint was among the more valuable possessions a human could have. In various cultures the Stone Age persisted for different lengths of time. In the Great Plains of the United States among the native people the Stone Age lasted until just a few hundred years ago as seen in the great quantities of arrowheads and other stone implements that were made and used until relatively recent times. And, in a remote area in New Guinea, while one man was walking on the moon, another man was cutting down a tree with a stone axe.

The Copper Age

In parts of both the Old and New World, deposits of native copper were discovered. Before that, gold was used as an ornament, because gold is commonly found native, that is, in pure metallic native form uncombined with other elements, and is therefore conspicuous and easily recognized. Bright and attractive, gold can readily be beaten into desired shapes, and this was done at an early date in human history. But the first "working metal" used by humans was copper, moving at least some local to regional segments of civilization out of the Stone Age.

Copper was extensively mined by early people in the Sinai Desert, and later on Cyprus (Poss, 1975). The deposits on Cyprus were so highly valued that war followed war in bloody contests for the metal. The island passed under successive control of many groups from the Egyptians through the Romans. The Romans gave us the word from which "copper" is derived, by shortening cyprium (Cyprium copper) to cuprum.

Native copper is relatively rare but it does occur in a few places. In the 1700s a fur trader found a 3,000-pound copper boulder on the southern shore of Lake Superior on the Keweenaw Peninsula of Upper Michigan (Sass, 1998). Here numerous prehistoric pits in the extensive native copper deposits testify to the widespread use of this metal by the native populations. The mining and working of copper was a large enterprise. More than 10,000 individual mines (some just small pits, others fairly large workings) have been discovered in this area. It has been estimated that it took at least 1,000 miners a minimum of 1,000 years to produce all the copper workings now visible. The presence of abundant native copper, which could easily be shaped into knives and other tools, was of great importance to these first miners who would otherwise have to use stones that were much more difficult to work.

Copper could be hammered into all kinds of implements, including arrowheads, chisels, hooks, and knives. This copper was also apparently a major basis for trade. Tools of native copper derived from this region have been found in early habitations throughout the Upper Mid-West, and down the length of the Mississippi River Valley. Those native Americans who had the use of this copper moved out of the Stone Age, while much of the rest of North America remained there until just a few hundred years ago.

Copper was the first metal employed as a shaped weapon in Old World warfare. Copper ores are relatively easy to smelt, so copper metallurgy developed early and copper became the first metal to be used extensively by several cultures. Its use marked an important transition from the long Stone Age into the age of metals.

In modern times, without copper the development of our highly electrified civilization might not have been possible, or at least considerably delayed, for copper has been the first and primary workhorse of the electric industry. Copper has the highest electrical conductivity of any metal, except gold and silver. It is now being partially displaced by aluminum, and glass fibers. However, the production of aluminum depends on vast amounts of electricity produced by copper coil-wound generators, and initially transmitted by copper wire to the aluminum smelters. Without copper, we might still be reading by candlelight or oil lamps. Widespread use of electricity is surely one of the most important achievements in human history. Every day we benefit from copper in myriad ways. For instance, all our lamp and appliance cords around the house are made of copper wire.

The Bronze Age

The Bronze Age was a logical successor to the Copper Age when an unknown metallurgist discovered that adding tin to copper would make a much harder metal. Along with copper its use continues to serve us in various ways. The first true bronze with enough tin to indicate that the tin was an intentional addition to the copper appears about 3000 B.C. in Mesopotamia (Poss, 1975). During succeeding centuries, bronze objects were widely made in that region. Later, the Romans made extensive use of the copper/tin mixture to produce numerous bronze weapons as well as "luxury" items such as tableware and artwork. In order to obtain adequate supplies of tin with which to make bronze, the Romans seized the tin deposits of Cornwall in England. Roman weapons, first made of bronze, and later iron, conquered much of the then-known Western World.

The Iron Age

Although iron was known far before Roman times, it had only limited use, because the metallurgy of iron is difficult due to the high temperature required to smelt it. For a long time iron was not well known nor widely used. However, there is a record of iron being employed as far back as 1450 B.C., and about 1385 B.C. the Hittites manufactured a substantial number of weapons from iron. With this superior weapon they subdued the Assyrians, and then drove into northern Syria and Palestine. There they fought the Egyptians, and ultimately established the Hittite Empire as a major political and military power in western Asia. The iron which equipped the Hittites for military success was eventually used against them. The Hittites had jealously guarded their secret of iron metallurgy, because of its great military importance. But the secret got out. Ultimately the enemies of the Hittites were equipped with the same metal, and the Hittite Empire was besieged and finally disintegrated.

The Iron Age and the Industrial Revolution

The Iron Age came much later in the sense that iron came into widespread use in industry and construction only fairly recently—during the last three hundred years or so (Sass, 1998). Iron has been of great importance since the beginning of the Industrial Revolution led by Great Britain starting in the eighteenth century. The Industrial Revolution made iron and coal the most valuable mineral resources a country could have. Great Britain had the geological good fortune of having supplies of both coal and iron as well as limestone needed in the smelting process in close geographic proximity so they could easily be transported (at first by horse and wagon) to a common site to produce iron. Britain also had substantial deposits of zinc, lead, tin, and copper. All these metals and the energy of coal were available to build and power the factories and machines necessary for Britain to launch (and for a long time to lead) the Industrial Revolution. In Scotland, Wales, and England, a combined area several thousand square miles smaller than the State of Oregon, all these resources were readily available. This fortunate geological circumstance can hardly be over-emphasized for without it, it is unlikely Britain could have developed as it has.

The Industrial Revolution and Metal Demand

Although metals have been important since the Copper Age, for a long time they were used in relatively small quantities. It was not until the Industrial Revolution that there was large demand for metals. Earlier, economies were largely agricultural. Rich, fertile land and fresh water were the resource prizes. Productive land is still prized, but to work it economically, metals and energy resources have become important, and nations are now much more interested in the supplies of these resources.

In the nineteenth century, Britain was successively the world's largest source of coal, iron, lead, tin, and copper. During that time it was the wealthiest nation in the world and supplied more than half the world's demand for some of these metals. From 1700 to 1850 Britain mined more than 50 percent of the world's lead, and from 1820 to 1840 produced 45 percent of the world's copper. From 1850 to 1890 Britain increased iron production from one-third to one-half of the entire world supply (Lovering, 1943).

This rapid exploitation of the minerals was followed by the inevitable decline of the industry due to increasing costs from deeper mining, and gradual exhaustion of the deposits. Peak production of Britain's lead occurred in 1856, copper 1863, tin 1871, iron ore 1882, and coal in 1913. Britain's coal industry continues to contract. In 1992, British Coal, the government coal monopoly after the industry was nationalized in 1947, announced that 31 of its remaining 50 mines would be closed, eliminating more than half the business that once fueled Britain's economy. In 1947 there were 718,000 coal miners. Now only about 48,000 people are employed in coal production.

Mineral might moves to the United States

During the same time in the late nineteenth century, as Britain's mining declined, the United States discovered and developed even richer and much larger mineral deposits. By the end of World War I, which put a heavy demand on Britain's mineral resources, the United States replaced Great Britain as the largest industrial power. The large new demand for oil that the United States was discovering in large quantities also caused the world industrial center to shift to the United States. Britain was not producing oil.

Since World War II, the world, led by the United States, has consumed more natural resources than in all previous history. That was the twentieth century. With the exception of oil, China is currently the leading consumer of resources. There is not enough world oil production now or in the foreseeable future to enable China to exceed the United States (19 million barrels a day) in that category. Increasing oil demand by China is helping to drive up world oil prices. Other raw materials such as copper, steel, cement, aluminum, and timber are also moving into the fast-growing Chinese economy.

Phenomenal Rise of the United States

North America, and particularly the United States, initially had resources in variety and abundance virtually unmatched by any other area of the world. With this marvelous spectrum of mineral and energy resources, the United States grew from a wilderness to become the richest and most powerful nation in the world in less than 400 years. Such development is historically unprecedented and can probably never be repeated.

The greater volumes of resources in the United States, and the generally higher quality deposits (especially of coal and iron) and the discovery of vast oil resources, allowed the

Figure 1-1. Annual per capita consumption of metals and nonmetals in the United States

Source: Mineral Information Institute, Golden, Colorado

United States to quickly overtake Britain and then surpass it in industrial development. By the late 1920s, the United States, with six percent of the world's population, was producing 70 percent of the world's oil, almost 50 percent of its copper, 46 percent of its iron, and 42 percent of its coal (Groner, 1972). The ability to produce and use these basic industrial materials and energy resources in large volumes was the key to the phenomenal development of the United States. It shaped today's economy and lifestyle.

Annual per capita consumption of metals and nonmetals in the United States is shown in Figure 1-1.

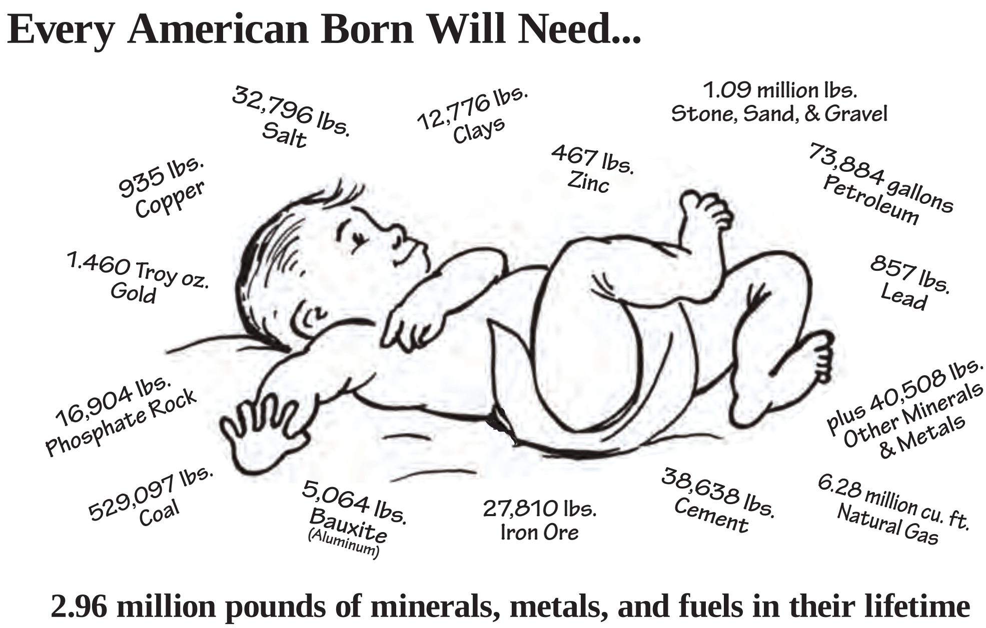
Non-Energy Materials We Use

Supplies needed each year

Including sand, gravel, cement, dimension stone, clay, and the energy and metal supplies already listed, more than five billion tons of new minerals are needed each year to support the U.S. economy. These demands add up to more than 20 tons of raw energy mineral and mineral supplies which have to be produced each year for every man, woman, and child in the United States, if our material standard of living is to be maintained. And, importantly, these demands increase in total size each year as our population grows by natural native increase, and by both legal and illegal immigration. Producers of these resources face a tremendous task whose vital role in the daily life of the individual is little understood or appreciated by the general public.

These consumption figures do not mean that each person directly uses this quantity of each material. The total supply of these materials used in the United States annually divided by the population gives the average figures. Steel, for example, is used to build homes, apartment houses, supermarkets, shopping malls, roads, and bridges. Railroads, cars, and trucks, which serve citizens every day, are made from steel and other metals.

Figure 1-2. Lifetime Energy and Mineral Needs of Everyone Born in the United States



Source: Mineral Information Institute, Golden, Colorado, 2011

The lifetime cumulative consumption of metals and nonmetals for an individual born in the United States is shown in Figure 1-2.

The Age of High Density Energy Sources

The hallmark of our present civilization is the widespread use of high density energy sources — coal, oil, natural gas, and uranium. Metals are also important, but only the use of high density energy sources has allowed us to inexpensively mine, smelt and fabricate metals into all the metal products we use today, especially the machines of transport — cars, trucks, rail engines, planes, and farm machinery. Aluminum is a particular example. It is never found in native form, but always with other elements. To break it from its bonds is a very energy intensive process.

Wood and other biomass sources of energy have been used from the time fire was discovered. Coal was the first widespread high density energy source to be used and it was coal that moved civilization rapidly forward during the early part of the Industrial Revolution. To produce large volumes of iron, the workhorse metal of that time, significant energy was needed and coal served the purpose. Oil had not yet become an important industrial energy source. Iron in quantity at a relatively cheap cost allowed the British to apply their ingenuity to iron fabrication, and they found many uses. The energy of coal together with iron created the Iron Age, the beginning of the Industrial Revolution.

The beginning of rapid mass transport

One very significant result of cheap and abundant iron was the invention of the steam engine and the railroad. The ability to move large quantities of materials inexpensively and rapidly over long distances moved Britain forward, and indeed has done so ever since for much of the world. The advent of the railroad was one of the great steps forward for civilization. Abundant coal made it possible to produce large quantities of iron.

Now we are said to be in the Atomic Age (made possible by the metal uranium). But we do not construct buildings or make cars, or other machines of uranium but rather out of iron, and its alloy, steel, and aluminum. So in the real and practical sense we are still in the Iron-steel/Aluminum Age. And with the development of petroleum (oil and gas) we are increasingly in the Plastics Age. The widespread use of petroleum for the manufacture of plastics has changed the composition of many things we use from toys to electronics to food containers to car parts. There is increasing use of plastics in construction. Plastics are cheaper and lighter than metal and can sometimes be made stronger. Often, a combination of materials is used. As a child, I played with toys of metal, and the family car had no plastic parts. Children today play with toys made mostly of plastic. Low price and lightweight means many parts of today's airplanes and cars are made of plastic. Coal, petroleum and uranium have moved civilization forward in ways nothing before could do.

Cultures Move at Different Rates

Human societies do not all progress at the same pace. The difference is clear in the example of the New Guinea native cutting down a tree with a stone ax while a man was landing on the moon with the use of high density energy sources and special metals. Most of the "Stone Age" people of New Guinea have moved into modern times in a single step. Much of Africa went from the Stone Age to the Iron Age without the intervening Copper or Bronze ages. With the arrival of Europeans in North America, Native Americans who did not live in the copper country of northern Michigan or had no access to it by trade, remained in the Stone Age (flint or obsidian arrowheads, knives, and scrapers). But, they suddenly found themselves in the Iron Age, facing rifles.

How fast a culture advances has largely been determined by what mineral and energy mineral resources it had available to it and to what degree technology development allowed them to be used. Mineral and energy resources combined with human ingenuity have been the mainsprings of civilization.

Petroleum

Petroleum has advanced civilization in many ways, and the possession of major oil resources has helped those fortunate nations progress much more rapidly than others. During the past century, the United States enjoyed a great increase in wealth and influence because of huge oil resources. A more striking example is Saudi Arabia.

No country has moved further and faster in terms of its domestic economy and also in terms of world influence than Saudi Arabia. To a lesser degree, this is also true of the adjacent oil-rich areas of the Middle East—Iraq, Iran, Qatar, the United Arab Emirates, Kuwait, Bahrain, and Oman. But, with Saudi Arabia's enormous oil reserves, its influence far exceeds the others, making it that region's dominant economic power and currently a world economic power.

For thousands of years, loosely organized nomadic tribes, a few small farm areas, and some little fishing villages occupied the Persian Gulf region. The economic impact of this relatively small number of isolated people was negligible in the world economy. There was no indication then that things would ever be any different. The market for sand dunes was not great. But in less than 70 years, Saudi Arabia came to have the largest and most modern airport in the world, a telecommunications system second to none, and first class hospitals and universities. The standard of living compared to a century ago is vastly different and incomparably better. The oil beneath the sand dunes changed the destiny of the region. With it came a world-influencing economic power.

The Saudis, still a very minor percentage of world population, shook the world's greatest industrial nation, the United States, with the oil embargo of 1973. This was possible only because Saudi Arabia had oil. Without the oil, Saudi Arabia and the other Arab states would have had no such influence. Oil brought the Persian Gulf region great prosperity in a phenomenally short time. Until the oil wells run dry, this small group of nations will have a very large say in world economics. And this influence is likely to increase over the next several decades as other oil-producing areas pass their peak of production, as the United States has.

Energy Mineral Resources the Key

The importance of mineral and energy mineral resources cannot be overstated. Most critical among the resources is energy. Energy is the key which unlocks all other natural resources and provides the physical and economic foundations of modern civilization (Ayers and Scarlott, 1952).

Without energy, the wheels of industry do not turn, no metals are mined and smelted. No cars, trucks, trains, ships or airplanes could be built, and if built, they could not move without energy. Without energy, houses would remain cold and unlighted; food would be uncooked. Our large agricultural areas could not be plowed or planted with the ease and on the vast scale they are today with relatively little human labor. Military defense as we know it today would not exist. Without energy resources we would literally be back in the Stone Age. And without energy and metals as we use them today, it is probable that the world's population would be reduced by at least one-half; some estimates say 90 percent.

In the industrialized world we take our high standard of living very much for granted, without realizing what a great debt we owe every moment to mineral and energy resources. We convert minerals to metals and the metals into tools and machines. Most machines run on mineral fuels. By these means, we easily produce great quantities of goods that previously either did not exist or took large amounts of hand labor to produce.

Metals and energy in agriculture—the basis of life

In many parts of the world, the use of petroleum-fueled farm equipment, and petroleum-derived fertilizer and pesticides is still a rarity. As a result, people are still engaged in subsistence farming. Often it precludes them from gaining an education, which might enable them to better their circumstances. The activity of tilling the fields is centuries old. Only when the burden and necessity of making a living from the soil by dawn to dusk labor is at least partially lifted can human societies develop sufficient numbers of scientists, engineers, doctors, and technicians to move society forward in a significant way.

Minerals and energy in the form of the steel plow, the tractor, and the fuel to move them, together with petroleum-derived fertilizer, herbicides, and pesticides have enabled two percent of the U.S. working population to feed all its citizens and some of the rest of the world. The United States has led the world in scientific advances, and petroleum-based agriculture has been an important part of making this possible.

Energy supplies and employment

In the industrial nations' factories and research laboratories, as well as in the service industries, energy is all important. This was strikingly demonstrated during the 1973-74 Arab oil embargo against the United States. As a result of that partial cutoff of oil to the United States, the Federal Energy Administration estimated that the nation's gross domestic product declined $20 billion (more than $90 billion in 2012 dollars), and a half million American workers lost their jobs.

Energy and goods distribution

Oil has enabled the products of our farms and factories to be widely and inexpensively distributed by truck, train, and plane. It would do no good to produce quantities of appliances, clothing, machinery, farm products, and all the other products that form the basis of our material standard of living if these could not be easily and inexpensively transported to the population at large. Oil is the key to this fortunate situation. Factory and supermarket shelves would be bare within days if not for oil-based transport.

Energy for each person

For many years the United States has surpassed almost all other nations in terms of per capita consumption of energy and mineral resources. The United States, with about four percent of the world's population, uses about a third of the Earth's annual energy supplies in all forms.

In ancient times, the ownership and use of slaves was one of the chief sources of wealth. Slaves were kept for their labor, and their labor represented valuable usable energy.

We now substitute the energy of slaves with oil, gas, coal, and uranium. These energy "slaves" for each U.S. resident add up to 8,000 pounds of oil, 5,000 pounds of natural gas, 5,000 pounds of coal, and 1/20 pound of uranium every year. The discovery and use of these energy sources has profoundly changed our lifestyle and our economy from the days prior to the industrial revolution, less than 300 years ago.

Some interesting calculations have been made with regard to the energy "slaves" we draw on each day. The figures are based on the estimate that one "person-power" (PP) equals 0.25 horsepower = 186 Watts = 635 Btu/hr. The study estimates that if the energy requirements of the United States were met by person-power, it would take more people working continuously on our behalf than presently exist in the world — almost three times as many. In more detail, the study says that:

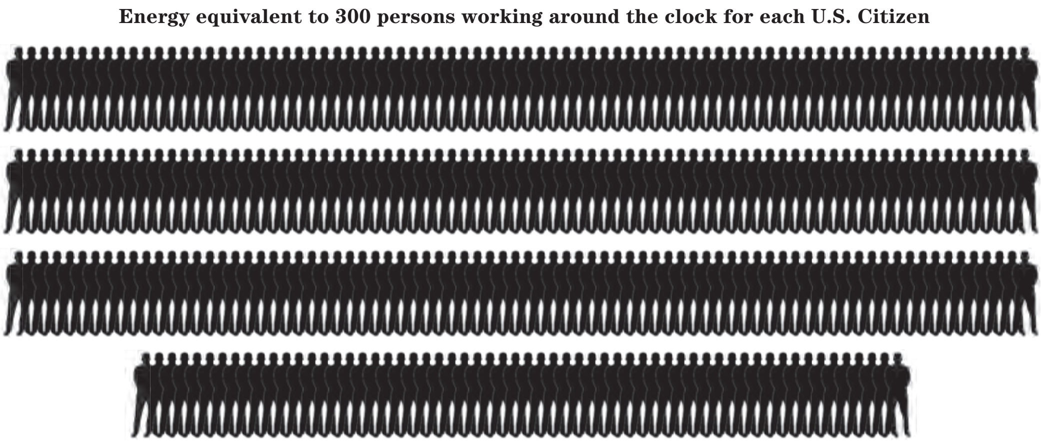
> If one prefers to visualize their energy servants working only an eight-hour day, then each individual would require the equivalent of 174 person-power to meet his/her energy needs. Surely a Roman nobleman would be extremely rich if he had 174 tireless personal servants working at maximum output on his behalf every day of the year. Yet, through our harnessing of energy, each one of us has an equivalent amount of power working on our behalf (Fodor, 1991).

Fodor (1991) estimates 174 persons working for each of us, whereas in Figure 1-3 (see page 10), the U. S. Bureau of Mines estimates 300 persons. Either way, we are greatly benefitting from cheap and abundant energy. A light bulb takes 1/2 PP, the TV takes 1 PP, hairdryer uses 8 PP, gasoline lawn mower uses 14 PP, a water heater takes 79 PP. The study goes on:

> Driving is the most energy-intensive activity commonly engaged in. It takes about

500 person-power to keep the average auto at 55 miles per hour. Our person-power athlete would have to pedal continuously for an entire year (8760 hours) to produce the amount of energy contained in a single barrel of crude oil. If we purchased the energy in a barrel of oil at the same price we pay for human labor ($5/hour), it would cost us over $45,000! [At today's $7/hour it would be $61,000.] Fortunately, a barrel of oil is an incredible value... (Fodor, 1991).

Figure 1-3. U.S. Per Capita Consumption of Energy Equivalent of 300 Persons Working 24 Hours a Day



Source: Energy Information Institute, Golden, Colorado

It is difficult to visualize how many slaves it would take to push your automobile up to the mountains or to the coast for a roundtrip of perhaps 200 miles. Human slaves would surely not be able to do it at 55 miles per hour. All this is done for you now by approximately 8 to 10 gallons of gasoline slaves in your car's tank. The richest ancient Egyptian Pharaoh or medieval European King never had it so good. The contrast between then and now is striking. It is the widespread use of fossil fuels that is the basis for these differences. Consider the problems then of obtaining power from human muscle.

There would be the energy cost of feeding the slaves, and cost and problems of medical care and housing. You don't have to feed, provide medical care, or house 10 gallons of gasoline. The same facts apply to the use of fossil fuels in agriculture. When horses or oxen were used, part of the agricultural land had to be devoted to raising feed and sheltering the animals. In areas with severe winters, animals must be fed and housed while they do not work for several months of the year. A tractor should be put in a shed over the winter, but you don't have to feed, water, and clean up after it every day. Fossil fuels are an incredible bargain and convenience, and make our lives much easier in many ways. Whether it is air conditioning that makes life livable and productive in hot, humid climates, or heat that keeps us comfortable in moderate climates, and allows us to survive in cold climates, energy is vital. Many parts of the world would not be habitable to large populations if it were not for abundant energy supplies.

Minerals in Everyday Life

Mineral resources have moved people from caves into houses, office buildings, and factories. We build with materials from the Earth (Dorr and Paty, 2002). The highways on which civilization moves in a literal sense, are made either of concrete (limestone and sand and gravel with some gypsum and clay) or asphalt (from an oil well) with crushed rocks mixed in for durability. An average asphalt road is about ten percent tar. Without the tar, it would just be gravel road. But even the gravel road is made from minerals.

Energy and mineral resources are vital to virtually all sectors of an economy from traditional farming, construction, and transportation to the newer high-technology areas of communications, where satellites and vast electronic networks span the world. All this is made of minerals of various sorts and uses vast amounts of energy. The initial process of xerography, which revolutionized the world of printing, was made possible by the metal, selenium. Tungsten is critical in high-speed hard tool steel used for cutting other steel. Cylinder blocks of automobiles are bored with tungsten carbide steel. Tungsten is the usual filament in light bulbs.

Our houses—since they first became a reasonably comfortable place with space heating and indoor plumbing—come largely out of mines. Surely, indoor plumbing alone was a major advance in civilization, especially in cold climates! The house foundation is probably of concrete, which is made from limestone, clay, sand, and gravel. The exterior walls may be made of stone or brick (clay). The insulation may be glass wool (quartz sand, feldspar, and trona—a sodium carbonate which is mined). The lumber is put together with screws and nails of steel and zinc. The wallboard that forms the interior walls of many homes is made chiefly of gypsum. The roof is probably covered with asphalt shingles. The asphalt came out of an oil well, and the filler in the asphalt shingles is a variety of colored silicate minerals. The fireplace is brick or stone with a steel fire box. The sewer pipe is made of clay or iron pipe or may be plastic from material out of an oil well. The electrical wiring is copper. Plumbing pipes are copper; fixtures are brass (copper and zinc) or stainless steel (nickel and chrome with iron). Roof gutters are galvanized steel (iron and zinc) or plastic from an oil or gas well. The various paints are derived from petroleum. Windows are glass made primarily from quartz sand. Doorknobs, locks, and hinges are of brass (copper and zinc) or steel (alloy of iron). It is truly said, "If it can't be grown, it must be mined." And finally the mortgage, if not written on newsprint, is written on quality paper made from wood or cloth fibers and filled with clay.

Clay

Clay is probably the most widespread and abundant mineral complex on Earth. It is given little thought except perhaps when we encounter it as mud on our shoes and clothes or when we get a vehicle stuck in it. However, clay is a very useful material which has been used in a variety of ways through much of human history. It is a key material in things we use every day.

Clay is derived from the weathering of feldspars, the most abundant mineral group in igneous rocks, presumably the first rocks to form on the Earth. Clay has a variety of compositions depending on the ratio and kinds of feldspars from which each clay is derived. This results in various kinds of clays adapted to particular uses from coating paper to making pottery or making bricks or insulation in electrical devices.

Whatever the detailed composition of a particular clay, it has been a most important Earth material throughout human history. Clay tablets record the first writing and clay pottery gave rise to both ancient and modern cooking storage of foods. Early Greeks and others made extensive use of large clay vessels for wine storage.

From complete specimens or pottery fragments (shards) frequently decorated in various ways we gain glimpses of past cultures. Clay figurines (huacos) which I have seen from excavations of pre-Inca cities in Peru such as Chan Chan on the north Peruvian coast reveal many aspects of that culture. Today we produce pottery with many decorations, that when found centuries from now, will tell many things about cultures of today. We eat on glazed clay plates every day and many bear decorations of our time, which will delight and intrigue archaeologists of the future.

Clay has been the mud that has covered huts around the world. Clay makes the "hogans" of the native people of the American Southwest—warm in winter, cool in summer. Clay was used to build early American communities including the cliff dwellings. Clay has been used for making bricks by many cultures. "Roman brick," notable for its shape, is still widely copied today. Although the Roman public structures such as temples, aqueducts, latrines, the Colosseum, and theaters were built of stone, many of the dwellings of the common citizenry were built of brick made from sun-dried clay.

Clay, often in brick form, remains a widely used construction material. Clay is included in the materials of cement. Earthen dams, of which there are many, have an impermeable clay core. The history of the use and importance of clay throughout civilization is detailed in a fascinating book entitled simply *Clay* by Suzanne Staubach (2005) who writes:

> The story of our relationship with clay is the story of material culture. It is the story of domesticity and the story of technological advances. The inventions of the wheel and the kiln, the understanding that fire could turn mud to stone, were the foundation for thousands of technologies that have followed.

We use clay today in many applications such as dinnerware and cookware. Spark plugs have ceramics in them and an internal combustion engine has been made from ceramics. Porcelain, widely used in kitchen and bathroom fixtures, is made from feldspar, the parent of clay.

One of the most important uses of clay has been in the manufacture of pipe, especially sewer pipe. Staubach describes how the Doulton Company, which made toilets, also discovered that the nonporous pipe could be useful as sewer pipe, which would greatly improve the sanitation of cities. The city fathers of London took to the idea of Doulton's sewer pipe. It was correctly seen as of great importance and came into wide use. Henry Doulton's clay sewer pipe and other clay-based items were eventually used even in the Royal Palace. For his contributions, Doulton was knighted. Few people today know that as they purchase Royal Doulton tableware and figurines, that "Royal" comes from the Royal recognition Doulton received for the production of toilets and sewer pipe rather than work Doulton did in the development of much higher grade uses of clay.

Wind-blown clay built up loess hills where many people live (as in western China). Clay also gives rise to dust storms that may carry the fine clay particles for thousands of miles. Clay from the African deserts is carried by wind to South America and helps to a degree to fertilize the Amazon rain forest. The extensive dust storms from the dust bowl days of the 1930s in the United States transported clay and other valuable topsoil to other regions generally to the east. I recall seeing the huge black dust clouds that would billow up to the west, blowing in from the Dakotas to my native Minnesota.

Clay has been the basis for economically important industries, large and small. The exceptionally fine pottery clays resulting from the weathering of the crystalline rocks of the Piedmont area of the southeastern United States, have given rise to more than 100 local cottage industries passed down through succeeding family generations, producing a wide variety of outstanding pottery products. For a time, at Redwing, Minnesota, "Redwing" pottery was a famous product. East Liverpool, Ohio, developed a sizeable pottery industry supplying relatively inexpensive products for the mass market. Based on the availability and quality of local clay deposits, many pottery "centers" have developed over the ages. The art of pottery making is a respected profession, still taught, and pottery remains a worldwide industry. We continue to use clay in many ways and take it for granted without reference to the fact that lowly clay ("mud") is the basic essential material.

As useful as it is, clay does have some negatives. Still widely used even as unfired sun-dried adobe brick, it is a weak building material. Earthquakes causing the collapse of adobe buildings have brought about many injuries and deaths over the years. On one occasion, more than 200,000 died in a single earthquake in China. On the fringes of the Sahara Desert and other normally dry regions, rare torrential rains do occur. Occasionally these have turned clay-built villages literally into piles of mud. After such an occurrence, some villages have simply been abandoned.

Clay will remain an abundant Earth material and will be used long after present civilizations are history. Clay is the stuff from which civilization has been physically built in many ways. Whatever form civilization takes in the future, clay will continue to be a useful material.

National defense

In national defense, everything from bullets to tanks, submarines, supersonic planes, rockets, and intercontinental ballistic missiles requires minerals for their production, and energy to power them. Modern warfare has become a matter of which side can deliver the greatest amount of energy in the most destructive fashion against the other side that determines who wins. This was demonstrated in Japan twice in August 1945, by use of the mineral uranium in the atomic bombs.

"Service economies" still based on minerals

It is sometimes said that the United States is becoming a "service economy." It seems doubtful that we can survive as an important nation by serving hamburgers to one another, and exchanging emails, text messages, and "tweets." Computers are made at least partly out of metal and the energy to run them, send electronic messages, and fry hamburgers must come from somewhere. Hamburgers and tweets do not make a great nation, and service economies are not an effective national defense. Nations cannot protect themselves with cell phones or hamburger sandwiches. Energy supplies and minerals win wars, build factories, make roads and vehicles to drive on them, and furnish our daily basic needs.

A simple standard of living index

The physical standard of living can be measured by noting the consumption of two basic resources — iron and oil. Oil is the largest single energy source of industrial nations. Iron is the chief metal used. In the case of iron, the 18 most-developed nations with a total of about 700 million people now use iron (and its derivative, steel) at rates ranging from 680 pounds to 1,400 pounds per person per year. This contrasts with 1.8 billion people in less-developed portions of the world who use less than 55 pounds of steel and less than a barrel of oil per person per year.

Minerals and moving forward now

We continue to depend on energy supplies and mineral resources but both are beginning to show the strain of our huge exploitation. In energy we may be able to devise renewable sources to replace nonenewables, but renewables are not likely to equal the high density energy sources we use now. Increasing our supplies and use of these resources as we have up to now cannot continue indefinitely. Moving forward will be more difficult in a material sense. This is a problem worldwide. Complicating the problem is the fact that in the United States and around the world, the most easily discovered and recovered, higher-grade mineral and energy mineral deposits are used first. Thus, there is increased demand each year against resources that are declining in quality and cost more in both energy and money to obtain.

Exponential demand

The understandable desire for an increased standard of living, together with the continuing rise in population, creates an exponential demand on mineral resources. In the first 50 years of the twentieth century, the total world production of minerals and mineral fuels was far greater than the total production of these materials during all previous history. Then, in the following twenty years, this production was exceeded again by approximately 50 percent. When graphed, these statistics show an exponential curve that is rising steeply toward a vertical line. Such a rate of consumption cannot be sustained. This strongly rising line representing energy mineral and mineral use also reflects the rapid rise in the world standard of living, especially for the industrialized nations. Domestic sources of these materials in the industrialized nations have been drawn upon very heavily, and many of the remaining reserves of generally higher quality materials are now held by underdeveloped nations.

Minerals needed to produce minerals

It is important to remember that the production of energy and mineral resources requires other energy and mineral resources. Imagine trying to drill a 10,000-foot deep oil well by hand or breaking up iron ore with a pick and shovel (although even in this instance you would still be using steel in the pick or shovel). To drill wells, blast out ore deposits, load and transport them, manufacture drilling pipe and drill bits, make oil well casing, build turbines and generators for power plants, make solar collectors, and make and run the chain saw used simply for cutting firewood, energy and metals have to be used.

Moving forward, change of resource location, shift of power

As energy and mineral resources are depleted and costs rise in one area, sources for these materials change, such as the shift of major world oil production from the United States to the Middle East. With geographic shifts of resource centers also goes the balance of economic power among regions and nations. Hibbing, Minnesota, was once the iron ore capital of the world, but the high-grade ore was mined out. Much of the iron used by the United States to make weapons to defeat Germany and Japan in World War II came from the Hibbing mining district. Today, Japan gets much of its iron ore from excellent deposits in relatively nearby Australia, and residents of Hibbing buy Japanese cars made from Australian iron. How things change!

Shifts in mineral source areas have occurred in the past and will continue to occur in the future. The United States is gradually experiencing this reality. Dorr and Paty (2002) have noted:

> The dependence of the United States on imported minerals continues to increase. In 1986, the country imported 100 percent of five essential minerals. By 2000, the number of minerals for which we are 100 percent import-dependent increased to 13...U.S. dependence on imports includes manganese necessary for steel production, the yttrium used in color TVs and computer monitors, and mica used in electrical transformers. In 2000 the United States had a net import reliance of greater than 50 percent for 33 mineral materials.The nations that currently provide the United States with these materials are at the same time endeavoring to raise their own standard of living. This has created increasing competition for these resources, raising the prices of all of them. And, like oil, it provides other countries with new economic "muscle." The U.S. is no longer the mineral and energy storehouse it once was. This is a fundamental circumstance with profound economic and political implications, elements of which are already apparent. Many do not understand this. The past abundance of raw materials for all basic needs provided for a smaller population with lower resource demands than exists now. This is the future: depleting resources colliding with growing demands of a an expanding population. This is a worldwide challenge for industrialized nations and those seeking to become industrialized.

This suggests a limited life for industrial civilization (Duncan, 2007). How long will the finite resources of the Earth meet the demands we place on them today? Obviously there is an end and lifestyle and economics will change. It is the industrialized nations that have the most to lose in the transition. The less industrialized a civilization is, the less its lifestyle will be affected by resource depletion.

Increasing U.S. reliance on mineral imports will have a continued and substantial effect on the lives of all U. S. citizens. Others have increasing control of our future. And the world over, those with vital Earth resources are demanding more for them, and using them in various ways for domestic and international political purposes. Economic and political power are increasingly tied to the possession of critical natural resources. Russia, source of much oil and particularly natural gas for Europe, and Saudi Arabia, the swing producer for world oil supplies, illustrate this. Australia's mineral and coal deposits give it economic importance it would not otherwise have. Yet many do not seem to realize the significance of the fact that the time of high-grade energy mineral and mineral resource abundance in the United States is past.

Beneath all historic organizations of people, including modern nations, is the need of every such group to obtain the basic necessities of life from the Earth—from possession of fertile soil and water to the more recent possession of energy resources. As it is said, "Power no longer comes from the barrel of a gun, but from a barrel of oil." But many do not realize that in the United States, the era of high-grade energy mineral and mineral resource abundance is gone. Every nation throughout history has sought the basic necessities of life, and to try to upgrade its standard of living. This has been an underlying theme in the story of civilization. Earth resources have been the chief factor in raising living standards. Civilizations in the past moved at irregular speeds in their progress, in large part due to the availability, or lack thereof, of mineral resources and the technology to find and use them. As resources are depleted in a given country, will that impede its progress as more and more raw materials have to be imported? Will that country be able to maintain its standard of living or will it decline in a material sense? The United States is beginning to enter the time when the answer to those questions will be determined.

A growing population demands more and more resources. Increasingly, the United States must import raw materials, which it could once supply for itself. This is reflected in the rising deficit in the balance of trade the U. S. has with the rest of the world. More and more we are living on "imported affluence." How long can that trend be sustained? Can the United States continue to move forward with this increasing constraint?

Other countries face similar problems. With the discovery and development of petroleum in the North Sea, the United Kingdom, for a time, enjoyed self-sufficiency in petroleum, in addition to a favorable trade situation and status, for a time, as an oil exporter. The British pound became a much stronger currency. But Britain is now an importer of oil and natural gas. Its ores for metal and its coal deposits are greatly depleted. What changes will the United Kingdom, with a growing population of more than 60 million people, see in its social and economic progress?

Rising Russia

The Soviet Union of the twentieth century is no more, and a new Russia is emerging. The former Soviet Union, and now Russia (still 80 percent the land area of the former Soviet Union) has made long-term energy and mineral self-sufficiency a major goal. Its geological good fortune has helped in this regard. Russia is now the most energy and mineral self-sufficient nation in the world. Russia had been a marginal world economic power, but with reforms in the economic system, they have the resources for significant progress. President Vladimir Putin has been re-nationalizing the petroleum industry. With huge gas reserves, and as the world's second largest oil exporter, Russia's resource influence is growing. Early in 2006, in a gas price dispute with the Ukraine, President Putin cut off the Ukraine's gas supplies. Because of the arrangement of the pipeline system, Russia's action also cut off supplies to other regions, and raised fears of what might be done in the future. Currently, Russia has the world's largest natural gas reserves and its pipelines extend to western and southern Europe to deliver the gas. However, the valves that control these gas supplies are on the Russian side of the border.

Perhaps in the future, nucelar war will not be feasible because the entire planet could be the loser. War may ultimately become strictly economic. Such wars may be won, not on the battlefield, but in having the economic advantage of mines and oil and gas wells of the various nations where those resources exist. Unfortunately, the United States has a growing disadvantage in this regard. We found and exploited a wealth of resources faster than any other nation. Now, resource depletion is our reality. Over the long term, fertile soil and fresh water supplies of the United States are the most valuable of all its resources.

Nations with few mineral resources

Some nations which have no substantial mineral or energy mineral base have been able to do very well. Japan, with very few such resources, became the economic miracle of the latter half of the twentieth century. Can that miracle be sustained or will Japan be the first major industrial nation to demonstrate the Achilles heel of having no domestic sources of vital materials? It was the lack of these energy and mineral resources and the cutting off of foreign supplies of oil in particular that caused Japan to go to war in 1941. Will Japan ultimately lose the industrial war because of a lack of raw materials? To try to offset that vulnerability, Japan has set up factories abroad, closer to resources and closer to some of their markets.

Minerals, including energy minerals, are the basis for our modern civilization. Nations not possessing these are either doomed to remain at a relatively low standard of living, or they have to get these resources in raw or finished form by trade or by moving industries abroad where the resources exist. Can free trade and access to raw materials prevent the "Japan decision" to go to war for resources? Minerals and energy minerals have markedly altered the course of civilization through warfare.

Education and technology can compensate—partly

Japan and Switzerland demonstrate that an educated work force and a technologically advanced country can compensate to some degree for lack of material resources. But they still must have access to materials from somewhere. Japanese cars and Swiss hydroelectric turbines and watches cannot be made from nothing. They are made of metals dug from somewhere on the Earth.

Can a global economy move everyone along?

It remains to be seen whether today's emerging global economy can smooth out the differences in economic development of various countries as now measured by their standards of living. The differences are currently large, and the present overpopulation of some areas, and the ever-increasing world population as a whole, will make this objective difficult to achieve.

Earth resources have been, are now, and will be in the foreseeable future a major factor in the progress of individual nations. The broad sweep of civilization has an inevitable geodestiny. Three classic references which clearly describe this are Lovering (1943), Poss (1975), and Raymond (1986). The economic geologist Lovering many years ago observed:

> The countries within whose boundaries such mineral treasures lie possess temporarily an asset that gives them a greater commercial advantage over their less fortunate trade rivals....Productive mineral deposits are among the most valuable resources that a nation may have; but such an asset will be widely coveted, and serious international problems may be engendered by the mineral policies of the government that controls the deposits.

Changing paradigm for use of Earth materials

Since earlier times of negligible impact on Earth resources with much smaller populations and before the Industrial Revolution, we have now come to a much different paradigm. Hanley and Mitchell (1980) recognized this some time ago and summed it up nicely:

> In our use of materials we have ignored the fact that the earth is finite. We get what we want, use it, and then dispose of it, in ways that prevent or delay its reentry into the regular cycle process. We behave as though having depleted the resources of one area, we could simply move over the next horizon and find another supply,

> without end. But when we go over the next horizon we confront other occupants who are dependent on the same resources. No room is left for the imperial system in which raw materials were gathered from the colonies. We must become stewards of the resources of our own regions, assuring that the fertility of the soil and the purity of water and air are maintained to provide material and energy needs and to absorb wastes, and recycling materials for continual use.

This perceptive view of the future is now borne out. Growing industrialization all over the world, and especially Asia, needs the same raw materials the earlier industrialized nations used. Now the U.S. and other industrialized nations confront China, India, South American nations, and others as resource competitors. With this new economy and resource paradigm also comes the need to reassess the "demand," the population each region can adequately support on a sustainable basis.

The Future

How mineral resources can continually be supplied in increasing quantities to a growing population, and to a world where more and more nations seek a rising standard of living, is the task ahead. It will be a challenge to do this in an orderly manner without conflict. With continued growth in population, continued inequalities of standards of living, and at least modest access to transportation, the incentives to migrate have never been greater nor as easily accomplished. As a result, the migration of people has never been greater. It is changing the demographics of nations, especially in Europe and North America.

Compounding the problem is the fact that in the United States and worldwide, the most easily recovered, higher grade mineral and energy mineral deposits are used first. Thus there is increased demand each year against resources that are declining in quality and cost more to obtain.

The desire for an increased standard of living coupled with the continuing rise in population create a worldwide exponential demand on mineral resources. Such a rate of consumption, of course, cannot be sustained. This sharply rising demand for energy and mineral resources also represents a rise in the standard of living for the world in general, and especially for the industrialized nations. This steep curve of resource consumption means the domestic sources of these materials in the industrialized nations have been drawn upon very heavily. As a result, many of the remaining, generally higher quality reserves of some materials are now held in other countries.

As never before, civilization will be affected in terms of lifestyles and economies, as the impacts of depletion of many Earth resources press in on the still growing populations worldwide. This is the century of great changes, as we move into the entirely new and uncharted territory of a growing population rapidly depleting finite Earth resources.

Chapter 2

Minerals Move People

The story of the importance of minerals and the rise and progress of civilizations are parallel stories. The search for and discovery of minerals from salt to gold and silver have caused mass migrations of people. Searching for minerals has been the cause of the opening of new lands. It has been said that "the flag follows the miner's pick." The quest for gold and silver lured Spaniards to the New World, resulting in the conquests of Mexico, Colombia, Peru, and some of the adjacent lands.

These movements continue to the present with the rise of industrial civilization devouring mineral resources in huge quantities. Mineral resources including energy are the centerpiece of our existence. They are the basis for the "good life" enjoyed by citizens of industrialized countries and which others less fortunate hope to eventually enjoy.

Migrations of people today to resource areas, or to nations that can import resources, are perhaps greater than at any time in the past. Seeking jobs and a higher standard of living, largely based on Earth resources, people today are moving, both legally and illegally, by the millions. As a result of resource depletion caused by rising population, refugees, often with different birthrates, will markedly change the demographics of much of the world in this century. The fundamental causes of resource-related population migration and growth, such as land degradation and desertification, energy, food and water demand, are the essential forces for monumental changes we will see this century (Duguid, 2004). People are on the move.

Salt and Trade

Except for occasional travel by native peoples to certain localities to obtain chert or obsidian with which to make tools and weapons, probably the first mineral to cause people to travel substantial distances was common salt. No doubt even before humans arrived on the Earth, animals traveled considerable distances to salt licks, just as they do today. Trails made by animals to salt licks in the eastern United States were some of the first trails the early settlers used.

History records the caravans and traders who moved salt in ancient times over great distances. Some of these salt routes are still used in Africa. In the sixth century, salt was the chief item of trade for Venice, which developed a salt monopoly that extended over parts of the Mediterranean. Venetian salt traders traveled widely in their commerce.

Gold Seekers

Gold was the first metal used by humans as it is bright and attractive in the native (pure) form, in which it commonly occurs. It can easily be worked into many shapes and does not tarnish. Gold nuggets in stream beds attracted attention very early. This attraction for gold probably precedes humans, as pack rats and some birds will pick up small gold nuggets and put them in their nests. Silver is rarely found in native form and it tarnishes easily. However, many silver ores can be smelted readily, so silver, too, has a long history of being sought by humans. It was put into use among earlier peoples chiefly as ornaments, and later as coinage.

Egypt

Gold was one of the earliest reasons for conquest and exploration. What is perhaps the first map ever made is a papyrus map of the Ramesside period in ancient Egypt that shows a route to the Coptos gold mines along the eastern border of Egypt next to the Red Sea. Egyptians took great quantities of gold from this area.

The gold occurred as native gold in white quartz veins, and in placers (sand and gravel deposits) downstream in the valleys below. But even richer gold deposits were in the upstream areas of the Nile, outside of Egypt in the Nubian Desert. The name Nubian comes from the Egyptian word “nub” which means gold. The Nubian gold lured the Egyptians to exploration and conquest of that area. The first gold was simply taken as plunder from the natives who already had it. Eventually the Pharaohs sent miners and established regular gold mining camps in Nubia. This pattern of exploration for gold plunder and later the establishment of permanent gold camps was repeated many times in history.

Spanish conquests

It was said that the Spaniards had the “gold disease,” but the sad fact is they had other diseases also, such as smallpox. Many of the native cultures the Spaniards encountered were virtually destroyed by the contagious diseases that the gold and silver seekers brought with them. In that way, too, gold and silver altered the history of the native nations of the Western Hemisphere.

Gold Rushes

California

The 1849 gold rush to California is one of the great examples of migration caused by a mineral discovery. Ships went around Cape Horn, and others went to Panama where the passengers hiked across the Isthmus of Panama to meet another ship on the other side. Still others took the overland route to California. After the gold discovery of 1848, located about 40 miles from present-day Sacramento, by 1850 California’s population reached 96,000. California was opened up by the discovery of gold, and it went on to become one of the great states of the United States, developing an economy of global significance.

Australia

The discovery of gold in Australia opened up large areas of that continent that had been previously ignored. The early gold rushes to Victoria and New South Wales caused many changes in Australia. In 1850, there were only about 400,000 people in all of Australia. By 1861, there were more than a million. Melbourne got its start during the gold rush. Many of the fine gardens and some of the buildings (such as Government House) are legacies from what the discovery of gold did in the middle of the nineteenth century. For a while, Australia was the richest colony in the British Empire.

Raymond (1986) emphasized the importance of gold in fostering the migration of people in world trade:

> The finding of gold in Australia, as in California, had a profound effect on the nation's economy, and would do so in other parts of the world where gold was soon to be discovered: New Zealand, South Africa, and Alaska. The gold rushes, wherever they occurred, brought new settlers, new ideas, new vigor, and created new wealth. Without the enormous amounts of gold that were produced in the latter half of the nineteenth century the commerce of the modern world could never have reached the proportions that it has today. Only after the gold rushes was it possible to speak of something called world trade.

South Africa

The discovery of diamonds in South Africa in 1867 brought thousands of immigrants to that region. The subsequent discovery of many other important minerals, especially gold, led to the transformation from what was largely an agricultural economy in South Africa to the present-day urban-industrial economy. The continuing international interest in South Africa over the years has stemmed largely from its possession of several strategic minerals including two-thirds of the world's chromium, and major deposits of platinum.

Siberia

Siberia had no gold rush in the classic sense, but with a need for acceptable foreign exchange, the Russians over the years established gold camps and gradually moved people into the Kolyma gold province of Siberia (Mowat, 1973). These camps have been expanded into permanent settlements, and now there are twelve cities in the region with a total population of more than half a million. Russia does not plan to allow these towns to be ghost towns when the gold is gone. There is lots of gold so it will last for some time, but planners have gradually established manufacturing facilities there. In this way, they expect to keep the gold country settled permanently. Gold was simply the basis for moving people there initially and getting the settlements started.

More recently the Siberian city of Norilsk has been built 200 miles north of the Arctic Circle. Temperatures there reach -40ºF and for two months there is no sunlight. Minerals are the only reason for the city, which is situated on what is probably the richest ore body in the world. It contains an estimated 35 percent of the world's nickel, 10 percent of its copper, 14 percent of its cobalt, 55 percent of its palladium, and 20 percent of its platinum. The mine, even without additional discoveries, can continue to produce at the present rate for at least 40 years. The city will be home to the mines' 155,000 employees and their families far into the twenty-first century.

Smaller gold rushes

To a modest degree, South Dakota, Colorado, and Georgia experienced gold rushes, which brought numbers of people into new territories. In South Dakota it was a military expedition that first found gold in the Black Hills. With this discovery, the gold miners moved into what was then Native American territory, causing numerous bloody conflicts.

In Colorado, an uninhabited broad upland valley in a few short months became Cripple Creek, which grew from a population of 15 people in 1891 to 50,000 by 1900. Similar growth occurred in several other areas of Colorado where gold was discovered, such as Central City.

The earliest discovery of gold in the United States appears to have been in North Carolina in 1799 when a boy found a shiny rock in a creek. But it was not recognized as gold until 1802 when a traveling jeweler saw it. By 1820 people from many parts of the world arrived, and at one mine 13 languages were spoken. Most of these people stayed and contributed to the growing population of the state.

In 1829, gold was discovered in what became the town of Dahlonega in northern Georgia and a new gold rush was on. Some of the land involved was Cherokee Indian territory, but with the influx of gold miners, the demand for the land grew and ultimately the Cherokees lost out. In 1835, the Cherokees were forced to give up all their lands east of the Mississippi River and ordered to move westward along the Trail of Tears. However, about 14,000 refused to leave, and in 1838 were forced out militarily. Some 4,000 died during their expulsion. The cause of this displacement was the discovery of gold.

Native Americans moved by minerals

Usually, it was trappers and miners who came first to the remote areas of the West, rather than settlers, who were largely farmers. It was often the miners who became the first settlers on the land occupied by the Native Americans. The Sioux knew there were gold deposits in the Black Hills and had shown specimens of it to Father De Smet before Custer's soldiers found it in French Creek (Wolle, 1953). Although the area had been set aside by the government for the Native Americans, this was ignored when news of the gold discovery spread, and miners flocked in. The initial discovery of gold in French Creek was on Native American land, which by the terms of the treaty of 1868 was off limits to white settlement. But miners persisted, and when restrictions were lifted during the years of 1875-1876, 11,000 miners entered the Black Hills. This invasion led the Sioux to resist and resulted in the famous Battle of the Little Bighorn where General Custer and his men were massacred on June 25, 1876. By September of that year, however, the Sioux were forced to sign a treaty giving up the Black Hills. Gold led to the expulsion of the Sioux. All across the West, Native Americans came into conflict with the miners and had to give up territory. This resulted in a great weakening of their economic and political positions and with destruction of what had been a sustainable, albeit primitive, way of life.

Alaska and the Yukon

The Yukon and Alaska gold rush of 1897-1898 was the last great gold rush of the nineteenth century, but it had all the excitement and problems of previous gold rushes, and it, too, opened up virgin territory. It had its origin when two prospectors, Robert Henderson and George Carmack, were salmon fishing in the Klondike River, a tributary of the Yukon River in far northwestern Canada. These men saw the glint of gold in the stream bed late in the summer of 1896, but news of the discovery did not get out until 1897. The Klondike Gold Rush was then on.

Dawson City grew from almost nothing to a population of 25,000 within a single year. By February, 1898, 41 ships made regular runs between San Francisco and Skagway, Alaska, the port nearest the gold fields. From Skagway, the prospectors had to climb up and over Chilkoot Pass or White Pass to the Yukon. During the winter of 1897-1998, 22,000 people were checked through the border between Canada and the United States on these trail routes. The interior of Alaska was largely opened up by the discovery of gold.

The town of Valdez at the head of Prince William Sound was a little fishing village until the Alaska gold rush started. Although it was not the shortest route to the goldfields, it was a route that did not cross into Canada and therefore avoided border inspection. Twenty-thousand people flooded into Valdez. In a few years the gold was mined out, and by the 1930s the population fell to about five hundred. The population remained small until it was determined that the Trans Alaska Pipeline would terminate at Valdez, and once again Valdez boomed. Now, with the steady work the pipeline terminal affords, the population of Valdez has settled to about 4,000. Thus Valdez has seen two major bursts of population growth, one caused by gold and one by oil. And after oil?

Fairbanks has had a history similar to that of Valdez. It got its start from the gold rush, and then dwindled in population. But the oil discovery at Prudhoe Bay on the Beau-fort Sea 390 miles north of Fairbanks brought a second boom time to Fairbanks. It was the logical place to build Prudhoe Bay support facilities such as warehouses, and it is the halfway point on the Alaska pipeline. The population of Fairbanks doubled in five years (Strohmeyer, 1993).

The northernmost road in North America ends at the northernmost and largest oil field in North America, Prudhoe Bay. The road now allows access to the region by the general public, and has caused some minor migration. The oil pipeline maintenance and the beginning of the freight road to Prudhoe Bay, and all that goes with that, keeps Fairbanks busy. But, as in the case of Valdez, what happens after oil?

More recently the discovery of microscopic gold in black shales principally in Nevada (the so-called Carlin-type gold deposit) has caused a number of sizable communities to be established. Named the Silver State from the Comstock Lode and numerous other silver mines, Nevada is now the major gold producer in the United States and silver mining has largely ceased. Several communities such as Carlin and Battle Mountain have expanded greatly because of adjacent gold mining operations.

Silver

This metal, being much less valuable per ounce than gold, has generally not attracted nearly so much interest as gold. However, the discovery of the Comstock Lode and the many smaller subsequent silver strikes in western Nevada attracted many people into the state, including quite a few Welsh minors from Great Britain. They became known as "cousin jacks," and a walk through the cemetery at Virginia City will show many tomb-stones noting the British origins of those who were buried there. The influx of population and the great wealth from the silver were also major factors in moving Nevada into early statehood (1864) compared with the adjacent states of Utah (1896) and Arizona (1912), and only 14 years later than California (1850).

Chinese and silver

In many mining areas of the West, significant numbers of Chinese arrived primarily to do menial tasks. They also had the patience to rework mine dumps left by the original miners. The Chinese generally were not accepted as part of the community, and so formed communities of their own, some literally underground. Remains of such communities are still in evidence beneath the streets of Pendleton, Oregon, and Idaho City, Idaho. As the mines gave out, some Chinese returned to China. Others stayed and established themselves in farming and various small businesses now scattered across the West.

Northern Idaho

This is the site of what was at one time the largest silver mine in the United States. The Sunshine Mine produced silver for many years and caused the initial development of the Coeur d'Alene mining district where both lead and zinc in quantity were also found.

Modern gold rushes

Twentieth century gold rushes include the black shale Carlin-type Nevada developments, and a much bigger gold rush in Brazil where tens of thousands of people in recent years have moved into the Amazon River Basin. Roads and airfields have been built in remote areas, and towns established, where a short time ago there was only jungle. In addition to affecting the local area environmentally and impacting the social structure of the native populations, miners, who were once simply people scattered throughout Brazil, have now been brought together by gold to form a cohesive group, and have become at least a modest force in Brazil's political scene.

The current Brazilian gold rush, however, was preceded several centuries earlier by the movement of people to Brazil caused by the discovery of gold by the Portuguese, who first held colonial control of that country. They left the legacy of Portuguese as the national language. In 1682, gold was discovered in southeastern Brazil in a province which, because of its rich mineral resources, was named Minas Gerias – General Mines. For many years, the taxes imposed on Brazilian gold production kept the Portuguese treasury alive. But when the gold supplies declined, so did the economy of Portugal. Gold briefly made that nation rich, but Portugal has never since enjoyed such affluence.

Somewhat smaller gold rushes, encouraging people to move into new areas have recently occurred on the southern Philippine Island of Mindanao, and also in New Guinea, where perhaps the largest single gold deposit now known in the world is located. In the relatively primitive wilderness of New Guinea, this event has had profound effects on the movement of people, with the construction of a large mining camp and supporting transport facilities in previously remote areas (Shari, et al., 1995).

Other Mineral "Rushes"

Canada and its northland

With more than half the people of Canada living within a hundred miles of the U.S. border, there are vast areas of this second-largest nation in area in the world that are even today very sparsely inhabited. The northern regions are largely lakes, swamps, muskegs, bogs, flat low-lying tundra plains, and some slightly more upland areas with forests of small trees. Small ranges of hills occur in some parts, and some mountainous areas exist in northeastern, western, and northwestern Canada. The northernmost portion of mainland Canada is chiefly a featureless plain.

Aside from limited hunting, trapping, and fishing, the only major economic resources are minerals and energy minerals. Hunting, fishing, and trapping did not provide an economic base to justify building roads, but minerals did. In Alberta, the northernmost road leads to the great Athabasca oil sands deposits near and beyond Fort McMurray, a city now almost entirely sustained by two large oil sands processing facilities. As the oil sands are more extensively developed, additional smaller communities have been established in this region. These areas can experience -50ºF temperatures at times and are beyond the economic limits of agriculture or forestry. The oil sands are the sole reason for the movement of people into this territory.

In Saskatchewan, the two roads that go farthest north are those that end at mines. The eastern one runs 269 miles to the Rabbit Lake uranium mine. The western road goes to the Key Lake and other uranium mines in the vicinity. This is one of the world's most important uranium mining districts, and it has opened up northern Saskatchewan, and moved people there.

In Manitoba, the north country was opened up by the great nickel discoveries in the vicinity of the now-thriving town of Thompson, with a population more than twenty thousand. The road going the farthest north from there leads to the Lynn Lake mining district of northwestern Manitoba. More recently, diamonds of excellent quality have been discovered at several localities in northern Manitoba with adjacent small communities established.

In Ontario, the great gold mines at Timmins, which once were the world's largest producers, brought people and large towns to that area, forming a complex of communities today with more than 50,000 people.

In Quebec, the northernmost road makes a big loop, and at the top of the loop are the gold mines of the Chibougamau area. Gold was the reason the road was built and is now maintained. Along the Quebec-Labrador border, tremendous iron ore deposits are the only reason for Labrador City, and the road and railroad to that area.

Oil

The opening up and development of new lands by the oil industry is also a cause for the movement of people. In the northern Sechura Desert of Peru, the town of Talara with several thousand inhabitants exists solely because of the oil industry. It rains only once every several years or less. Without the oil field, there would be little basis for settlement except perhaps as a subsistence fishing village that existed before oil. The now-thriving city of Maracaibo, Venezuela, located near the southeast end of the semi-desert Guajira Peninsula, is there only because of the rich oil deposits in the Maracaibo Basin.

The 1859 oil discovery in the United States by Col. Drake (assumed title, he was actually a railroad conductor) near Titusville, Pennsylvania, brought a "Fifty-Niner" rush. Some 30,000 people almost immediately moved into the area, and then spread out to other areas to search for more oil.

Oil in the Persian Gulf created work opportunities that brought tens of thousands of people to the region. Indians, Pakistanis, Filipinos, Palestinians, and Egyptians were among the major groups represented. When the 1991 Gulf War broke out, more than half the people living in Kuwait were foreigners. Today, in Dubai, of the United Arab Emirates, the population is only 15 percent native.

Neighboring Qatar sits atop the world's largest single natural gas deposit (12 percent of proved world reserves) and has oil exports that give it a per capita income of $13,600 a year. This robust economy has attracted Indians, Pakistanis, Iranians, and Palestinians to the extent that they make up more than two-thirds of Qatar's current population of about 700,000. Qatar is a desert peninsula with an annual rainfall of only about 2 1/2 inches. For centuries fishing was the principal occupation of the relatively few inhabitants of the region, who led a subsistence existence. Petroleum made profound changes, and caused a large migration of people to the country.

Ghost Towns and Some that Survive

Just as minerals move people into areas, exhaustion of these deposits may cause an outward migration. Many ghost towns in the western United States as well as in other parts of the world are grim testimony to the fact that minerals are a one-crop resource.

The complete economic cycle is the discovery, development, and then decline and exhaustion of the one-time mineral crop. People move into developing mineral resource areas. Then, as the mineral base gradually declines, people move out. There are examples of this in partially abandoned mining towns, and the decline of once rich oil-producing areas. This can be seen even now in parts of the one-time oil producing giant, Texas. However, in some instances, once people have come to an area because of its mineral wealth, they find other ways to survive after the minerals are gone. Some areas become farming or ranching communities. Others become tourist attractions like Virginia City, site of the once fabulously rich silver Comstock Lode in Nevada. And some have become gambling communities like Cripple Creek and Central City in Colorado. Kellogg, Idaho, grew because of the Sunshine Silver Mine. The mine is closed and Kellogg has tried to transform itself into a tourist destination, in part, by developing a small skiing facility.

Fertile Topsoil

Gold rushes are a strikingly visible demonstration of how minerals move people and make for romantic history. Far more people have moved because of the availability of new lands with fertile topsoil to cultivate. Unlike the one-crop minerals and energy minerals, properly managed soil brings a crop year after year so people move in and stay. In North America, Canada and the United States were widely settled first by farmers, after which came migration to the cities and the large development of cities today. The rich lands of South Africa, the pampas of Argentina, and the wheat growing plains of Australia also encouraged mass migrations of people.

In the case of the United States, the Homestead Act, which granted tracts of public land to settlers who would first claim and then farm the land, moved people westward. On at least one occasion, this was a rather dramatic movement, when lands in Oklahoma were about to be released for settlement. There was a fixed opening date and a firm boundary behind which people were to assemble, and at a signal, to go in and claim land parcels. But some people did not wait and sneaked into the territories offered before the opening date. They arrived sooner and thus the nickname for Oklahoma as the "Sooner" state.

Railroads were granted lands, usually alternate sections (a square mile), in a strip ten-miles wide along each side of the tracks to encourage the building of the railroads. Once built, the railroads advertized free lands and were eager to move people to them, so the railroads could generate business by hauling settlers and their goods west, and agricultural products east. Availability of rich, fertile land was the prime motivation. A similar situation existed in Canada and resulted in the settlement of the last large agricultural area of the world, the southern portions of Alberta, Saskatchewan, and Manitoba.

Possibly the last mineral to significantly move people in the United States is the oil in the Bakken Formation in the Williston Basin of North Dakota. People from all across the United States moved to Williston to work in the development of the Bakken Field and all the supporting facilities. Building housing for the inflow of population could not meet demand, forcing people to sleep in their trucks. When the oil is gone, North Dakota will likely return to its agrarian economy, perhaps symbolic of all economies when the exploitation of nonrenewable Earth resources ends, and industrial societies must revert to agrarian economies.

Move to the cities

Even as the rich, fertile land resource initially brought immigrants to North America (and to other places such as the pampas of Argentina), energy resources have since moved much of the population off the farms and into the cities. Today, with the use of petroleum powered farm machinery, only about two percent of America's population farms the land, where a hundred years ago the majority of people did. But energy slaves (chiefly oil) now do the farm work, causing another great migration of people to the industrial areas, which, in turn, exist because of abundant energy to run factories. This has also been true in Europe, and is now taking place in China and Southeast Asia. Mineral and energy resources have caused and continue to cause great human migration, both within countries and across international boundaries.

The Continued Invasion of North America

In a broad sense, the migration to North America was caused by the availability of fertile lands and other mineral resources. As they were discovered and developed, they produced an ever-higher standard of living, luring more people to come. This attraction continues. Currently, the United States annually takes in more legal and illegal immigrants than all the rest of the world combined. The natural resources that are still available in the United States together with those that can now be imported, provide the basis for the standard of living envied and sought by much of the rest of the world.

Haiti

The persistent attempts by Haitians to enter the United States are resource-based. Haiti, which occupies the western third of the Island of Hispaniola in the Caribbean, has an area of about 10,500 square miles. It has no oil, gas, coal, water power, nor any other appreciable mineral resources. When one flies into the capital, Port-au-Prince, there is a noticeable brown ring in the ocean-shore area where rivers are depositing silt and clay from continually eroding hilly and mountainous regions that make up most of Haiti. What little fertile soil remains continues to be lost at a disastrous rate.

More than 10 million people crowd Haiti's limited area. Once almost entirely wooded, Haiti is now nearly treeless. People are digging up roots for fuel. The contrast of this situation to the abundance of resources available to citizens of the United States is enormous. As a result, Haitians have an overwhelming desire to migrate to a land that has resource wealth sufficient to provide even its lowest economic segment a better standard of living than the average Haitian has. With Haiti's population growth rate of about 2.8 percent annually, one of the highest in the Western Hemisphere, the problem will only intensify. At that rate, the population will double in about 25 years, which can become an absolute disaster. Supplying more and more imported food to such a situation with no attention to population control, simply treats the symptoms and not the cause, ensuring even greater problems in the future. Some reasonable relationship between population and the resource base a country has or can import must be established. Otherwise, people will either starve or depend on permanent international welfare. To continue to export population cannot be the ultimate solution. Fewer and fewer countries are now willing or ultimately able to continue to be the safety valve for migrating population. Japan accepts virtually no immigrants, and Sweden for the first time has been turning some away. Germany has been expelling foreign nationals. Resources to house and feed the immigrant flood is the critical factor.

Increasing urge to migrate

With rapidly growing populations, and mineral resources becoming more costly as the higher quality and easily accessible sources are exhausted, problems of resource access and distribution will grow. The pressure for populations to migrate to areas which still have resources available will increase. By both legal and illegal means, mass migrations of people will continue, and are already a problem that has the potential of great social unrest. This is already happening. In 1995, the decision by President Clinton to return all Cuban refugees to Cuba, led to riots in Miami. Riots and demonstrations in Los Angeles have also had an immigrant origin.

The problem of refugees is not decreasing. What is decreasing is the willingness of many countries to accept more refugees. In contrast, the United States now has a liberal immigration policy, allowing over a million newcomers in each year. It also has a relatively porous border, which lets in another estimated half million or more illegal immigrants. The result is that some states are beginning to resist this burden. In 2004, one county in Idaho sent Mexico a bill for $545,000 for health and welfare care of illegal immigrants in the previous year. So far, they have received no reply, and the county residents are stuck paying the bill.

Because of the impact of illegal immigrants upon their resources, the states of California, Texas, and Florida filed lawsuits against the U.S. Government in 1994. The suits asserted that lack of enforcement of federal immigration laws resulted in an intolerable drain of resources from the states. In California, all the recent growth of that state has been due to foreign immigration. To accommodate the increase in children, in 1995, one new schoolroom had to be built each hour, and one new school each day (Carrying Capacity Network, 1995). In 1994, California passed Proposition 187 denying illegal immigrants a variety of services, including schooling. This caused numerous protests and demonstrations. But the immigration which accounts for almost 100 percent of the state population growth continues. California, which has had a 75 percent increase in population since 1970, now has 38 million residents, and expects to have a population swelling to 58 million by 2040. California is now the fourth largest consumer of oil in the world behind the United States as a whole, China, and Japan. Water is becoming critically scarce in some areas of the state, with Imperial Valley agricultural irrigation water from the Colorado River being sold to the cities. California's resource base is already strained. How will the additional 20 million expected by 2040 be supported? This prospect must be squarely faced because most people living in California today will see that increase and its accompanying demand on resources.

The high physical standard of living in the United States, which attracts immigrants, legal and illegal, is based on availability of Earth resources. To maintain that standard of living, each year, each person in the United States must be provided with some 20 tons of mineral resources. As more and more people enter the country by birth or legal or illegal immigration, 20 additional tons of minerals must annually—not just once, but every year—be provided for each individual.

As the United States becomes more and more dependent on importing these resources, the balance of international payments problem grows. Being able to supply resources to immigrants is what draws them, but at some point this in turn will adversely affect the future of the United States if the balance of payments problem will no longer allow increased resources to be imported. The much valued U.S. standard of living will fall, and its destiny will be altered. A nation that does not control its borders loses its sovereignty, and control of its economic future.

In a study of why people migrate, Hal Kane (1995) has observed, "Water tables will continue to be drawn down far faster than they can replenish themselves in many countries; soils continue to erode, and more people will react to these pressures in the future by leaving their homes." Describing Ethiopia, with a present population of 57 million, he states:

> ...the nation faces a colossal increase of 106 million during the next forty years, based on current growth rates. It is almost impossible to imagine how Ethiopia could possibly feed so many more people. It has some of the world's most severely eroded soils, much of its cropland is on steep slopes, and its tree cover stands at a mere 3 percent. Many in Ethiopia's next generation will probably have to choose between emigration and starvation.

Kane (1995) calls the tendency of people to migrate, "The push of poverty, the pull of wealth." He concludes that a major and increasing cause of human migration is the exhaustion of natural resources:

> Many countries, particularly in Africa, but increasingly elsewhere as well have been living off their capital, consuming their foreign reserves, their forests, soils, and freshwater aquifers.... As these reserves are diminished, pressures and conflicts mount and some people are forced to flee. The number of people on the move today has reached its highest point in history. But if nations do not shift spending priorities from military security to investments in the long-term environmental and social health of their citizens, these numbers may be dwarfed by the tide yet to come.

The End of the Physical Frontier

Today there are no large unoccupied resource-rich areas to absorb migration. There are no vacant fertile, well-watered lands. During the last 500 years, the major waves of human population have generally migrated westward. When the final big wave hit the Pacific shores of North and South America, beyond lay Asia and India with their teeming billions. The circle was complete. The globe filled up. New lands with untouched resources were no more.

With no new geographic frontiers in which to expand, today's nations jostle for position within the well-populated and fully explored world. The competition through migration and perhaps military conflict will increasingly be over access to Earth's remaining resources of energy, water, fertile soil, and other minerals. Making rational and successful adjustments between population and resources will determine the destiny of the human race. Populations must recognize that this destiny is by geology imposed upon them. There must be a recognition of natural limits (Hardin, 1993; Meadows, et al., 2004). Continued growth of population compounds problems that must be faced sooner or later, and the sooner, the better.

Globalization of Carrying Capacity Problems

Because resources and population are unevenly distributed, the current trend is for people to move from distressed areas to areas that have more resources, or for wealthier nations to send basic resources to the impoverished regions. Such aid does not solve the basic problem and may only make it worse if it allows more people to survive temporarily on a land already over-populated for its resources.

If emigration from distressed areas to areas that still have resources continues, without eventually stabilizing population, will there ultimately be worldwide prosperity or a worldwide slum? Hardin (1993) considers this matter: "...the production of human beings is the result of very localized human actions; corrective action must also be local. Globalizing the 'population problem' would only insure that it would never be solved". Hardin adds:

> Some social experiments have had very bad outcomes indeed. The wisdom is very old: Don't put all your eggs in one basket. Given many sovereign nations it is possible for humanity to carry out many experiments in population control. Each nation can observe the successes and failures of the others. Experiments that have a good outcome can be copied and perhaps improved upon; unsuccessful experiments can be noted and not repeated. Such learning by trial and error is perilous if the borderless world created by unrestricted migration converts the entire globe into a single huge experiment."

The "lifeboat ethics" concept

Hardin's observations are a facet of his "lifeboat ethics" (Hardin, 1974). A ship is sinking, and there is one lifeboat. It is launched and filled to its stated capacity of 50 people, but there are still 100 people in the water. Do you, in the spirit of fairness for everyone, take on the additional 100 from the water and have everyone drown, or do you preserve the one lifeboat and its passengers so they can get to the far shore and survive? Do you convert the entire world to a giant slum by unrestricted immigration and no population control? Or do you restrict immigration and insist that individual nations do something about population, so that at least some of them who are successful survive? At present, a number of nations are trying to export their population problems, which ultimately will, if not checked, become a global disaster. However, it will have the merit of equality. Poverty will be universal.

Continued population migration will make this concept of "lifeboat ethics" a serious consideration. Responsible and firm action may be required to prevent "lifeboat nations" from being swamped and sunk. Lucas and Ogletree (1976) relate this problem to world hunger. Pimentel and Giampietro (1994) have an implied "lifeboat" role for the United States in their statement, "Self-sufficiency in food production and other basic resources should be viewed as a strategy to guarantee a continued high standard of living and national security to U.S. citizens in the face of turbulence that can be expected around the world in the next decades. There is no time for delay. Choosing not to change the current pattern of high immigration and rapid population growth means moving into the Malthusian trap in the United States."

Immigration Today

Immigration can be both detrimental and beneficial to a country. However, overwhelming massive immigration, legal or illegal, dilutes available resources, with an accompanying reduction in physical standard of living. It also negatively impacts the environment.

The primary motivation for people to move from poorer nations to more affluent ones is usually pressure from population growth that requires limited local resources to be divided among more and more people, reducing the standard of living for all. Migration to another country, with more current resources per capita, simply brings the resource problem with each immigrant. Worldwide, family planning in all nations, and, at least population stabilization, is the front line of attack on the problem of mass migrations of people. It will determine what standard of living we ourselves, our children, and our grandchildren will have in the future. And, this future is arriving at the rate of more than 200,000 people a day.

Chapter 3

Minerals and War, Economic and Political

As the chapter title implies, minerals have been involved in various kinds of warfare in several ways. Minerals have been the cause of armed conflict. Nations that wanted them took them or tried to take them by conquest. Minerals were used by nations in economic warfare, by withholding access to minerals, or by cutting off the supplies of minerals by an embargo to accomplish some political end. Economic warfare can be waged by forming a cartel and fixing the price of oil, as the Organization of Petroleum Exporting Countries (OPEC) has done in the past. The Arab oil embargo of 1973 was done for political purposes to influence the U. S. position on Israel.

As demands for Earth resources, especially oil, have risen markedly, another version of economic warfare has developed. It might be called simply "open market competition," but the playing field is somewhat uneven. Some countries use government subsidies, or low cost loans to secure resources. China has companies that benefit from such loans. Behind-the-scenes political maneuvering along with bribes to key political figures can also be important economic factors in securing resources. As pressures rise to acquire resources to support growing populations, and with increased industrialization by some countries, notably China and India, these strategies are increasing.

Minerals Used in Warfare

For early humans, hand to hand combat with perhaps a few minerals in the form of rocks were the weapons of warfare. Then the stone axe, knife, and spear were invented, followed by improved spears, knives, and the longer knives called swords, made of metal. Arrows had a similar history. Arrows were first tipped with stone materials such as flint and obsidian, and later were metal tipped. The first knife was stone, but when native copper was discovered and hammered into knives, as was done in several places in the world, the metal age of warfare began. Metals in war have been important ever since.

Early use of oil in warfare

Oil in its various forms has long played a key role in warfare. In modern times, its role has been to fuel warplanes, ships, tanks, and the great variety of motorized transport vehicles of warfare. But oil had a very early history in war. About the year 672 A.D., the Byzantine navy was besieged by the Muslims. But a native of Syria named Kallinikos defected to the Byzantines, and brought with him the formula for making a petroleum mixture which would burn even on water (Bilkadi, 1995). Armed with this information, the Emperor Constantine IV built a siphon-like structure on the bow of some of his ships so that the flaming mixture could be squirted onto enemy vessels and on the water near them. During the seventh year of the siege, this weapon was used with remarkable success against the Muslim navy, in what was called the Battle of Kyzikos. The entire fleet, manned chiefly by Syrians and Egyptians, was destroyed. One historian estimated the losses at 30,000 men. A modern modification of this use of oil in warfare in the form of a flame thrower was extensively used in World War II, particularly on some of the rocky and cavernous islands of the South Pacific.

Oil, in the form of naphtha, continued to be important in Middle East conflicts. In 1167, the Christian king in Jerusalem, Amalric I, decided to annex Egypt. He moved against Cairo with his army. Unable to successfully resist, the city commander resolved to reduce Cairo to rubble. This he did with the aid of thousands of naphtha pots, some of which were apparently modified to become primitive explosive grenades containing a kerosene jelly, nitrates, and sulfur. An Egyptian historian, al-Maqrizi, reported that the city commander sent 20,000 naphtha pots and 10,000 lighting bombs and distributed them throughout the city. Flames and smoke engulfed the city and rose to the sky in a terrifying scene of a blaze raging for 54 days.

Alexander the Great, in his military ventures in the Middle East, was given a warmer reception than he anticipated when the natives of one area poured naphtha on a downward slope toward Alexander's tent and then set it afire.

Uranium—the ultimate weapon

World War II in the Pacific was triggered over oil supplies. World War II in Europe was over land and the resources the land contained. Hitler especially wanted the huge metal and petroleum resources of the Soviet Union. But it was a metal that at the beginning of World War II was not much more than a laboratory curiosity that ultimately ended the war, and forever changed the world. The metal is uranium. Before World War II, it did not have much of a market, and, in fact, was regarded as an undesirable impurity in some ores. Silver ores in the Coeur d'Alene mining district of northern Idaho, especially those from the Sunshine Mine, contained some uranium and this ore was penalized at the smelter. Some of the rock from the mine which contained uranium was used simply to make and maintain part of the road to the mine.

But possession of uranium allowed the U.S. to dramatically end World War II by dropping two atomic bombs on Japan. Japan's demand for oil started the Pacific war and uranium ended it. This single mineral moved warfare a quantum leap forward in just six years. The war started with the use of horse-drawn cannon and mounted cavalry (in Poland), and ended in a nuclear flash over Japan.

Salt, Rome, and Carthage

Salt has been used as a final act of warfare. After the long series of the Punic wars with Carthage from 264 B.C. to 146 B.C., Rome finally prevailed. It utterly destroyed Carthage, plowed the site of the city and its fields, and sowed salt on the fields to destroy their fertility.

Minerals Used to Pay for War

Silver and war

Silver was discovered in many areas of the ancient world, but in one particular area, it played an important role affecting the course of Western Civilization. In the limestone hills near the town of Laurium, and also near the village of Plaka, about 30 miles northeast of Athens, large deposits of silver were discovered. For many years, Athens and Greek culture flourished in part because of the wealth taken from these mines. Each citizen of Athens was given an annual share of this treasure recovered at great effort and loss of life by thousands of slaves working in the mines. But Persians threatened the wealth and culture enjoyed by the Greeks. They first moved against Greece in the year 492 B.C., under Mardonius, who had a substantial fleet and many men. The Persian fleet was largely wrecked by a storm as it approached southern Greece, and the survivors returned home. But the threat did not disappear. It only grew as the Persians reassembled and attacked Attica in 490 B.C. with a fleet of 600 ships.

After invading southern Greece, the Persians landed on the beach at the Plain of Marathon, only a few miles from Athens. Here, anywhere from 20,000 to 100,000 Persians (estimates vary widely) were met by only 9,000 Athenians and 1,000 Plateans. But the Greeks, with great courage, staged a mass running attack against the Persians, which demoralized them and they fled in confusion. Reportedly, some 6,400 Persians were killed, whereas the Greeks lost only 192 soldiers.

Even after this defeat, the Persian menace did not vanish. The Persians planned yet another invasion and this time silver played a crucial role. Themistocles, a perceptive and foresighted Greek, had argued persistently for a substantial navy. To accomplish this, he suggested that the Athenians forgo their annual dividend from the great silver mines near Athens, and that the money be used to build ships. At the time, the Greeks had only about 70 ships. The Athenians heeded Themistocles, and ultimately 130 more ships were built, paid for by the silver (Lovering, 1943).

The Persians invaded again with a great fleet and several hundred thousand men. After a series of skirmishes, the Persians overran and sacked Athens. It now remained for the Persian fleet to destroy the Greek navy, which consisted of about 300 ships, 200 of them Athenian. The 130 ships built with the silver revenues from the Laurium/Plaka area were the newest and best ships, designed for speed and maneuverability.

In late September 480 B.C., the Persian commander, Xerxes, took a seat on a prominence overlooking the Bay of Salamis, just west of Piraeus, the port to Athens. Here he confidently prepared to witness the destruction of the Greek navy. The ships of the Greeks were smaller and outnumbered about three to one by the Persian vessels. But the Greek ships were fast and easy to maneuver, and they were fitted with battering rams. They quickly moved through the Persian fleet, shearing off their oars, ramming them, and leaving them dead in the water, waiting to be further rammed and sunk. The Persian fleet was destroyed.

The Battle of Salamis marked the high water mark for the Persians in Greece, and eventually the Greeks freed themselves from the Persians. Greece continued to flourish and provided the foundation of western civilization in the form of its democratic ideals, and the corresponding liberties in individual freedom and in economics. Without the silver mines to build the ships with which the Greeks destroyed the Persian fleet, the course of western civilization would have been markedly different.

Minerals and Sweden's military ventures

The exploitation of the silver, copper, and iron deposits in Sweden about 1600 was a major factor in the increase in the wealth of Sweden. Money derived from Sweden's minerals helped to finance the Thirty Years' War, and the invasion of Germany in 1630 by the Swedish King Gustavus Adolphus. In the end, the Hapsburg Empire was destroyed and Germany was divided into more than three-hundred independent states, principalities, and free towns (Lovering, 1943).

Oil financing the Iraq/Iran war

Oil was a major factor in the hostilities in the 1980s between Iran and Iraq. In this instance, it was the ability to market the oil and thus obtain foreign exchange with which to buy the weapons of war which made oil so important. Iraq, greatly outnumbered in terms of fighting men and equipment, initially had a difficult time against larger and more powerful Iran. The materials of war had to be purchased by both sides with their oil resources. Iran had the Kharg oil terminal on the Persian Gulf, and also largely controlled access to the Gulf at the Strait of Hormuz, through which almost all of Iraq's export oil had to travel. This put Iraq at a great initial disadvantage in selling oil abroad to pay for the war. Iraq survived this early crisis because of massive aid from friendly Arab nations who used their own oil to buy war materials for Iraq. (Iraq is both Muslim and Arab; Iran is Muslim but not Arab).

With help chiefly from Saudi Arabia, Iraq eventually built a pipeline to the Mediterranean followed shortly by a second line. Then a pipeline was built from Iraq to the Saudi Arabian port of Yanbu on the Red Sea, which Iran could not control. By these means, Iraq was able to increase production from virtually nothing to more than a million and a half barrels a day to buy war materials. This turned the tide in the war. Mineral resources often affect the destinies of nations through the procurement of much needed foreign exchange, and the materials it buys. In this case, it literally meant the survival of Iraq.

Later, when Iraq became stronger, it attacked Iran's Kharg oil terminal, rendering it at least partly useless as an oil outlet. Iran had no pipeline alternative to markets as did Iraq. As a result, Iran's ability to sell oil abroad was substantially reduced. The initial advantage which Iran had over Iraq was lost and the war became a stalemate. Furthermore, popular support for the war fell within Iran because without substantial oil revenues, Iran could no longer subsidize its domestic economy as much as it had in the past. Large imports of foodstuffs (chiefly wheat and rice) had been distributed at reduced prices to the general population. Iran's inability to market oil was the swing factor in this conflict.

Equipment of War

From ancient times to the present, various metals, but especially iron, copper, tin (to make bronze), and aluminum, have been used to make the equipment of war—chariots, swords, spears, guns, bullets and shells, trucks, tanks, ships, planes, bombs, and missiles.

The Romans' ability to develop an iron-based weaponry (after bronze weapons) led to the defeat of Greece and the transfer of what was left of the Greek treasury to Rome.

In modern times, aluminum, which was not isolated as a metal until 1827, has become exceedingly important as the critical metal for aircraft. Flying a plane made of iron would be difficult due to its weight. But lightweight aluminum made aerial warfare and long-range bombing possible. An aluminum plane delivered the atomic bombs on Hiroshima and Nagasaki.

Many specialty metals are very important in war. For example, magnesium is used in flares to illuminate enemy positions. Without cobalt and vanadium, the jet engine would be impossible.

Molybdenum is a particularly useful metal employed in equipment of war as well as in civilian uses such as automobile sheet steel. It makes steel tough, rather than brittle. Prior to World War I, the Germans, who were good metallurgists, had obtained and developed the world's largest molybdenum deposit at Climax, Colorado. It was called "Mount Moly." These properties were, of course, confiscated during World War I. But the Germans had already taken quantities of molybdenum from Mount Moly before the outbreak of hostilities, because they knew that molybdenum made especially tough steel. They used this property of the metal in building the longest range cannon ever constructed. It was nicknamed "Big Bertha" by the Allies and was used by the Germans to hurl shells into Paris from a distance of 75 miles.

The Germans knew that the physical damage from this sort of bombardment from just one cannon would be minor, but they hoped the shelling would have a demoralizing effect on the French. It did not, and it was largely regarded as just a nuisance. Molybdenum remains a critical metal in many steel products, civilian and military. Without it, neither the ships and guns of the navy, nor the tanks and guns of the army, could be built.

Oil and World War II

Oil may have been the decisive factor in ending World War II in Europe. Germany, with virtually no oil of its own, stockpiled some before the outbreak of hostilities. Subsequently, small amounts were obtained from the conquest of Poland, Austria, and Hungary. Romania, an Axis power, became Germany's major oil source. The German's main goal, in the summer of 1942, was toward the huge Baku oilfields in southern Russia (Rich, 1973). When this was thwarted, and the Romanian oilfields came under intense bombing by the Allies, Hitler's oil supplies began to fail. German motorized divisions toward the end of the war suffered markedly from lack of oil. When General George Patton was finally on the move across France with the Germans in full retreat, pipeline specialists from Texas (where else!) followed Patton's tanks and laid pipeline at a rate of up to 50 miles a day. And there was oil to fill those pipelines, because during World War II, the Allies controlled 86 percent of the world's oil supply.

Minor military actions and oil

In some less-developed countries, where oil production is an important part of the economy, military factions frequently try to seize control of the oil facilities. In 1990, in the west African nation of Gabon, anti-government forces battled to gain control of the oil-producing center of Port Gentil. Gabon earns 80 percent of its income from oil, and whoever controls the oil production controls Gabon. The government forces won this skirmish.

Water and war

The resource that all warring sides must have is water. Control of water supplies has been a tool in warfare in various ways. In the sixth century B.C., the King of Syria seized water wells as part of his campaign against Arabia. The Inca conquered the desert coastal cities of Peru such as Chan Chan by cutting off their water supply. In feudal times in Europe, castles or other fortresses under siege were vulnerable if they did not have water supplies within their walls. The enemy quickly determined if such was the case. Also, moats filled with water were part of the standard military protection of the day.

In peacetime, control of water can be used as a form of economic warfare. More than 30 nations receive one-third or more of their water from outside their borders. In the case of Egypt, it is 97 percent, Hungary 95 percent, Syria 79 percent, and Iraq 66 percent. With their surface waters chiefly under the control of other countries, these and 16 other nations which obtain more than 50 percent of their surface waters coming from outside their borders are vulnerable to economic water warfare.

Wars to Obtain Materials for War

Native Americans fought for possession of Obsidian Cliff in what is now Yellowstone National Park, probably one of the earliest battles fought for the possession of mineral resources in the Western Hemisphere. Obsidian, a volcanic glass, makes razor-sharp arrowheads and is easy to shape. Those who had obsidian had a great advantage in both hunting and warfare. The Phoenicians, and later the Romans, fought for the possession of the tin mines at Cornwall in England after it was discovered that tin added to copper made bronze, a very hard alloy for weapons.

German expansion

In the middle of the nineteenth century, Germany, once a collection of independent principalities, became one nation. It became clear to the Germans early on that their military operations were dependent on having raw materials for the conduct of warfare, and Germany was not self-sufficient in this regard. To obtain markets for finished industrial goods, and to obtain raw materials, chiefly minerals, for building armaments, and to supply their industrial complex, Germany began to look hungrily at adjacent territories. After the Franco-Prussian War of 1871, Germany annexed iron-rich Alsace-Lorraine. Unfortunately, they later found that the boundaries they set did not include the bulk of the iron deposits because of the geologic structure there. Germany captured the surface outcrop area, but the iron-formation beds, with most of the iron ore, dipped westward into French territory. They apparently had a good military department, but a poor geology department. Germany fought the First World War in part "to correct the error of 1871." After losing World War I, however, Germany had to give up this territory.

The experience of World War I made both the Allies and the Central Powers (Germany and its allies) keenly aware of the need for minerals with which to conduct military operations. Immediate and extensive post-war mineral exploration and development programs for both foreign and domestic sources were started by Britain and France. Because these countries, especially Great Britain, still had extensive colonial holdings, there was a lot of territory to explore. Germany, in contrast, lost all its foreign possessions, which was one of the circumstances that precipitated World War II. As Germany prepared for World War II in the 1930s under Hitler, it had been unable to regain its colonies, so it began to annex its immediate neighbors who possessed useful resources. Austria was next door and had some small iron deposits. It was the first to be taken. Czechoslovakia contained famous mining districts with fairly large iron deposits, and a variety of other metals. Czechoslovakia was taken next. With the early defeat of France in World War II, Germany regained control of the iron of Alsace-Lorraine.

Global reach for minerals for war and peace

In the 1930s, the world witnessed a global series of political and military moves to obtain raw materials, chiefly minerals and energy minerals. Growing industrialization, with its huge demand for raw materials, growing populations, and the desire for a higher standard of living were the immediate causes for the intensified search for resources. And in the background was the thought that should another war come, the materials must be available in order to survive and win it.

Hitler covets Russia's resources

In World War II, once Germany had conquered France and driven the British back across the English Channel, Hitler turned east. In keeping with his belief in *lebensraum* (the territory necessary for national existence and economic self-sufficiency), Hitler long held the view that only the Soviet Union had adequate land and minerals to take care of Germany's needs (Rich, 1973). After taking this region, Hitler said, "We shall become the most self-supporting state in every respect in the world. Timber we will have in abundance, iron in unlimited quantities, and the greatest manganese-ore mines in the world, and oil—we shall swim in it." Hitler turned his armies toward the Urals and the Ukraine. This region, along with the Donets Basin, contains extensive deposits of hematite (high grade iron ore), excellent coking coal, and limestone—the three fundamental ingredients for steel-making. Germany, Hitler thought, was now on its way to becoming a permanent world power, and his troops headed into the Soviet Union. But they were stopped at Stalingrad, and also at Leningrad (now, once again, called St. Petersburg) by heroic Russian defenders. The Russian winter also did its part.

Oil to move implements of war

It was not only metals that became so clearly evident as important tools of warfare in World War I. Energy, chiefly in the form of that relative newcomer, oil, was obviously going to be very significant. Some of the Allied ships bringing troops and supplies across the Atlantic from the United States to Europe were coal-fired and some were oil-fired. The oil-powered ships were the better and faster vessels, greatly speeding delivery of both troops and equipment. Oil grew more important in warfare. Gasoline-powered tanks made their first appearance on the military scene in World War I. Airplanes, fueled by gasoline, primitive as they were, also came into the war in a limited fashion. For the first time in a major conflict, trucks replaced horse-drawn vehicles on a large scale. Recognizing this in the time between World War I and World War II, world military establishments began to give serious consideration to oil supplies. This is why Hitler coveted the oilfields of the southern Soviet Union.

During World War I, the British Empire was still intact, and because the Allies controlled the sea lanes, raw materials for warfare were funneled in from all parts of the globe. As World War II began to loom as a possibility, Britain began strategic planning to ensure the proper flow of war materials. The United States made similar moves in 1939 when the

U.S. Congress authorized funds to start an emergency stockpile of certain critical materials. Fortunately, Britain had access to many of its colonies and former possessions around the world. To a large extent, the British still controlled the sea lanes so materials could be transported to the United States for processing into finished war material products, and also to Britain.

Axis submarines made Allied shipping lanes much more hazardous. The situation then and during the rest of the war was summed up by Simon Strauss, an officer of the Metals Reserve Company set up by the United States Government just before World War II for this emergency. He stated:

> By the time Pearl Harbor broke out, all of Europe was under the domination of Hitler. Africa, Latin America, Australia, India, and even parts of China remained accessible to the U.S. The only competitive customer for the mineral exports of these vast areas was the United Kingdom. An agency called the Combined Raw Materials Board was created by the U.S. and the U.K. and a coordinated buying program was launched. It was possible to fight World War II without an actual shortage of these critical materials. But the key was the fact that we retained access to Latin America, to all of Africa, to most of Asia and to Australia. Had we been denied access to them, we would have been in trouble.

The United States and Britain had access to large supplies of raw materials at the outset of World War II. This was not true for Japan.

Japan

After it opened up to the rest of the world in the late 1800s, Japan resolved to become an empire, but it had very few natural resources (Abbott, 1916). The nearest significant coal and iron deposits were in northern China (Manchuria). In the early twentieth century, as an emerging Pacific power, Japan was increasingly in need of raw materials, particularly metals, coal, and oil to equip its military. Japan invaded Manchuria for its deposits of iron and coal, and later southeastern Asia for more raw materials. As the military seized such resources, it also gained materials for Japan's expanding civilian economy.

Imperial Japan continued to expand its sphere of influence, innocently but deceptively named the "Greater East Asia Co-Prosperity Sphere," largely through military action. The United States decided to invoke economic sanctions, and in July of 1940, put an embargo on aviation fuel. But this was only a nuisance because other grades of gasoline could be cracked in Japanese refineries to produce aviation fuel. In September of 1940, the United States also embargoed scrap iron and steel shipments to Japan. Until then, the United States had been primarily concerned with matters in Europe. Asia was a secondary consideration, but when the Tripartite Pact was signed in September 1940 among Germany, Italy, and Japan, the shape of things to come began to emerge. With the signing of this pact, which said that each of the signatories would go to the aid of any other in time of war, the war that was already in progress in Europe since September 1, 1939, became fused with hostility in the Far East. This made the United States more anti-Japanese than before.

Oil: Chief concern of Japan

Records of meetings of the Japanese General Staff clearly show the great concern about

Japan's ability to survive a war with the resources it could have at hand at the start of hostilities, and those which they hoped they could obtain immediately thereafter (Ike, 1976). Their major concern was oil. The United States and what was at that time the Dutch East Indies (now Indonesia) were the main suppliers of petroleum products to Japan. In July 1941, Japanese troops invaded southern Indo-China. Britain, the Dutch East Indies, and the United States immediately embargoed all exports to Japan including oil. The U.S. had been a major supplier. This reduced Japanese oil imports to about 10 percent of their previous volume. Immediately, Japan saw its storage tanks of oil as an hourglass gradually running down. Something had to be done and done very quickly.

The Japanese General Staff had to make some critical decisions (Ike, 1976). If Japan were to retain its position as a substantial power, and maintain or improve its standard of living, it had to have access to raw materials. Without oil to fuel its merchant ships and its navy this would be impossible. Japan would have to retreat to its own islands and remain a limited island-bound economy. At that time, the Japanese could not envision how they might develop into an industrial power.

The hourglass of oil would last two years or less. Under conditions of intensive warfare, the oil might last only six months. "An outline plan for carrying out the national policy of the empire" was drawn up and presented to a meeting of the Liaison Council on September 3, 1941. Faced with the alternatives of either beginning to withdraw or trying to move ahead, Japan decided to go to war with the United States if an agreement on oil could not be reached by October 15. The date was later extended to November 25 and then November 30. Japan's consumption of 12,000 tons of oil a day made oil the critical resource (Yergin, 1991). If Japan had possessed adequate oil deposits within its own borders, the Japanese probably would not have gone to war with the United States. Japan's military was determined to seize the Dutch and British oilfields in Southeast Asia. To do this, they had to neutralize the United States Fleet at Pearl Harbor. The attack was made December 7, 1941.

Pearl Harbor: Key to Japan's access to oil

Japanese Premier Tojo was the deciding influence on the decision to go to war. When the decision for war was made, and December 7 came, Japan had two interrelated immediate objectives. The first was to destroy, or at least neutralize, the United States Fleet in the Pacific. The second was to immediately move south and seize the oilfields of the Dutch East Indies. To do this, the United States Fleet had to be sufficiently disabled so that it could not protect the Dutch East Indies. This is what happened, and Japan did take the oilfields from the Dutch. Had the United States Fleet been able to intercept the Japanese as they headed for the Dutch oilfields, the Pacific war probably would have been over in less than a year. Oil was the key and Japan got its needed supplies, at least for awhile.

However, as the war continued and the United States was gradually able to cut off oil shipments to Japan, the matter of fuel became increasingly desperate for the Japanese. In the waning days of the war, Japan resorted to "kamikaze" (Japanese for "divine wind") action – suicide pilots who would crash their planes into the ever-closer ships of the U.S. Navy. This was in large part a matter of fuel efficiency, because the planes would be given just enough fuel to fly one way. They were not expected to return and the pilots were told so. More than 4,000 young Japanese men were sacrificed this way. It was a desperate way of stretching fuel supplies. If a plane did hit a U.S. Navy ship, this would be a highly effective use of a small amount of fuel. Some planes did get through the anti-aircraft barrages and did considerable damage, but many more kamikaze planes were shot down. Finally, there was not enough oil to keep either the Japanese navy or air force operational. Oil was Japan's Achilles heel in World War II.

Wars Simply to Gain Minerals for Domestic Use

Some wars are fought to enlarge an empire. Others, however, are fought simply to obtain mineral resources for domestic use, not political aggrandizement.

Huns and salt

In the vicinity of Salzburg, Austria, there are ancient salt mines. Although these did not provide minerals for war, they provided a necessity of everyday life. As such, they were richly prized and various clans of the Huns fought for their possession.

Polish zinc, lead, and coal

Battles were fought by principalities of the time over the possession of the lead and zinc mines of Poland. As part of the settlement after World War II, Poland received some of the coal mines that were previously in German territory. These coal mines are very important to the economy of Poland.

Chile and nitrates

For a long time there was a boundary question between Chile and Bolivia, but no one really cared about the exceedingly desolate northern Atacama Desert territory until nitrates were discovered there in great quantity. These were the causes of the Nitrate War. Chile declared war on both Peru and Bolivia on April 5, 1879. The Chileans were victorious and obtained all of the Atacama Desert area by the Treaty of Ancón in 1883.

The victory was of great economic value to Chile. From 1879 to 1889, the duty on nitrate exports alone reached more than $557 million dollars, a very considerable sum in those days. The total value of nitrate exports in that period exceeded $1.4 billion. Nitrates have continued to be an important Chilean export, although the synthetic production of nitrates has reduced their value.

Falkland Islands

The Falkland Islands are British possessions, which geologically lie on a shallow shelf extending east from Argentina. On April 2, 1982, Argentina invaded the islands, which they call the *Malvinas* and which they claim. On May 21, British landed troops there, and on June 14, Argentina surrendered.

This British action was ostensibly to protect the sovereignty of Britain in the Falklands, as well as the self-determination of the islands' residents, who wished to remain British citizens. There were, however, other interests at stake, as the Falklands planned to offer offshore oil concessions for bid. Argentina, trying to do what it could not do militarily, offered to pay the Falklanders for citizenship by suggesting that they might pay up to $100,000 for each islander and up to $800,000 for each family if they voted to transfer sovereignty to Argentina. The Argentine Foreign Minister, Guido di Tella, stated that Argentina wanted the islands back for their "intrinsic value," not for their potential oil and gas resources (New York Times News Service, June 12, 1995). As there are only about 2,100 islanders, at $100,000 per person, it would have cost $210 million for Argentina to buy the islands. A modest oil discovery would make that a very good investment. The Falklanders declined the offer, in good part due to their British loyalty. Since that time, oil exploration has continued and a recent modest discovery has been made.

Recent and Current Conflicts

With the recent large price increase of both oil and gas, along with improved technology for deeper water drilling, the ownership of ocean waters, which was previously of little interest, is now being contested by the adjacent countries.

South China Sea

This is a region where oil was recently discovered, and the potential for future modest discoveries is good. The Spratly Islands dot the area and consist of about a hundred coral reefs, tips of rocks, and 21 slightly submerged landforms. The emergent land is less than two square miles in total. Although these islands are located about 700 miles from China and only 100 miles from the Philippines, China claims a huge swathe of sea that overlaps and conflicts with the claims of other nations. Indeed, ownership in the strategic South China Sea is asserted in whole or in part by nine nation states, mainly China, which claims at least 80 percent, and Vietnam. In 1988, China and Vietnam clashed violently over the Spratly Islands, and in 2012, China and the Philippines are in a tense naval standoff over their competing claims there as well. All nine nations have set up little outposts on different rocks. Despite lacking clear ownership, both Vietnam and China have issued lease blocks to oil companies. In the meantime, oil-short China is building its navy and expanding its presence in the South China Sea. China needs much more oil as it plans to greatly enlarge its road network, increase motor vehicle production, and fuel its rapid industrialization, and transport system.

China/Japan

The boundary line between China and Japan in an area of open sea north of Taiwan was not important until a gas field was discovered in what China and Japan each claim as an Exclusive Economic Zone. In 2005, a dispute over ownership arose that has not yet been settled. Both countries, especially Japan, are short of energy and ownership is likely to be strongly contested. In 2005, Japan began issuing drilling rights to Japanese companies in waters which China claims (Moffett and Areddy, 2005). In late 2004, China began building drilling platforms near the disputed area and Japan protested, fearing that Chinese development would deplete reserves from under the seabed in the Japanese-claimed zone.

Thailand/Malaysia

Avoiding a dispute, Malaysia and Thailand entered into a joint agreement to develop the petroleum resources in the Gulf of Thailand, which has worked very well.

Australia/East Timor and the Timor Sea

The Timor Sea is the body of water that lies between northern Australia, East Timor, and Indonesia. East Timor became independent from Indonesia in 1999, after a brutal 24-year civil war. Australia now wants to renegotiate the treaty about the area it had with Indonesia. At stake are large petroleum resources, both oil and gas, with an estimated value of $30 billion including the giant Greater Sunrise gas field. Sixty percent of the residents of the tiny country of East Timor live on less than $2 a day according to the World Bank, and revenue from the gas field would mean prosperity to East Timor. The field lies 95 miles south of Timor, and 250 miles north of Australia. East Timor wanted to draw the line in the Timor Sea at the midway point, giving all the major energy deposits including Greater Sunrise gas field to East Timor. Although Australia helped East Timor achieve independence, it opposed this division.

Oxfam Australia, an aid agency, reports that one in ten East Timor children is likely to die before the age of five. It also claims that Australia has received ten times more from Timor Sea oil and gas revenue than it has given East Timor in aid since 1999. The Australian Prime Minister said the report was "emotional claptrap…." East Timor wanted monthly meetings to get a quick resolution of the dispute. Australia proposed two rounds a year. At that pace, a lot of oil would have been gone before the dispute was settled. A joint operational agreement was finally reached.

Offshore Gulf of Guinea

Nigeria and Equatorial Guinea both claim territorial rights in the Zafiro oilfield, which lies offshore between the two countries. The argument continues at this time, but the outcome might be imagined from the fact that Equatorial Guinea has a population of 500,000 and Nigeria, the most populous country in Africa, has a rapidly growing population of 137 million.

Persian Gulf region border disputes

Asher Susser, a Middle East expert at Tel Aviv University, states, "The average Middle East border is only 70 years old, which is nothing in the context of the history of the region. In the eyes of many Arab countries, the region's borders remain fundamentally illegitimate, the artificial creations of foreign powers."

The main reason for the border disputes that exist in the region today is the geography of its broad relatively featureless desert areas that were occupied by nomadic tribes. In the past, there was little concern about boundaries and national borders were rarely surveyed or marked.

Iraq's stated reason for the invasion of Kuwait in 1990 was a disputed border that crossed a very large oilfield. More recently, United Arab Emirates officials say Iran is threatening military action over three islands in the Persian Gulf with probable oil potential. Because of the large number of border disputes in the Middle East, some believe it may take as much as 30 years to settle them all. But some countries are using joint development arrangements for natural resources to solve the problem. Whether this approach can resolve all the border disputes remains to be seen. Iran is actively building up its military strength and all the Persian Gulf nations are increasing their spending on armaments. In 2007, the United States awarded $20 billion in armaments to Gulf nations (except Iran).

Peaceful Settlements

The United States has an example of the peaceful settlement of a petroleum dispute. When oil was struck in the valley of the Red River between Texas and Oklahoma, the state boundary was the center of the river. But the legal boundary was the Red River at the time Texas became a state in 1845, and the river had since changed course. The location question was finally settled by students of tree rings who determined where the channel ran in 1845.

This was a simple issue to settle. Will disputes in progress now or in the future be settled peacefully or will the increasing population pressures and needs for mineral and energy resources result in armed conflict? Many think that water may be the oil of the future relative to resource disputes. If so, nations like Egypt may face critical decisions about military action for its very survival, because nearly all of the water from its lifeblood, the Nile River, originates in other nations which are now building dams. Up from just 28 million people in 1960, Egypt now has 82 million and is expected to have 111 million in 2025, and 124 million in 2050. Clearly, Egypt has some critical times ahead. Thirsty and hungry people become desperate people.

Minerals in Economic/Political Warfare

The first use of oil as a weapon in economic warfare occurred when Britain tried to maintain control of the Suez Canal in the 1950s. In support of Egypt, Saudi Arabia cut off oil supplies to Britain. At that time, the United States still had surplus oil producing capacity and simply opened the oil well valves wider to supply Britain's needs.

The Arabs lost that economic skirmish (although the Suez Canal eventually went to Egypt). But in the 1970s, the Arabs and Iran realized that the United States was no longer self-sufficient in oil (after the 1960s). As a result, the Persian Gulf nations were able to do two things. They could exert economic/political influence on the United States (with regard to Israel) and they realized they could begin to take control of their own economic destinies as industrial competitors with the western world (Bilkadi, 1995).

Between 1940 and 1970, the price of Middle East crude oil ranged between $1.45 and $1.80 per barrel. This price was set in dollars not adjusted for inflation which meant that the price of oil actually went down during that period. But realizing that the western world, especially the United States, was no longer self-sufficient in oil, the Gulf countries, and all the Organization of Petroleum Exporting Countries (OPEC) members, raised the price to more than $35 per barrel in less than eight years. Colonel Gaddafi of Libya was the leader who broke the price barrier. When he seized control of Libya in 1969, he pressured one Libyan oil producer to make a 30 cent a barrel price hike. Other Libyan producers soon did the same. Then other OPEC members followed, and the price spiral began. By 1965, when the United States could no longer supply its own oil needs and began to depend on imports, the Persian Gulf nations could start using oil as a weapon.

When Arab-Israeli fighting began in 1973, the oil producers of the Middle East declared a selective boycott against consuming countries, especially the United States, because of its long-standing support of Israel. OPEC, using its newfound economic power, raised the price of oil from three dollars a barrel in September 1973 to $11.65 in December, a near quadrupling of price. Henceforth, neither the oil companies nor their Western govern-ments could control the price of oil. The best that could be done was to convince the oil-producing nations that their interests were intertwined with those of the West, and that reasonable oil prices were vital to preserving their oil markets. For the most part, this logic has prevailed.

Economic warfare by resource processing at source

There is, however, another kind of economic warfare developing, which might simply be called "economic competition." This takes the form of industrial developments in some of the nations of the Persian Gulf. They include the large petrochemical complexes of Saudi Arabia and the United Arab Emirates (UAE), and the aluminum refining capacity of the UAE, which compete directly with similar facilities in the West. This form of economic warfare will continue and probably intensify as the petroleum-producing capabilities of the world become more and more concentrated in the Middle East, and the nations that hold most of the petroleum continue to develop more petrochemical and refining industries to upgrade oil and gas to higher value-end products. The oil-rich countries have been endowed by geology with the resources to be able to do this, and this guides their economic development. At the same time, it transfers jobs from the here to for dominant petrochemical industry of the industrialized countries, to the Middle East.

Saudi Arabia is increasingly turning its attention to its large but relatively undeveloped natural gas deposits, and has ambitious projects underway for a large petro-chemical industry. In a sense, these events are not strictly warfare but the evolution of a resource-producing nation into a more industrialized nation. It is free-market competition. Abundant cheap domestic natural resources and a free-enterprise system put the United States at the top of the world economies. Now with U. S. natural resources dwindling, others with substantial resources within their borders are having their turn. Earth resources continue to exert control over nations and individuals in an ever-changing economic scene.

The United States and Rhodesia

There has been an interesting variation tried at times in using minerals in economic warfare. Rather than a producing country withholding a mineral resource, an importing country puts a ban on importing it to try to influence the producing country. The United States at one time embargoed the importation of chromium from Rhodesia (now Zimbabwe) to influence the then Rhodesian government with respect to its apartheid racial policies.

But the United States still needed chromium, and the only other substantial supplier was the USSR. The Soviets promptly tripled the price of the chrome they sold the United States. What they could not supply themselves they bought from Rhodesia, and also tripled the price of that chrome when it was re-sold to the United States. The United States finally gave up the embargo.

USSR and Lithuania

In the final days of the former Soviet Union, the Baltic Republics, and particularly Lithuania, showed intentions of wanting to break away. Fearing the precedent this might create, Soviet President Mikhail Gorbachev threatened to cut off all energy supplies to Lithuania in April 1990. Almost all of Lithuania's coal, oil, and gas came from what is now Russia. This was blatant economic warfare. It imposed a hardship which the Lithuanians endured without shaking their resolve to leave the Soviet Union. After the Soviet Union collapsed, supplies were restored, because Russia needed the income.

Minerals to Finance Internal Struggles

Unfortunately, mineral resources within a country sometimes have been used to finance insurgent groups, and in some cases, civil wars.

Colombia has an on-going drug war. It is the world's largest producer of cocaine, 90 percent of which goes to the United States. Oil accounts for a third of Colombia's export earnings. Drug-running rebels have tried to cut the government's oil income. Since 1986, they have attacked the country's major pipelines more than 900 times. In

2001, they put a pipeline out of operation for 266 days, which cost the government nearly $600 million in lost revenue (Renner, 2002).

In the Democratic Republic of the Congo (formerly Zaire), major conflicts between rival groups over very rich deposits of cobalt, tin, copper, molybdenum, and diamonds have resulted in the killing and displacement of several million people. This has given rise to the evocative term "blood diamonds," which have also helped spark and sustain cruel insurgencies in Angola, Liberia, Sierra Leone, and Ivory Coast.

The Future

Economic warfare over Earth's energy and metals clearly exists in various forms today. It will continue, and may even intensify as resources become scarcer in the face of growing populations and rising industrial demand around the world, especially as less-developed nations like China become more industrialized. China today is running short of many raw materials, including oil, to support its rapid industrialization. It is bidding against all other industrial nations for an increasing share of the remaining world oil, and other mineral supplies.

Economic warfare using energy and mineral resources as weapons can only be employed by those who possess these resources in some significant quantity. There are currently two places where this situation exists. One is the Persian Gulf region, and the other is Russia, which includes about 80 percent of the former Soviet Union with its vast mineral wealth.

Persian Gulf

As oil in other regions is depleted, and more and more of the remaining world oil resources become concentrated in the Gulf area, the opportunity for effective economic warfare using these resources increases. However, Gulf nations are not united. Saudi Arabia, with the largest oil resources in the region, and with excess production capacity, has occasionally gone it alone to determine oil export policy. Whether all the Gulf nations could present a solid front in the future for economic warfare is an open question. Their greatest unifying element is that they are all Muslim countries. The increasing control of the world's oil resources by the Gulf nations will correspondingly enhance their ability to engage in economic warfare. However, their need to export oil on a continuing basis to support their growing populations is a strong moderating element. The demand of an increasing population may preclude any reduction or cutoff in oil supplies except from those imposed by the eventual natural geological limits of oil production.

Russia—mineral resource giant

This largest country in terms of area in the world saw two political upheavals in the twentieth century. First was the rise of communism and the Soviet state following the fall of Nicholas II, the Czar of Russia, during World War I. Second was the disintegration of the Soviet Union in the early 1990s with Russia as the remaining dominant unit in a rather uncertain political and economic condition. At this time, its leadership seems at least moderately constructive. But one thing is certain, Russia has huge natural resources within its borders that can be used in economic warfare.

In the past few years, Russia's oil production has been built up with significant foreign expertise, a trend for a constructive, cooperative future. Recently, however, there has been a re-nationalization of the Russian petroleum industry, reversing a trend toward a more open-economic system that emerged with the breakup of the Soviet Union. There is some international uneasiness about this.

Russia has the world's largest deposits of natural gas, very large coal deposits, extensive and still mostly undeveloped copper resources, and large deposits of virtually all other important minerals. But it has been difficult to develop this wealth because of limited access. To correct this, the Soviets decided years ago to build another railroad through Siberia, to augment the heavily overloaded original Trans-Siberian line. This new rail line, called the Baikal-Amur Magistral (the BAM), was completed, and has opened up a mineral-rich region that will allow Russia to export a variety of important resources (Shabad and Mote, 1977). As a result, Russia will be in a position to influence world mineral markets well into the future.

Slow to develop, but much left

Russia has been slow in developing its great natural resources, reducing the standard of living of its citizens. But this delayed development also means that Russia still has untapped resources. In contrast, the United States developed its resources early and rapidly, propelling the United States to the top of world's living standards in record time. But in the process, the richest U.S. energy mineral and mineral resources have been exhausted. Russia still has most of its resources undeveloped, and this could be a factor in future economic warfare.

Whether or not the new regime in Russia will pursue economic warfare against the western democracies only time will tell. The record of the USSR in the "Cold War," which followed World War II, and continued until the breakup of the Soviet Union in 1991, was clearly one of economic warfare against the North Atlantic Treaty Organization (NATO) allies, and particularly the United States. Currently, Russia seems inclined to join the rest of the world in a mutually constructive fashion. It is a major oil and gas exporter, earning hard currency. To some extent at least, the present Russian administration is turning its attention to the welfare of its citizens, exploiting its mineral wealth, and a broader middle class is emerging.

Russian gas = economic and political strength

Russia, with the world's largest gas reserves, lies adjacent to the western European industrialized countries, which must increasingly import substantial energy supplies. Although the apparent immediate intention of Russia is simply to sell natural gas to obtain foreign exchange, a long-term result could be that western Europe becomes more and more dependent on Russia for energy supplies, and vulnerable to Russian influence. Over the longer term, Russia will be in an increasingly strong position in the European energy supply situation, and can exert a corresponding influence on this region.

Sweden and Russian energy

Sweden has voted to eventually phase out all existing nuclear plants, and not to build any new ones. Since Sweden has no coal or oil and only a modest amount of hydropower, where its future energy supplies will come from is a problem, which seems to have been ignored. Some people in Sweden envision a solar/biomass/wind economy. Whether these combined energy sources, dispersed and intermittent, can replace steady, predictable, and high-quality nuclear power at the scale required is questionable. For the immediate future, Sweden has begun talks with Russia about obtaining Russian oil and gas supplies. What the ultimate result of its energy policy will be, only time will tell. But it is likely to make Sweden somewhat economically vulnerable to Russia.

Finland and Russian gas

Finland already gets some of its gas from Russia through a pipeline into southeast Finland completed in 1974. The pipeline network has been extended into the Helsinki and Tampere districts. Most of the oil Finland uses comes from Russia. Finland also imports substantial amounts of Russian coal.

Germany and Russian resources

Fifteen percent of Germany's energy demand is met by natural gas, and most of this is imported. Russia is its most important supplier. Inevitably, Russian gas will be increasingly important to its one-time adversary, Germany. Germany also imports 95 percent of its oil, about six percent of which now comes from Russia. In the wake of the 2011 disaster at the Fukushima Daiichi Nuclear Power Plant in Japan, and Germany's subsequent decision to phase out nuclear power, Germany may become even more dependent on natural gas imports from Russia.

Turkey

Turkey has long been a thorn in the side of Russia because it controls shipping and naval access to the warm waters of the Mediterranean through the Dardanelles. The border between the two countries has been a tense one at times. But the Russians have penetrated energy-short Turkey with natural gas lines, and Russian gas now heats homes and fuels factories in the Turkish capital, Ankara.

Poland dependent on Russia

Poland is an example of a country, which has, in effect, already lost the battle of economic warfare. Nominally it is an independent country, but it depends on Russia for very basic needs. Russia can bring Poland to an economic standstill merely by cutting off its oil supply. Poland also depends on Russia for large supplies of fertilizer, made from natural gas, and for magnesium and nickel. However, by using the new technology of shale hydrofracking for gas, Poland may achieve some degree of independence from Russia for its gas supply. The Baltic Basin offers a promising region for gas exploration.

Russian need for foreign exchange

Russia has been obtaining about 60 percent of its hard currency from the sale of oil and gas. Without this income, Russia would have a difficult time supplying its military with needed technological equipment such as state-of-the-art computers. Oil and gas earnings also buy grain, something in chronic short supply in Russia. Grain bolsters the civilian economy, but grain also feeds Russia's large standing armies.

Russia in the future

It is inevitable that Russia, with its generous geological endowment of energy and mineral resources, is geodestined to play an important role in the future of many nations. This may bring the new Russia more fully into the world economy with trade in vital raw materials.

Will the Russia of the future prove to be a friendly neighbor to the western nations, or will it return to its political isolation and antagonism toward the West, using its huge coal, gas, and metal resources as weapons? The Cold War was a time when the Soviet Union was active in economic warfare against the NATO allies in many regions. That activity appears to have ceased, or at least eased, and now Russia shows a somewhat friendlier attitude toward the West. The need for western technology may bring the new Russia more fully into a world economy.

Russia is the most natural resource self-sufficient nation in the world, and the least vulnerable to cut-off of a wide variety of mineral and energy mineral supplies. It is in a better position to avoid conflict over mineral resources than the rest of the world. The reality of Russia's nearly complete self-sufficiency in minerals and energy minerals compared with other industrial nations will be important in future world affairs. With the largest and broadest energy and mineral resource base of any nation, Russia could do very well economically.

Oil: The United States, China, and Japan

In order, these are the three largest oil-consuming nations in the world, and their economies are vitally dependent on oil at the present time. It is doubtful that alternative energy sources can arrive in quantity or in time to replace diminishing quantities of oil. The result will be an intensified scramble for the remaining world oil reserves, in competition, of course, with all economies that use oil. The principal sources of the remaining oil will be the Persian Gulf countries, particularly Saudi Arabia, and Russia, although Russian oil supplies will run out before the Persian Gulf nation supplies do.

How this war for oil resources will be conducted is not entirely clear, but to some degree it is already in progress. All three countries are engaged in a worldwide search for oil, both through their oil companies and also through investments in various operations in oil regions—pipelines, refineries, and others. In the iron-mining region of northeastern Minnesota, for example, Chinese investment has reopened a mine and built a pelletizing plant (to upgrade the low-grade taconite iron ore—only 30 percent iron). They are shipping the product to China.

This trend will continue, and the outcome is uncertain as we create a globalized economy. China is the 800-pound gorilla on the scene. It is becoming an industrial giant. The steep increases in the prices of steel, copper, aluminum, and especially oil, are due in considerable part to China's growing resource demands. In regard to oil, China is moving from bicycles to motorized wheels. Several major auto firms have established factories in China, recognizing it as a prime market for future growth. China's resource demands are also mirrored in Southeast Asia and India. A new world economy is emerging, different from the twentieth century. Things change.

The cheap labor weapon

Economic warfare over the past two decades is also seen taking place in the area of labor costs. Low-wage countries aided by free trade agreements have been able to transfer the manufacture of many products from industrialized countries, particularly the United States, to their own shores. This has created huge trade imbalances. China, in particular, has a large positive trade balance with the rest of the world, especially the United States.

Armed with U.S. dollars and other foreign currencies, China, and to a lesser extent India, have embarked on a worldwide buying spree to obtain a variety of raw materials. Particular investment targets are Canada for its metal resources; Chile for its metals; Venezuela for its oil; and Australia for its metals, natural gas, and coal. This investment strategy is intensifying, particularly by China as it also reaches into Africa for both metals and oil.

One result of low-wage competition for the United States has been a large decline in its manufacturing base. The increasing deficit in international balance of payments threatens the stability of the dollar. Dollars exported to pay for things previously produced domestically, come back to compete with the United States in the form of buying power of the cheap labor countries who use the dollar to bid against the United States for natural resources worldwide. Thanks to its trade surpluses, China has had a great inflow of dollars to use for worldwide resource acquisition.

The Wall Street Journal (August 22, 2005) raised the question: "Do economic threats or military threats pose a bigger challenge to the U.S.?"

War or Reason?

Struggles for resources, especially oil, will continue as population pressures grow and resources become increasingly scarce (Tanzier, 1980). Will this worldwide increased demand for energy and minerals, compounded by the current exponential growth in population, be resolved by reason, or will the struggle result in war and anarchy as suggested in the very thought-provoking book by Robert D. Kaplan, *The Coming Anarchy* (Kaplan, 2000)?

Around the world, reason and goodwill are in shorter supply than they should be. By myriad adjustments in lifestyles and economics, the world must adjust to the new realities of resource availability. It is clear that the future cannot supply a continually growing population with resources as we use them now. But we seem to be trying to do just that. As a result, there is a race for resources beyond the scope of anything ever before seen. As Klare (2001) has noted in his book, *Resource Wars*, there is "a new geography of conflict." It is truly global.

Chapter 4

The Good Geofortune of the U.S.

Mineral resources have shaped the course of history and development of many nations, but two examples stand out, the United States and Saudi Arabia. Each is a phenomenon that will never be repeated. Each is worthy of special note. Saudi Arabia is discussed in the next chapter.

Wilderness to World Power

The establishment of a government by a free people, and an open economic system together with a great variety of abundant and easily exploited natural resources, destined the United States to change from a three-million square mile wilderness to the wealthiest and most powerful nation the world had ever seen in less than 300 years. In terms of the total energy minerals and minerals spectrum, the United States was without equal among nations at the time the Declaration of Independence was signed. Also, the millions of acres of fertile soil in the nation's heartland favored by a good growing season are unmatched in the world. At the time, its citizens did not know what riches this relatively unexplored country contained. As the pioneers moved westward and exploration proceeded, word spread of the abundant natural resources of this region both in minerals and fertile land. A flood of immigrants swept into the undeveloped territory, and in three centuries, the United States became the leading world power with material wealth beyond anything previously experienced in all of history. This was the result of a combination of the right time, a motivated people, and the great geofortune of a resource-rich country.

Right time

Part of its good fortune was that the United States was established at the right time. The U.S. emerged as a nation shortly after the Industrial Revolution, which started in Great Britain and promptly spread to Europe, and then to the United States. New inventions and new technologies developed rapidly. The technologies enabled people to extract and process important raw materials like iron ore in great quantities. The invention of the steam engine fostered the development of the railroad, which was able to haul raw materials cheaply and in great quantities to the factories and distribute finished products across the country. Many of these technologies were brought to the United States by immigrants, ready to be used on a resource-rich land.

Motivated people

The people who arrived in North America often hailed from lands where they had been ruled by kings and oppressive landlords. Most who came were not of the nobility. Why would anyone already well off in Europe come to the wild and the primitive living of North America? A few did. However, the vast majority were the oppressed and those with little material wealth. They were united by one thing: a burning desire to establish a nation where all persons would have equal rights regardless of status at birth, and where wealth gained by hard work could be retained. This was written into the U.S. Constitution and the Bill of Rights, and democracy and the American free enterprise capitalistic system emerged.

A fortunate place

Great Britain and Europe had fewer mineral and energy resources than did the new nation across the sea. When the immigrants of the time, who were then largely from northern European lands, came to North America, they found a much greater and richer spectrum of mineral resources than what they had left behind. They had witnessed the beginnings of the Industrial Revolution, and now they had tremendous natural resources with which to implement the technologies of the Industrial Revolution. The free political and economic environment gave people the incentive to maximize their talents and to invent new technologies. Soon came the telegraph, the telephone, the electric light, the cotton gin, and many other inventions.

This combination of the right time (during the spread of the Industrial Revolution), together with a poor but ambitious free people, and the right place (three-million square miles of virgin land with a tremendous variety and quantity of mineral resources), was responsible for producing the great economic and military might of the United States in the first three hundred years of its existence.

Of the three factors, the great variety and abundance of mineral and energy resources was probably the most important. Without these, even a free people would have seen the industrial age largely bypass them, or else arrive much later. But the rich geological endowment of the United States shaped its destiny.

Boyer (1984) expressed it very well: "Fertile farmland, vast forests, open ranges, coal, hydro-power, and abundant petroleum provided more opportunity for each person to gain material abundance through hard work and initiative than people had ever experienced before." Kennedy (1987) notes that the Industrial Revolution arrived just at the time the United States ended the Civil War, and could combine the new technology with its great natural resource wealth:

> Of all the changes which were taking place in the global power balances during the late nineteenth and early twentieth centuries, there can be no doubt that the most decisive one for the future was the growth of the United States. With the Civil War over, the United States was able to exploit its many advantages: rich agricultural land, vast raw materials, and the marvelously convenient arrival of modern technology (railways, the steam engine, mining equipment) to develop such resources....

Canada?

One might suggest that Canada also had the same potential as did the United States, but Canada has somewhat less conveniently deposited mineral resources. It does not have high-grade iron and coal adjacent to the inexpensive Great Lakes transportation system. Little oil was discovered until recently in eastern Canada (which is offshore), whereas there were numerous oil fields in Pennsylvania, Ohio, West Virginia, Kentucky, and Indiana where people first settled and industry was established in the United States. There is no region in Canada comparable to the prolific Gulf Coast region of the United States where the famous Spindletop oil gusher discovery was made in 1901. Canada's major oil industry really dates only from post-World War II, and, although important, it does not rival the size and wide geographic distribution of oil fields all across the United States. Also, Canada's northern geographic position with its hostile cold climate and the difficult terrain of lakes, bogs, swamps, and large areas of tundra underlain by permafrost delayed its development except for roughly a two-hundred mile wide strip of land adjacent to the United States.

Canada did not attract the large population necessary to form the basis for a big industrial complex with sizable internal markets needed to foster large-scale manufacturing such as occurred early in the history of the United States. It may be, however, that the best is yet to come for Canada. The world's largest deposits of oil sands, for example, will be an asset for many decades to come, and large high-grade iron ore deposits remain to be exploited. The United States has already depleted its high-quality iron deposits as part of the price for its phenomenal economic growth.

Russia?

Russia had the resource potential to achieve development similar to the U.S. But it lacked a political system that encouraged or, more importantly, rewarded individual initiative. Wealth could not be easily accumulated by enterprising individuals, and it, therefore, could not be efficiently re-invested in more enterprises to build a better life for the average citizen.

The early immigrants to the United States came to a land with no established economic or political system. This allowed them to establish a political and economic environment where individuals were rewarded for their initiative, and money could be retained and invested. Although Russia's agricultural base is not as large as that of the United States, Russia now has the richest mineral and energy spectrum of any nation on Earth. If the new Russia can establish and retain a political and economic society that allows individuals to realize and be rewarded for their full potential, Russia could significantly raise its standard of living and substantially increase its position as a world economic power. However, Russia would miss one advantage the United States had in its rapid economic rise, a relatively small population compared to large mineral wealth. Today Russia would have to spread its geological wealth over a far greater number of people than the United States had when it rose to its affluent world position. In 1880, as the United States began to reap the advantages of the Industrial Revolution, the population was approximately 50 million. The Russian population today is about 142 million. Large mineral wealth spread over a small population has the potential of raising the standard of living. This has been clearly illustrated in such countries as Saudi Arabia and Kuwait. Russia missed a great opportunity. Now, although it does have mineral wealth, it has more people. And Russian oil production has peaked before the benefits of its oil riches have been enjoyed to any large degree by the average citizen. The United States combined its oil wealth with its world class motor vehicle industry to bring a degree of affluence and lifestyle for the average citizen, which would be difficult if not impossible for Russia to duplicate now.

U. S. Resources

Abundant resources and rapid rise to the economic top

The United States has had an incredibly fast ride to the top in terms of economic power and affluence. Oil was discovered in Pennsylvania in 1859. Large, very high-grade coal deposits were discovered in Pennsylvania before then. The world's largest-known iron ore deposits at the time were put into production in Minnesota in 1884. The United States soon became the world's largest producer of coal, iron, and oil: three basic ingredients of the dawning industrial age.

For many years, the United States was the world's dominant producer of most vital raw materials. The United States was, until 1982, the world's largest copper producer. Until about 1950, it produced half the world's oil. It has been the leader in molybdenum, zinc, and lead output, and it still has the largest recoverable coal reserves in the world.

Following the 1859 discovery of oil, the United States was completely self-sufficient in petroleum for more than 100 years. Ultimately it was the possession of large oil resources and U. S. self-sufficiency that brought about the reversal of power between Great Britain and the United States. Until World War I, coal was the dominant energy source, and British coal mines were a major source. After World War I, oil became the major fuel on which the world depended. Britain at that time had no oil production. With the arrival of the oil age, economic power shifted to the United States. One might note that the dependence of the United States on foreign oil has substantially decreased the relative world economic strength of the United States, a matter taken up later in this volume.

Helpful geography

The United States not only benefitted from a uniquely favorable sequence of events combining mineral discovery with the developing technology of the Industrial Revolution to exploit those resources, but the geographic location of some of its resources was also very fortunate. This was especially true with respect to iron ore and the raw materials needed to smelt the ore to produce iron, the single most important metal in our industrial civilization. The richest iron ore deposits then known in the world were discovered in the Mesabi Range of northeastern Minnesota. The large, local lower-grade taconite deposits had been fractured, weathered, and leached of worthless rock material leaving behind the mineral hematite, which is 60 percent iron.

These rich iron ores were easily and economically connected with the two other main ingredients for making steel, high-grade coal and limestone, by the fortunate geography of the Great Lakes region. Iron ore could be brought down first by rail (downhill, an economically important fact for the transport of heavy iron ore) to Lake Superior. From there, cheap water transport moved the ore to steel mills in Chicago where the first American steel rails were rolled in 1865, and also to the Pittsburgh area — which also became a steel producing center — adjacent to the rich Pennsylvania coal fields. Both areas had abundant coal and limestone to combine with iron ore to produce iron and steel.

Timely Discoveries and Inventions

Timely discoveries

The rich iron ore discovery came just when it was needed at the time the railroads began to dominate transportation. The engines, cars, and rails all demanded great quantities of steel. The blast furnaces around Chicago, Cleveland, and Pittsburgh produced it. American steel production was only 20,000 tons in 1867. But by 1895, it surpassed the British production of six million tons, and reached 10 million tons annually before 1900. Ultimately, a large steel network of rails stretched from coast to coast, an impossible task were it not for the great iron ore deposits, which had been discovered and developed on such a timely basis.

Steel also built the factories and machines with which more goods were produced. The railroads efficiently distributed the manufactured products such as steel farm implements for the pioneers breaking sod in the Midwest and the Great Plains. The railroad brought needed equipment and supplies to miners and ranchers of the mountain regions, and to the growing settlements on the West Coast, previously supplied mainly by ships, which had to go all the way around the southern tip of South America, rounding the treacherous Cape Horn.

Steel made the world's first skyscraper possible. After the great Chicago fire of 1871, large areas of the city needed to be rebuilt. An architect named William Jenney demonstrated that walls of buildings were no longer needed for bearing the weight of the structure. Rather, with abundant and relatively cheap steel available, he could build a steel frame to act as the skeleton of the building. Using lighter weight materials, the structure could be walled in. Thus the first skyscraper was erected, the 10-story Home Insurance Building finished in 1885. It was such a success that two more stories were added later. The giant steel mills came into being because of the rich iron ore deposits of the Mesabi Range, which built the great railroad network, and provided the structural steel to build the huge complexes of office buildings and factories we know today.

Copper and the electrical age

About the time the steel business was booming, the electrical age was dawning. The electric motor had been invented about 1854. In 1879, Thomas Edison produced the first usable electric light, and visualized lighting cities. But how could electric current be transmitted to lamps for use in the home, offices, and factories, and to the motors that could replace so much of the hand labor in the factory?

Again, geology favored the U.S. with deposits of large native copper deposits, some of the richest known in the world, on the Keweenaw Peninsula of Upper Michigan. These deposits were mined to meet the demands of the electric age. Copper became the workhorse of the electrical industry. Upper Michigan, located not far from the industrial East and Midwest where much of the copper was used, produced huge amounts of this most useful metal. And it was inexpensive native copper. One mine struck a deposit of pure solid copper about 50 feet long with an average thickness of about 14 feet, weighing more than 500 tons. The copper, being so malleable, could not be blasted out, but instead had to be cut into small pieces. This procedure was economical because the mass was almost pure copper requiring little smelting and refining. That it was not pure copper was also fortunate because the impurity it contained was silver. Silver is an even better electric conductor than copper, so the wires made from the Michigan copper with its silver content were superior in transmission performance.

Michigan copper was made into thousands of miles of wire that carried electric power to homes and factories. It made the workday more pleasant and efficient, and domestic life brighter. Copper wire carrying electricity allowed factories to operate three shifts a day instead of one. Copper greatly increased the productivity of the American economy.

In the United States, the Rural Electrification Administration (REA), launched in the 1930s, brought electric power and light to rural America and substantially improved the living standards of people living outside the cities. Copper wires carried the electric power and still do.

Copper and communication

In the 1830s, Samuel Morse established his telegraph line from Washington to Baltimore. Copper telegraph wires soon spanned large areas of the nation, first running along railroad tracks, and then spreading out and connecting many otherwise isolated communities with the outside world. Telephones began to appear, and copper wires were available to put this most useful instrument into many places. Business and industry greatly benefited by this communication system. All this was facilitated by the abundant rich copper deposits in Michigan, which could be developed at just the right time to promote the electrical age in the United States in all its many and varied useful forms. It should be noted that the Michigan copper deposits fed far more money into the American economy than did all the gold from the California gold rush.

Cheap steel, oil, and cars

Then came the development and mass production of motor vehicles made possible by the abundance of cheap steel combined with the discovery of oil in increasing amounts in many parts of the United States. After first finding oil in Pennsylvania, drillers soon discovered oil in New York, West Virginia, Ohio, Texas, Louisiana, Oklahoma, Kentucky, Kansas, Colorado, Wyoming, and California. Oil was available coast to coast. By 1909, the United States was producing more oil than the rest of the world combined, and continued to do so through 1950. With the discovery of oil found all across the U.S., and the development of trucks and automobiles, soon a nationwide network of roads and service stations was established. Travel came into vogue, because oil was inexpensive. The average citizen could afford it. Thus the great travel boom arrived and the novel idea of motels spread across the country. The travel industry became an important part of the U. S. economy.

In 1930, the great East Texas Oil Field was discovered, the biggest ever found in the 48-adjacent states, and oil prices dropped briefly to as low as four cents a barrel. The United States found itself with more and more and cheaper and cheaper oil, and ultimately led the world away from coal as the major fuel to the present dominance of oil. In myriad ways, oil has powered the United States to its leading world position, including, until recently, being the world's largest motor vehicle manufacturer.

Minerals and Two Wars

Ample minerals and energy minerals won two wars

In the early and middle decades of the twentieth century, mineral and energy mineral resources in the U.S. were in seemingly endless supply. The United States provided its allies with vital energy and mineral resources first to win World War I, when it was said that "the Allies floated to victory on a sea of oil." U.S. oil supplies again played a vital role in World War II. Both Japan and Germany lacked oil. In terms of metals, it has been said that both wars were fought from the great hole in the ground which is the Hull-Rust iron mine on the north side of Hibbing, Minnesota.

Minerals: Standard of Living and World Power

With cheap and abundant mineral and energy mineral resources, the United States enjoyed an unprecedented rapid rise to the world's highest material standard of living and to economic and military pre-eminence.

Abundant cheap energy, high-grade metal deposits

When considering the future, as compared with the past, it is important to note that the United States achieved its industrial position and its high standard of living on abundant, cheap energy, and rich mineral resources. It took enormous energy to mine and smelt the ores to produce the metals vital to industrial development. It took vast amounts of energy to conquer the frontier and do the work needed to convert a raw wilderness into the world's largest, most affluent society. During most of the time between 1940 and 1960, the United States enjoyed $3-a-barrel oil, natural gas costing about 15 cents a thousand cubic feet, and coal costing about $4 a ton, all available within the United States. Abundant and inexpensive energy sources and high-grade iron and copper deposits were exceedingly helpful to a young and rapidly growing nation. High-grade metal deposits take less energy to mine and smelt than low-grade deposits do.

The combination of high-grade ores and inexpensive energy combined to provide very inexpensive finished products that fostered economic growth. Conversely, as ore grade decreases, it takes more energy to produce the same amount of metal as previously. Combined with higher energy costs, the result is substantially higher finished product costs. The far more favorable economic combination of high-grade mineral deposits and low-energy costs (coal and oil) of the past will never likely again return to the United States.

The zenith

The United States' peak of power may have been symbolized by its use of the ultimate energy weapon, the atomic bomb, to end World War II in 1945. At the time, the United States was the sole owner of this fearsome form of energy. It was the possession of a particular metal, uranium, within its borders that allowed the United States to arrive at this zenith of world power. Now this capability is shared by several countries, and the number is growing.

Foreign oil dependency and some loss of economic control

After the break up of the Soviet Union in the early 1990s, there were those who argued that the United States stood alone as the unrivaled world power. Unlike 1945, however, in the 1990s the United States was no longer self-sufficient in its principal energy need, oil. In fact, it was importing more than half of its supplies, and lacked the ability to reverse the trend. The United States no longer controlled its economic destiny, which was partly in the hand of foreign oil producers. And the continuing imbalance of foreign trade, in which imported oil was the largest single (and growing) factor, hurt the prestige and value of the U.S. dollar in world markets.

Future warfare

After the atomic bomb, the United States and the world may have entered a time when wars will not be fought by the violent methods of the past. Possession of atomic weapons now by a number of countries and the destructive ramifications of atomic warfare for all sides of a conflict are such that it is unlikely anyone would really win. Therefore, the military might of the United States may not be as important in the future as it once was.

The new battle is likely to be waged on economic and industrial fronts, using mineral and energy mineral resources mainly for non-military purposes. The United States already is engaged in such conflict with China.

Resource Depletion

The United States rose to international economic dominance in record time, but in the process depleted many of its high-grade resources. The rich ores of the Mesabi Iron Range are gone. All the high-grade native copper mines of Upper Michigan are closed. The United States now searches for oil off the frozen north coast of Alaska and in the deep waters of the Gulf of Mexico. The U.S. is no longer nor will it ever be self-sufficient in oil again. Its oil reserves, once the largest in the world, are now dwarfed by those of several other countries. Although it consumes about 25 percent of the world's oil, the U.S. now contains only about four percent of the estimated conventional proved world oil reserves. How much shale oil can add to U. S. oil supply is not yet known, but it will probably make only a modest contribution.

The United States has changed from being an exporter of energy and mineral resources to now being a net importer on an increasingly large scale. In the process, the United States also went from being the world's largest creditor nation to being the world's largest debtor nation in less than 20 years. Oil imports now are the single largest item contributing to our annual balance of trade deficit. Other basic commodities are increasingly imported as the U.S. continues to decline in resource self-sufficiency.

In 1920, the United States produced 80 percent of the world's oil. But, in 1965, the curves of rising U.S. oil consumption and declining oil production crossed. That year, the United States produced just enough oil for its own needs. By 1994, more than half of its oil was imported. The long-term, overall downtrend of domestic oil production continues.

In metals, the story is much the same. The copper mining industry survives in modest form in southwestern United States, but other countries are now the dominant producers, notably Chile and Peru. The rich iron deposits of northern Minnesota are gone and a lower-grade ore, taconite, is processed to supply most of U. S. demand. Iron ore deposits in Canada, Liberia, Brazil, and Australia now dominate the world supply. With little domestic aluminum ore (bauxite), the U.S. imports most of its ore from Jamaica and Australia and a few other places. The United States still has rich fertile land, but even that is being degraded by erosion and soil nutrient depletion, and the groundwater supplies needed to support irrigated lands are being over-pumped. Increasingly, the United States lives on "imported affluence." Unending tides of immigrants continue to arrive in a land that is now the third most populous nation in the world, to share in a fading American dream.

The United States should consider where these trends are taking the nation. Together with Canada and Australia, it is one of the few industrial nations still experiencing rapid population growth. With an increasing population consuming diminishing domestic resources, it is difficult to see how the present standard of living can be maintained. By some measures it is already in decline. Inevitably, a balance between resource consumption and population must be achieved. The question is: at what standard of living will that be achieved? People use resources. Divide resources by population to help answer the question.

A unique world event

The saga of the astonishing rise of the United States to affluence and power will never be duplicated in the world. There are no more virgin continents to exploit. The story of the growth of the United States has been a phenomenon beyond comparison. The question now is: where does it go from here?

Jones (1976) has drawn an interesting analogy between the past and present position of the United States with respect to mineral resources, and oil in particular:

> For its first 150 years, the United States was a boy with so much candy that no matter how much he ate he always had some to give away. For the next 25 years, he had as much as he wanted provided he gave very little away. Today he cannot supply enough to meet his very large, and increasing appetite, and must, for the first time, go to the world's candy store and stand in line like everyone else to buy it.

Chapter 5

The Extraordinary Geodestiny of Saudi Arabia and Other Gulf Nations

The nations of the Gulf are Muslim countries, and all are Arab, except Iran. The national language of Iran is Persian or Farsi, with Kurdish, Turkic, and several other languages also spoken. Iran (named Persia until 1935) has long been a traditional enemy of the peoples of the Arabian Peninsula. For that reason, Saudi Arabia does not recognize the name Persian Gulf, but calls it the Arabian Gulf. I am told by geological colleagues who went to Saudi Arabia after its petroleum industry was launched, that one of their first tasks was to be sure that the term "Arabian Gulf" appeared on all maps, not Persian Gulf. I notice now that the British, in the *Oxford Concise Atlas of the World*, avoid the problem by simply calling that body of water "The Gulf." Regardless of these differences, each nation that borders any part of the Gulf's geologic province shares the extraordinary destiny bequeathed to it by geological events of the past. In Figure 5-1, my British friend, John Bulloch, who allowed me to use the figure, also diplomatically calls it simply the "Gulf."

Figure 5-1. Geography of the Gulf Region

Source: *The Persian Gulf Unveiled*, John Bulloch, by permission

Special Geological Circumstances

To understand why I apply the term extraordinary to the Gulf nations, one must know something about how such a huge accumulation of oil that exists in that region could be formed today. Oil in the great quantities that can be so relatively easily and, therefore, cheaply produced as in the Gulf required a special combination and sequence of geological events. These occurred elsewhere where oil is found, but not on the scale as happened in the Gulf. The oil accumulation in the Gulf region has no world equal. It is truly extraordinary. The Gulf nations won the world oil sweepstakes!

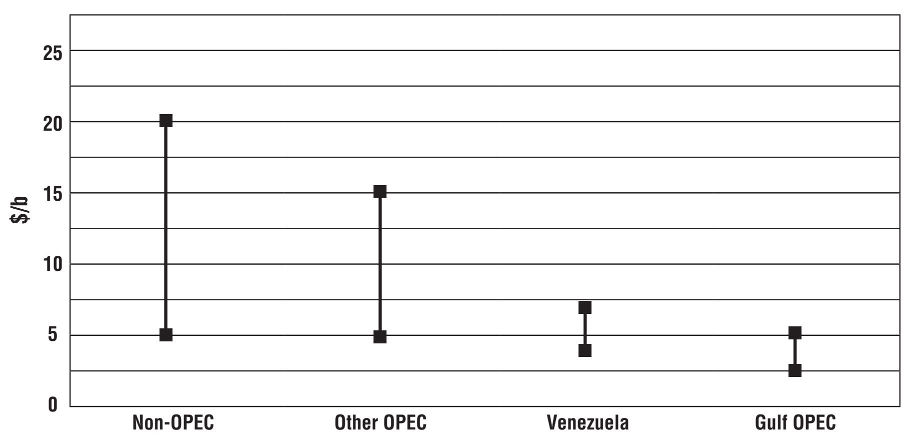
Forming commercial oil deposits

A more detailed description of how large accumulations of oil are formed is given in Chapter 9, The Oil Interval, but here is a brief summary. Oil is derived from organic material accumulated chiefly in structural depressions in the Earth's crust called basins within continental areas invaded by the sea and along land mass margins. Incoming sediment eroded from adjacent land masses subsequently bury the organic material deep enough to allow the heat of the Earth to transform the organic material to oil (Haun, 1971; Hunt, 1996). A permeable porous rock is needed eventually to be the reservoir for the oil and an overlying impermeable cap rock of some sort must be present to prevent the oil from leaking out.

The Gulf nations were endowed by geological events to have all these features on a huge scale. Saudi Arabia, the largest of these countries, got the largest amount of oil, and also was endowed with large structural upfolds in the Earth called anticlines. Oil in great quantities accumulated in these structures, which are easily discovered by surface mapping and by reflection seismograph methods.

Because these oil traps are easy to find, exploration costs are low. Furthermore, the reservoir rocks are so porous and permeable that only a few wells can drain a large area. The result is that this area has the lowest production costs of any oil province, as low as two dollars a barrel (Figure 5-2).

Figure 5-2. Comparative Oil Production Costs in Dollars per Barrel, Various Oil Producers



Source: Campbell, 2005. These costs clearly show the advantage of the Gulf region oil producers over others. As more marginal production comes on line, these costs can only go up, modified to some degree by new technology, but still going up. Data as 2004, but relative production cost of various producers remained the same in 2009. Gulf producers maintain large advantage.

Sixty percent or more of remaining world oil

The future of our present petroleum-based industrial world will increasingly lie in the hands of the Gulf nations that geology endowed with 60 percent or more of the world's remaining oil. We need to understand them as they will collectively influence our future for the next several decades. Here are brief descriptions with salient facts about each of these countries.

The petroleum Geodestinies of the Gulf nations

It is obvious that petroleum has profoundly influenced the course of Gulf nations who share this treasure. How possession of petroleum has affected each nation differs in detail, but in every case, relatively obscure and poor nations moved into the modern world in a phenomenally short time. This sudden transition has markedly affected the cultures, the religions, the economies, and the demographics of these countries.

Saudi Arabia

This is largely a desert country, with a land area equal to about a third that of the 48 adjacent United States. Ninety percent of it is too dry to be cultivated. In the past, it was a loose organization of tribes, many of which were desert nomads, together with some fishermen along the coast of the Gulf. However, a very able desert chieftain, Ibn Saud, unified these peoples into a kingdom that was recognized by the British by treaty in 1927. Ibn Saud became King of the Hijaz and Najd and its dependencies. The country was renamed the Kingdom of Saudi Arabia on September 22, 1932.

The first oil well was completed on March 3, 1938. By 1979, it had produced more than 27 million barrels of oil and is still pumping today. At that time, the population of Saudi Arabia was approximately three million. It is now about 29 million.

In the less than 70 years since oil was discovered, Saudi Arabia changed from an undeveloped Third World Country to an economic giant. It has constructed the world's largest and most expensive airport, and the world's most modern communication system with its own satellites. It has built railroads, schools through the university level, advanced medical facilities, and miles of modern highways, and it has its own fairly sizable airline.

Thanks to the immense wealth derived from oil, Riyadh, the capital of Saudi Arabia, grew in less than a century from a mud-wall city of no more than 20,000 people, to a metropolis of five million. Today, it has traffic jams rivaling any in the U.S., high-fashion shops, and high-rise malls.

Early oil production was not very large, and, therefore, economic development proceeded slowly at first. The years of World War II (1939-1945) intervened to delay progress. Until 1965, the United States was self-sufficient in oil, and had been a major exporter so there was little demand for Saudi oil.

Oil and the development boom

As late as 1954, Saudi Arabia had only 147 miles of paved roads. By 1986, Saudi Arabia had built more than 50,000 miles of pavement. The number of vehicles using these roads increased from 60,000 in 1970 to nearly four million in 2005. The Saudi Public Transport Company now has 900 buses providing low-cost transportation between all sizable cities and many villages.

Saudi Arabia came almost as far in 70 years in terms of its standard of living, and the use of modern technology and equipment, as the United States did in 300 years, or as the European nations did in thousands of years. In relative terms, the Saudis arrived in the modern world almost overnight, making the trip from a simple mixed nomadic and scattered agricultural economy to the technological twentieth century. Oil made it all possible.

It is true that money cannot buy happiness, but it can buy almost everything else. That is the story of Saudi Arabia. It was able to make the leap into the twentieth century and obtain all the material things that characterize this industrial age, by simply buying them. The Saudis did not have to wait for the development of the telegraph, the telephone, automobiles, the electric light, the radio, antibiotics, television, satellites, and jet airplanes. All these had been invented and were on the shelf waiting to be purchased when Saudi Arabia began to receive its oil money. The United States contributed ingenuity and many inventions to the Industrial and Technological Revolution. Saudi Arabia simply bought it all, to some extent with money the United States paid for Saudi oil.

> "Oil changed the whole of life in Saudi Arabia," said Abdullah Ibrahim Al-Ajmi, a Bedouin who gave up nomadic life to work in the oil industry. When he was a boy, he and his father used trained falcons to hunt rabbits and lizards to supplement their diet of dates, bread, and camel's milk. His early home was an open-front tent. Now he manages a permanent camp for 660 oil workers.
>
> Saudi society was molded by the self-sufficient egalitarian virtues of desert life, yet today, it's in thrall to fast food, cell phones and gas-guzzling SUVs. The country's oil wealth has paid for an imported culture of conspicuous affluence, typified by modernistic shopping malls and highways worthy of Southern California. (Stanley, 2004)

Besides its great oil deposits, Saudi Arabia had another advantage that allowed it to come so far and so fast. It initially had a small population. Saudi Arabia has the world's largest oil reserve of any nation, and production profits were initially spread over relatively few people. As a result, raising the standard of living in terms of material things was a comparatively easy task. It would not have been so easy if the oil wealth had to be spread over, say, 100 million people. Oil income has made a big difference in the lives of all Saudi Arabian citizens. More recently the Saudi population has risen rapidly, whereas oil income is leveling off. Consequently, per capita income has declined markedly.

Although Saudi Arabia has about 80 oil and gas fields, more than half its oil reserves are in eight fields including Ghawar, the world's largest onshore field, which was discovered in 1948. Its remaining recoverable reserves are estimated at 70 billion barrels. Saudi Arabia also has Safaniya, the world's largest offshore field, with estimated reserves of 19 billion barrels (Energy Information Agency, 2003). (Note: Some experts feel these reserve figures are too high.) The Ghawar field alone still accounts for more than half of Saudi Arabia's total current oil production. But it is beginning to show its age, as the amount of water being produced with the oil is increasing. The water-cut is now about 30 percent. (As oil is extracted, over time, the pressure in an oil-bearing reservoir decreases, and water is injected down-well to boost the pressure and allow the oil to continue to be pumped upwards, along with the water that was injected. Water-cut refers to the percentage of the oil-water mixture that is water; the greater the percentage, the more depleted the reservoir is.)

There is still a lot of Saudi oil to be pumped, but there have been some ups and downs. In the middle of the 1980s, a temporary oil surplus developed. Saudi Arabia chose to support the price of oil by cutting back on production to about four million barrels of oil a day. This was far below their potential production, now estimated to be 12.5 million barrels, and the 10 million barrels a day they once briefly produced.

The welfare state and budget deficits

Cutting back on production, however, caused a domestic problem because Saudi Arabia launched a number of long-term projects, which had to be temporarily put on hold, including social programs of various kinds. Some observers call Saudi Arabia the world's largest welfare state. The problem is how to maintain it indefinitely with a growing population to serve.

The other side of the oil bonanza

Although oil has brought great economic advantages to Saudi Arabia and made it into a significant world power, it has also brought troubles. The increasing presence of westerners, especially from the United States, who are involved in managing the various aspects of the oil industry from exploration and production to marketing, has upset some religious elements of Saudi society. In addition, since Saudi Arabia is the only country named after a family and is run chiefly by that same family, wealth from oil has not been evenly distributed, although nearly all citizens have benefitted to some extent.

There has been a Saudi petroleum alliance with the West and particularly the United States. The Saudi government needed both the technical expertise for oil field development, and markets for the oil that the West, and especially the United States, provided. This has led some Muslim elements to attack the Saudi government and the westerners in Saudi Arabia. Although a Saudi himself, Osama bin Laden swore to bring down the House of Saud. Reed (2004) writes, "It is dawning on everyone who does business with the kingdom that the Saudi government is locked in a long, vicious struggle with Islamic militants that threaten to send wave after wave of jitters through the oil markets and shake the timbers of the House of Saud."

With westerners and oil revenue distribution as focal points of irritation for the earlier tribal elements that existed before the Kingdom was created, disparate Muslim opposition groups are beginning to surface. The Saudi leadership is increasingly experiencing difficulties asserting its authority. "The well-organized tribes, meanwhile, are tightly knit and well-armed, and urban middle classes and business elite fear that the old tribalism will fill the current power vacuum." (Pope, 2004)

How all this will turn out cannot be foreseen, but it appears likely that major transformations of Saudi society will take place in the not too distant future. Reed (2004) states: "But hoped-for political changes such as elections for the Constitutional Council have been slow to materialize. The Crown Prince promised elections for municipal councils this fall but preparations are lagging…. 'All we have heard is promises; we haven't seen a single sign of practical reform,' says Mohsen Al-Awaji, a leading critic of the government."

Population growth

Part of Saudi Arabia's success story is that Saudi Arabia has experienced the largest natural increase in population in any of the Gulf nations (2.9 percent annually). This increase in population has been fostered in large part by better sanitation, medical facilities, and food supplies provided by oil revenue. Oil has greatly improved the life of the Saudi population. Demographically it has set the stage for another huge increase in population, which is likely to have a very negative effect on living standards. With 28 million people now, the population is projected to reach 36 million in 2025, and 45 million by 2050.

Whereas its population of today is expected to increase by nearly 70 percent by 2050, oil production by the Saudis' own estimates cannot grow more than about 50 percent. Other estimates are for somewhat less (Duncan and Youngquist, 1999). Supporting 45 million people in 2050 will be a challenge because it is likely to be at or past the time when oil production begins to decline. The solution would seem to be to begin reducing population growth now. Even with its oil riches, Saudi Arabia, because its population growth outpaces its oil income, may see a marked change in its fortunes. Fisher (2004) writes:

> Although there is some hope that, at least globally population growth will lessen particularly as women become more educated and join in the business workforce, this is a particularly distant hope in the Middle Eastern oil-exporting countries. That most of the world's exporters can no longer rely on oil revenues to keep up with rampant population growth means a continuing increase in poverty. And I am sure that no good will come of it. Saudi Arabia is one of the most critical in this regard.

The rise in Saudi population has not been matched by employment opportunities. Unemployment is estimated to be as high as 35 percent, and this is having very negative effects. "Saudi Arabia's deeply conservative Islamic society is coming to terms with a crime wave ushered in by a population boom, rapid social change, increased unemployment, and a reduction in oil revenue" (Bradley, 2005). Drug smuggling, theft, prostitution and murder, once rare in this Islamic state, are now becoming everyday events. "[Crime] among young jobless Saudis rose 320 percent from 1990 to 1996 and is expected to increase by an additional 136 percent by 2005" (Bradley, 2005).

The winds of change are beginning to blow across Saudi Arabia. Population growth with few jobs in sight is one of the winds. So is the royal family's penchant for extravagant living. " …such opinion polls as there are show the main preoccupation to be jobs. Per capita income has fallen to a third of the level of 20 years ago. Nearly two-thirds of the population is under 25, yet the oil-dominated economy creates few jobs to employ them, while a bloated monarchy squanders fabulous public wealth. Military spending, for example, is about three times the average for a developing country and is used as a mechanism for distributing power and wealth within the top ranks of the House of Saud — around 5,000 princes strong" (Gardner, 2004).

Beyond oil?

It remains to be seen how Saudi Arabia's petroleum boom will influence its future development. It depends on how the reality that petroleum is a finite resource can be accommodated. There is a Saudi Arabian saying: "My father rode a camel. I drive a car. My son flies a jet airplane. His son will ride a camel." With the largest oil reserves of any nation, it may take an additional generation or two before the Saudis return to camels. Someday the oil will run out. The present scene may then be remembered as the Golden Age. Then what?

Nevertheless, Saudi Arabia's rise, floating up on a sea of oil into the modern world, has been an unmatched phenomenon. They have made good use of much of their wealth. The problem for them now is to invest it in such a manner that they can build an economy that will last beyond oil. It will be a very great challenge with a growing population when the inevitable decline of oil production occurs. To help find solutions, a research university complex at the graduate level has recently been built on the shore of the Red Sea.

Other Persian Gulf Nations

The story is somewhat more mixed with regard to how petroleum has influenced events in the other nations that share in the Gulf's oil wealth.

Bahrain

This country is a group of 33 low-lying islands with a total land area of about 340 square miles and a maximum elevation of 400 feet. It lies in the lower Persian Gulf about 18 miles off the coast of Saudi Arabia. The largest island, Bahrain, is 30 miles long and eight to 15 miles wide. Bahrain's oil was developed relatively rather early. The discovery well was drilled by the Standard Oil Company of California (now Chevron) and started production on June 1, 1930.

Bahrain's oil deposits are small, (remaining reserves are about 124 million barrels). But because of its small population, its deposits have been sufficient to allow the country to participate in the fortunes of the Persian Gulf region. Petroleum has taken Bahrain from being a largely fishing-based subsistence economy to a much-improved standard of living. With a strategic offshore position in the shipping lanes, Bahrain has used its oil money to capitalize on this situation, becoming a Gulf trading and financial center. Oil production now averages about 170,000 barrels a day, last in volume among the Gulf nations. Its current population of about 800,000 is projected to exceed to two million by 2050. This presents a potential problem.

Iran

In land area, Iran is the second largest country in the Gulf region. It covers 636,000 square miles compared to Saudi Arabia's 830,000 square miles. Oil in Iran was first discovered in 1908 by the Anglo Persian Oil Company (now BP). For many years, a combination of British and Persian interests produced the oil. But in 1979, all foreign interests were nationalized. Iran's oil reserves are very large, estimated at about 151 billion barrels. There are still large areas to be explored.

In addition to oil, Iran also holds over half of one of the largest known accumulations of natural gas in the world (Bakhtiari, 2004a).

The Iranian portion of the structure is called the South Pars field. Although nationalized along with Iran's oil in 1975, the area was partially opened to foreign investment in 1995. The French company, Total, with Russian and Malaysian interests, are making a large investment. The gas is "wet gas," which means there are substantial amounts of high-grade liquids produced with the gas.

With increased worldwide emphasis on gas for fuel and its widespread use as a raw material for many petrochemicals, Iran's gas is a huge asset. Given an increase in transporting gas as liquefied natural gas (LNG) and new transport technology showing substantial cost reductions, the future market for the South Pars gas appears good. New technology can also convert natural gas to a liquid. This is a very high-quality product and its potential market is large.

Another positive factor for the future of Iran is that, in contrast to Saudi Arabia, Iran has reduced its population growth dramatically. With a natural rate of increase of only 1.2 percent, Iran's current population of 78 million is projected to grow to 88 million in 2025, which is a 13 percent increase compared with Saudi Arabia's projected population growth in the same period of 29 percent. Iran, among the Gulf nations, also has the most diversified economy, with 10 percent arable land as compared with less than two percent for Saudi Arabia. According to the World Bank, Iran's per capita gross domestic product income is $11,600. Over the last few decades, Iran spent a large percentage of its oil revenue on military operations. The eight-year war with Iraq (1980-1988) was very costly in both men and material. Recently Iran has invested money in nuclear development, which it claims to be for civilian electrical power but is widely suspected of also having a military component.

Iran has an ongoing internal religious/political struggle. Its outcome will do much to shape Iran's future. Pro-democracy and hard-line supporters of Islamic rule clash frequently, intensively, and violently.

Even though Iran has additional areas for oil exploration, it appears that it passed its oil production peak in 1973 (Duncan and Youngquist, 1999), so even the current modest increase in population presents a standard of living challenge for the future. Petroleum is Iran's chief source of foreign exchange. But with some oil still to be discovered and produced, and the possession of huge gas reserves, Iran's geological fortune has a good longer term future. It might also be noted that Iran has spectacular mountain scenery beyond any of the other Gulf nations. It has developed a modest tourist industry, which has potential for expansion.

Iraq

This country, with an area of 169,190 square miles, slightly larger than the State of California, has had a turbulent history. It was part of the Ottoman Empire from the sixteenth century until it was taken from the Turks by British forces in 1916. It was made a kingdom by a League of Nations mandate in 1921. Iraq became independent in 1932, under the Hashemite Dynasty, which was overthrown in 1958 by a military coup that formed a Republic. In 1968, the Ba'ath Party seized control and established the Revolutionary Command Council.

In 1980, Iraq invaded Iran and a full-scale war continued for eight years. The war eventually ended in a stalemate, and Iraq was left with a huge war debt. On August 2, 1990, Iraq invaded Kuwait without warning. Even in the face of a large assembled military force from the western nations, Iraq refused to withdraw. At 12:01 a.m. on the night of January 17, 1991, a coalition of forces led by the United States began an air attack on Iraq, and on February 24, launched a land offensive which inflicted massive military losses on Iraq and forced them to withdraw from Kuwait. Over the following years, Iraq waged an internal war including poison gas attacks against its Kurdish population in the north, intensifying ethnic hatreds, which persist to this day.

Iraq's oil fields are only partly located in the Gulf. Considerable oil is produced in the northern part of the country (Kurdish region) from structures in a different geologic area. However, there are also very large oil deposits in southern Iraq geologically in the Gulf basin. Much of the oil in this region has only recently begun to be developed. Estimates are that several fields in this area are probably large enough to support production of as much as 300,000 to 500,000 barrels a day each. The stakes there are large, and one reason for Iraq's invasion of Kuwait was a dispute between the two countries over their boundary, which lies over a major oil field.

Iraq's oil reserves are estimated to be about 143 billion barrels, five times those of the United States. Unfortunately, much of Iraq's excellent oil inheritance has been squandered in military misadventures. If Iraq can eventually unite the disparate ethnic and religious groups into a peaceful country, with a broadly stable civilian economy, the average Iraqi may yet benefit from their good geological fortune. Also in its favor is that Iraq has about 12 percent arable land, which is relatively good in the Gulf region. A negative is that, next to Saudi Arabia, Iraq has the highest annual natural population increase (2.5 percent) among the Gulf countries. The present population of 33 million is expected to reach 49 million in 2025, and 83 million in 2050 (Population Reference Bureau, 2011).

Because of Iraq's difficulties getting back into production, with civil war raging at the time of this writing, and U. S. troops leaving, its projected oil peak in 2010 may be delayed a number of years. This could mean its maximum rate of production will occur at a time when oil will be priced higher than it is at present. So Iraq may gain in the longer term by the disruptions of oil field development and production related to the invasion of Iraq in 2003. A further positive factor is the possibility that Iraq's undeveloped oil may be more than 200 billion barrels (Takin, 2004). Of all the Gulf nations, Iraq also appears to have the best prospects for more major oil discoveries.

Kuwait

This country is almost all desert. Agriculture is exceedingly limited with less than 10 square miles under cultivation. Almost all fresh water is obtained from desalinization plants dependent on local natural gas supplies for energy. Kuwait owes its existence almost entirely to oil and natural gas. How Kuwait has used its petroleum wealth is described in Chapter 6. Kuwait holds about nine percent of total world oil reserves including the second largest field in the world, the Burgan field discovered in 1938. It initially held an estimated 87 billion barrels of recoverable oil, but is now in decline with reserves estimated at less than 50 billion barrels. The Kuwaitis are keenly aware that their destiny is very dependent on their access (disproportionate to its size) to the oil wealth of the region. This great wealth in such a convenient, small next-door neighbor, was a motivation for Saddam Hussein to invade Kuwait in 1990.

One encouraging sign is that Kuwait's natural population increase has declined from 2.7 percent in 1990 to 1.9 percent in 2003. However, even with this decrease, the present population of 2.8 million is expected to reach 3.7 million in 2025, and 5.2 million in 2050. Duncan and Youngquist (1999) projected a Kuwait oil production peak of 4.66 million barrels a day in 2018 with a 38 percent decline in production by 2040. Clearly these projected population and oil production figures are on a collision course as population grows and oil production declines.

Oman

Oman has an area of about 81,000 square miles, approximately the size of the State of Kansas. Desert makes up approximately 82 percent, mountains 15 percent, and coastal plain about three percent of the land area. Oman lies on the southeastern end of the Arabian Peninsula with the Gulf of Oman as its northern border and the Arabian Sea its eastern border. Much of Oman is not in the Gulf geologic basin, but the northwestern portion of Oman bordering the United Arab Emirates (UAE) includes a part of the oil productive Gulf geologic province.

Until the discovery of oil, Oman was the poorest country on the Arabian Peninsula. As recently as 1970, it had only six miles of paved road (Range, 1995). A complete census has never been taken, but the population is estimated (2009) at about 3.1 million. Oman's growth rate of 2.2 percent annually means the population will double in 32 years.

Oil was discovered in 1962, but until the export of oil began in 1967, Oman's national budget was supported entirely by religious taxes, customs duties, and loans and subsidies from the British. Its economy now is dominated by petroleum and the service sector. Petroleum contributes about 82 percent of government revenue. The government is using its petroleum wealth to try to develop a sustainable economy based on renewable resources, chiefly fishing and agriculture. It also is building small manufacturing operations. Some of these are based on other mineral resources, including limestone (for a cement plant), iron ore, copper, lead, manganese, nickel, silver, and zinc. Some of the deposits are fairly large.

Coal also exists and is being developed for the time when oil will no longer be available for electric power generation. However, Oman's coal reserves are small, only about 22 million tons, which will be sufficient for domestic use for a time, but not enough for export. Tourism is also being encouraged, and Oman now has seven international hotels, and several golf courses. It also has an electric power grid. In 1969, all of Oman had only one generating plant that produced just one megawatt of power, used only in the capital city, Muscat. Now several communities are lighted, and an electric grid is planned for the interior. Power is generated by petroleum.

Oman's development has been entirely petroleum-based, and its immediate future will rely on that resource. Oil reserves are estimated to be 5.5 billion barrels. The country also has gas reserves of about 29 trillion cubic feet, which is significant considering the size of the population. By comparison, the United Kingdom has about 24 trillion cubic feet in the North Sea. Oman's oil production appears to be slightly past its peak, but its gas production will peak considerably later. Both these resources will be available for some time to come. With natural gas increasingly in demand worldwide, Oman's gas market has greatly expanded. A major purchaser is the Chubu Electrical Power Company of Japan, which has agreed to buy four million tons of liquefied natural gas a year for 25 years. The recent development of gas-to-liquid (GTL) technology gives an added dimension to the market for Oman's gas.

In the longer term, Oman's metal deposits, now being developed with oil revenues, may help to maintain its economy. Whether a truly sustainable economy can be built from these resources, especially with a rapidly expanding population, is questionable. For the present, the good fortune of having petroleum has given Oman an entrance ticket to the modern world.

United Arab Emirates (UAE)

This nation is the consolidation of seven emirates, which were former British dependencies. The merger took place in the winter of 1971-1972. The total UAE area is somewhat uncertain due to disputed claims concerning some islands, but its land area is about 30,000 square miles, and stretches for about 300 miles along the southeastern end of the Persian Gulf. The UAE has estimated reserves of about 98 billion barrels, with a probable 41 billion barrels yet to be discovered.

The Emirate Abu Dhabi has 92 billion barrels of those estimated oil reserves, and Dubai has four billion. The other five emirates have no significant amount of oil. For the combined UAE, the oil income is huge and the economy is almost entirely based on petroleum. The present population is 5.1 million and is estimated to reach 12.2 million by 2050. The projected peak year of oil production is 2017, the latest of all the Persian Gulf countries, except for Kuwait, estimated to be 2018 (Duncan and Youngquist, 1999).

Before the discovery of oil, the principal products of these emirates were fish and pearls. Arable land (0.48 percent) and fresh water resources is very limited. Income obtained for foreign trade was based on slaves who dove for pearls. The slave trade continued until 1945. Other occupations were mostly family or small enterprises, which hammered metals into pots, livestock herding, and limited date palm cultivation. A substantial part of the population was nomadic.

Oil dramatically changed their way of life. People began to work in the oil industry in various occupations. But the population was so small and unskilled that in order to take care of the rapidly developing petroleum economy, foreign workers had to be brought in. In 1993, the total population was estimated to be about two million. Of these, only about 12 percent were actually UAE citizens, and they constituted only about seven percent of the labor force. That ratio has been reduced slightly since, as more UAE residents have received an education and have assumed a larger role in the labor force. The economic changes oil has brought to the UAE are nothing short of huge, and are described in Chapter 6.

Qatar (pronounced "Cuttar")

In land area, Qatar is the second smallest country of the Persian Gulf nations, covering approximately 4,400 square miles. It claims an additional area in the Gulf waters, making a total of about 17,000 square miles. It is controlled by a ruling family, the Al Thani. Qatar is a barren peninsula scorched by extreme summer heat. Although oil was discovered in 1939, little was developed until much later. In the early 1960s, it was still a poor British Protectorate whose chief industry was pearling. Since the middle 1960s, oil has changed Qatar to an independent state with modern infrastructure, services, and industries. It was built mostly with foreign labor and technology, paid for by oil.

In addition to oil, Qatar sits atop the world's largest-known gas field, the North Field, part of a large geologic gas-bearing structure shared with Iran. Initially, this was "stranded gas" — there was no way to export it. But with the technology to convert it to liquid natural gas that is shipped out by tanker and then allowed to warm up to a gas again at the receiving terminal, this gas is now in the world market.

Another advantage of possessing this huge gas field is the ability to use natural gas as the basic ingredient in the production of ammonia fertilizer, the world's most widely used fertilizer. Seventy-five percent of state-owned Qatar Fertilizer Company is owned by Qatar Petroleum Company, while Norsk Hydro AS owns 25 percent. This is the world's largest single-site urea producer, and also produces ammonia. This gas field and fertilizer production complex will be an increasingly valuable asset for many years to come. Qatar's gas is also used locally to manufacture more than a half million tons of petrochemicals annually.

The population of Qatar is about 1.7 million and is projected to reach 2.4 million by 2050. These statistics combined with Qatar's huge gas deposits and its approximate 25 billion barrels of oil reserves indicate a bright long-term future for this flat desert region of sparse vegetation. What a difference oil and gas can make!

A Brief Fortunate Interval

No other countries have been so profoundly changed in such a short time as the Gulf nations have by the discovery of the single resource, petroleum. For a time their destinies have been greatly altered by geological events that no one suspected a century ago.

Appropriately, these Muslim nations call their petroleum riches "a soft loan from Allah." After the discovery of huge oil reserves in the United Arab Emirates, the President, Sheikh Zayed bin Sultan Al Nahyan, said, "The problem is not how to get money, but how to spend it." The same could be said for all the other oil-rich Gulf nations. They know that this is a brief fortunate interval in their countries' histories.

One of the things that has come from this is the recognition of the need for what has been termed "Arab Future Studies"(Abdulla, 1993). These studies are now under way to make practical workable plans for the time when the oil is gone. It was the GeoDestiny of these countries to become rich from petroleum. But since oil is finite, it is also GeoDestiny that these countries must eventually exist without the resource that made them rich. Beyond any other countries, the Persian Gulf nations demonstrate the vital role that Earth resources play in determining the course of nations and the lives of people…their Geodestiny.

A mixed blessing

Although oil brought many good things to the Gulf nations, it also has brought many problems. The first Gulf War was precipitated by an Iraqi grab for the Kuwait oil fields, with an eye toward those of Saudi Arabia. The Iraqis hoped to secure a stranglehold on world oil supplies. That and then later intrusion of foreign troops in Iraq in 2003, served to intensify the animosity of religious groups toward the West, with a concordant increase in terrorist activity. Even Saudi Arabia, which is seen by some as an economic ally of the West because of its oil shipments and the presence of about 100,000 expatriates, mostly non-Muslim technical personnel, in the country that contains Islam's two holiest sites — Mecca and Medina — has experienced terrorist attacks. Because the House of Saud is partially identified with the West, the destabilization of the Kingdom by terrorism is part of its present-day political reality, and is far from settled.

Population

Beyond the internal strife, there is the broader problem of population growth. Thanks to the arrival of oil and gas money that brought sanitation, education, modern medicine, and the ability to both grow and import more food, and desalinate water, the populations of the countries bordering the Gulf have greatly increased. Subsidies of various kinds — for food, utilities, and housing — have been handed out so that the general population can have some share in the petroleum wealth. But as petroleum income gradually diminishes, painful adjustments will have to be made.

The demographics of the Gulf region present great challenges ahead. More than half the population is under the age of 25. In Saudi Arabia, 38 percent are younger than 15 years of age. The Gulf region will experience a huge population expansion. How can this oncoming wave of people be successfully accommodated without severe social disruptions?

Oil income even now is not keeping pace with population growth. In Saudi Arabia, the per capita income in 1981 with oil at $15 a barrel was $28,600. Today with oil at about $90 a barrel, it is below $6,000. The House of Saud is politically vulnerable. The ever-expanding Saudi royal family now numbers 30,000, all of whom are supported by oil income. It is facing increasing criticism.

Demographics will keep oil flowing

Occasionally, the idea is raised in the industrialized world that the vital oil production of the Gulf could be cut off by the regimes in the region. Takin (2004) writes:

> The question of political constraints for oil supplies from Saudi Arabia, Iraq, and elsewhere in the Middle East is an open-ended question and numerous scenarios could be envisioned.... However, these concerns are probably misplaced. Middle East oil producers will always want to export their oil.
>
> In the last few decades their economies have become even more dependent on oil revenues. An obvious example is the rise of the young population and their job requirements. The investments for job creation cannot be provided if oil is not exported, whatever the political preferences of a new regime in any Middle Eastern country.
>
> Saudi Arabia and Iraq will strive to produce and export their oil whatever the political alignment of their governments in the coming years.
>
> Revolutions, wars, even an Al-Queda government might introduce a hiatus in oil production and exports, but no government can remain immune from these basic issues. Sooner rather than later, the new government would come back at producing and exporting oil again.

Changes ahead

Even as oil ushered in great changes to the region, oil's decline will also bring great changes. No one can fully visualize the Gulf a century from now when oil production is a trickle compared with today except to know that the scene will be vastly different. As oil revenues shrink, how will a bloated population adjust in size and lifestyle to a post-petroleum existence? Except for Iran and Iraq with their modest agricultural bases, all the other countries are largely desert, and the market for sand dunes is limited. This is the century of great and permanent change. It is remarkable that one substance, petroleum, can have such a phenomenal effect.

Chapter 6

Mineral Riches and How They Are Spent

Eons to form

The mineral resources we are using today were formed during geologic ages past, some as long ago as two or three billion years. The coal deposits in Pennsylvania and West Virginia that were the original energy basis of the steel industry in that region are more than 250 million years old. The relatively young coals of Wyoming are 60 to 80 million years old. The banded iron deposits of Minnesota called taconite took several million years to be deposited, well over a billion years ago. Then, by the process of geologic uplift, fracturing, and subsequent eons of weathering, some of these deposits were further enriched to form the high-grade iron deposits called hematite. These deposits remained in the Earth for more millions of years before being mined.

In the case of oil, untold myriad organisms along with algae lived and died, and sank into an anaerobic (devoid of oxygen) watery environment to be slowly buried with accumulating sediment. Ultimately, when buried to sufficient depth and with the proper increase in temperature, some of these deposits became oil that had to further migrate into reservoir rocks, which in some cases were arched, or pierced by salt domes, or faulted to form traps for oil. Economic oil deposits result from long and complex geologic processes that in only a few places form very large deposits. The Persian Gulf is the best example.

Used in an instant

Fossil fuels and minerals are the great heritage of geological events upon which we now build and maintain our civilization. But, in a relative geological fraction of a second, these resources are being consumed. Soon these gifts from the past — in the case of mineral energy resources, petroleum, coal, and uranium — will be gone forever. Some metals can be reclaimed and recycled. Still, there is an inevitable percentage that will be dissipated and can never be recovered.

How Some Wealth Has Been Preserved

One of the interesting and important aspects of the discovery and development of mineral deposits is the variety of ways in which individuals, communities, and nations have spent this great one-time wealth. Although the resources are consumed mostly by the generations that discover and develop them, there is an argument that at least some of these riches should be passed on in some form to future generations who did not have the good fortune of living during this period of great mineral wealth. These are your children and your children's children.

To be sure, some of this wealth will be there in the future in the form of the buildings, factories, houses, roads, bridges, railroads, locks, canals, power stations, water lines, sewers, and many other structures for which mineral resources and the wealth derived from them are used. But in the case of fossil fuels, although they help to construct these physical features of civilization, their use leaves no legacy when used to power motor vehicles. The same is true with other energy uses such as space heating, and in producing products with a limited life such as automobiles, airplanes, household appliances, and sporting goods. Some of these products can be recycled, but inevitably much will be discarded.

Thus, the legacy is mixed, because in some cases, the resource will be of lasting benefit to people and to regions, but in other instances it may literally mean that more people suffer hardships in the long run as populations expand, enabled by and dependent upon a resource base that will eventually be depleted.

Individuals and Their Wealth

Although it is the miner or the oil wildcatter who discovers the valuable resource, they are not necessarily the ones who make the largest profit. Frequently, it is the developer or entrepreneur who reaps the greatest rewards. Miners come and go but the general store and the storekeeper selling the potatoes, flour, nails, and shovels remain. It has been said that "those who mined the miners were the ones who got rich."

Leland Stanford — gold

Leland Stanford supplied the California '49ers with their mining and household needs. The miners are lost to history, but Leland Stanford survives as the founder of a great university that he named The Leland Stanford Junior University (still the legal name), in honor of his son. The gold of the Sierra Nevada has largely been mined out, but its legacy, through Stanford University, in the form of educated human minds, is the most important resource of all. A nation can benefit greatly from the discovery of mineral resources long after that resource is gone.

Levi's

An interesting sidelight to the California gold rush is the origin of the now-famous blue jeans called Levi's. Levi Strauss was a poor immigrant in New York. He made tents out of canvas material. His brother went to California during the gold rush and enthusiastically wrote back to Levi that there was great demand for tents for the miners. But by the time Levi arrived in California, the demand for tents had fallen off. Instead, there was a great need for durable work pants, which could also be made from heavy tent-like material, denim, with which Levi worked. Levi Strauss set up his factory in San Francisco that still supplies Levi's to the world — a legacy, in a sense, from the California gold rush.

John D. Rockefeller

It is reported that when they sang the doxology, students attending chapel at the University of Chicago would sing, "Praise John from whom oil blessings flow." This was because John D. Rockefeller, with his oil money, funded the University of Chicago. Years later, from a laboratory underneath the stadium, the atomic bomb that ended World War II was invented at a University of Chicago laboratory.

Rockefeller became the object of much hostility because of his single-minded development of the great oil monopoly, which became the Standard Oil Company. In 1911, it was broken into many parts by anti-trust legislation. But even before he had any wealth, Rockefeller was a generous person. During the first year he worked, he made frequent small contributions to charities, missions, and Sunday schools. Later, as his wealth grew from his oil interests, his gifts became very large. During his lifetime, he donated $530 million to various causes. And this was when a million dollars was worth much more than today — the equivalent would easily be more than five billion dollars today.

Rockefeller funded the Rockefeller Sanitary Commission, later incorporated into the Rockefeller Foundation to promote worldwide health. Its research determined that the hookworm disease could be eliminated; it also conducts research on tuberculosis, yellow fever, pellagra, malaria, and various viruses. The foundation continues to make numerous grants to medical schools, not to increase their number, but to improve their quality.

One of Rockefeller's lesser-known grants was to Spelman College, a school founded in Atlanta in 1881, which was then and still is devoted to the education of African-American women. The school, known as the Atlanta Baptist Female Seminary when the grant was made, was renamed Spelman in honor of the abolitionist parents of Rockefeller's wife, Laura Spelman Rockefeller.

Other gifts from the Rockefeller oil legacy include land given to help create Acadia National Park. In 1901, Harvard University President Charles Eliot and George Dorr organized a board of trustees to acquire as much land as possible in the scenic Bar Harbor, Maine area, and to set it aside for public use. The surprising single largest bequest was 11,000 acres given by John D. Rockefeller, nearly a third of Acadia that was incorporated into the U.S. National Park system in 1919 by President Theodore Roosevelt. More than 40 million people visit the area each year. Rockefeller money also purchased the land for the site of the United Nations in New York. Rockefeller funds established Rockefeller University, which focuses on the causes and cures of diseases, population studies, and related disciplines. Land donated for the site of the Memorial Sloan-Kettering Cancer Center, land contributed for the establishment of the Jackson Hole Preserve (Wyoming) "to preserve the primitive grandeur of the area," 33,000 acres of land for national parks in the Grand Tetons, the U.S. Virgin Islands, and parks in New York State were all Rockefeller gifts. Rockefeller oil money was among major contributions made to the New York Zoological Society, Lincoln Center for the Performing Arts, the United Negro College Fund, and the Metropolitan Museum of Art. Rockefeller money restored Williamsburg, the capital of colonial Virginia, visited annually by more than a million people.

Altogether, Rockefeller founded or was a major contributor to 47 philanthropies. Most, if not all, will survive even beyond the entire period of the world Petroleum Interval. Over the course of their existence, these philanthropies will have touched millions of people who never heard of Rockefeller and his oil company. His family has carried on the tradition of giving. His son, John D. Rockefeller, Jr., gave $10 million to the New York Metropolitan Museum of Art, $1 million to the Massachusetts Institute of Technology, and $5 million to the United Negro College Fund.

Henry Flagler

Henry Flager, Rockefeller's partner in Standard Oil, is not nearly so well known. He used his oil money to develop Florida, pushing a railroad all the way through the state to Key West, and building hotels along the way. He also bought huge tracts of land and lured people to Florida both to live and as tourists. Oil money helped to put Florida on the map.

Wallace Pratt — oil

One of the survivors of the break up of the Rockefeller oil interests was the Standard Oil Company (New Jersey). A Kansas farm boy, Wallace Pratt, a geologist educated at the University of Kansas, ultimately rose to become a director of the company. As a geologist, Pratt was fascinated by a part of west Texas where great Permian coral reef structures are clearly exposed. One example is a distinctive promontory named El Capitan. Pratt purchased a ranch there, and upon his death, willed the ranch to become the basis for what is now Guadalupe Mountains National Park. At the park headquarters, his legacy is properly noted.

Andrew Carnegie — iron ore

Carnegie built U.S. Steel Corporation, capitalizing on its high-grade iron mines in Minnesota and Michigan. He became a multimillionaire by the age of 40. Andrew was born in a poor weaver's cottage in Scotland in 1835. By the age of twelve, he was the family bread-winner and he and his family emigrated to the United States where he became a telegraph operator at the age of 17. By savings and making careful investments, he eventually owned his own business and ultimately got into the steel industry. In 1873, he built the first fully modern steel mill. The country was growing rapidly and steel was in great demand, especially for railroads. Carnegie made a fortune. At one time, he was the richest man in the world.

Always remembering the poverty of his past, Carnegie said that "it would be a disgrace to die rich." However, he did not simply give money away. In fact, he was contemptuous of almsgiving. Instead, he gave money, as he said, "to assist, but rarely or never do it all."

He preferred to donate money to build, as he said, "ladders upon which the aspiring can rise." In many small towns all across America today, there remain solidly built Carnegie libraries. He gave a library building to nearly every community that offered a site for it and would agree to maintain the building. Eventually, his fortune built 2,500 libraries in English-speaking countries. Forty million dollars went to erect 1,679 libraries in the United States alone. These libraries originated from the iron ore deposits of the Upper Great Lakes region.

True, these libraries are small, and for the sake of economy, most of them are of only one design (now classic). In many communities this was the first, and for many years, the only library for miles around. Who knows how many youngsters got their first introduction to science and literature in these places, and how many went on to distinguished careers which grew from this seed? Many of them continue to be places where students in relatively remote areas have access to a library that they wouldn't have otherwise.

In the State of Oregon, Carnegie built 32 libraries, of which 16 are still in use in such places as Union, an isolated community of fewer than 2,000 people in the Blue Mountains of central Oregon. Without Carnegie money, there would probably be no library there. But Carnegie donated one in 1912, where it has remained in service ever since. In 1908, the small community of Petoskey on the eastern shore of Lake Michigan received a Carnegie grant of $25,000 to erect a library that continued to be used for that purpose until 2004. The community of less than 7,000 then built a new library. Over those intervening 96 years, the Carnegie Library undoubtedly opened new worlds to many children and adults in the community.

The Carnegie Foundation of New York was established "for the promotion of the advancement and diffusion of knowledge and understanding." The foundation is one of the major supporters of the Public Broadcasting System and was an underwriter of the award-winning educational children's program, *Sesame Street*. Untold numbers of children, who never heard of the man who made his money from iron ore, have benefited from his generosity.

The Carnegie Endowment for International Peace is another legacy from iron ore. In a variety of ways, this fund seeks to promote world peace. Given the current state of world events, it could hardly be more relevant and timely.

The Carnegie Museum in Pittsburgh, the Carnegie Institutes in Pittsburgh and New York, and Carnegie Hall in New York are examples of Carnegie's idea of "ladders" upon which people can rise to greater things. Carnegie also generously gave to Cooper Union in New York, established as an evening school to train engineers. Later it expanded into daytime operations. Because it is endowed by Carnegie and other donors, it charges no tuition. The Carnegie Foundation for the Advancement of Teaching based in Princeton, New Jersey, recently announced a comprehensive plan to revamp elementary education, and made $1.5 million in grants to 13 schools across the United States to embark on this project.

Carnegie gave generously to black schools including Hampton and Tuskegee, which promote industrial arts and character building. He also established an interesting endowment, named the Carnegie Hero Fund, which annually awards medals and financial grants to persons who exhibit outstanding acts of bravery on behalf of their fellow citizens. Carnegie also gave money to the Pratt Institute, established as a co-educational school for "practical training." These are prominent examples of what American iron ore did for society at large. The high-grade iron ore that made these things possible is now depleted, but the legacy lives on.

This iron ore legacy even reached the Old World. Andrew Carnegie was a loyal Scot, and eventually retired to Scotland, where, among other things, he set up the Carnegie Trust for Universities of Scotland. Carnegie's first library grant was to his birthplace, Dunfermline, Scotland. In total, Carnegie gave away more than $350 million dollars at a time when the dollar bought much more than it does now. Although he died without being as poor as he started, the money he left at his death was given to various causes which he designated. His children inherited none of his money, because Carnegie believed people should earn their way in life.

Carnegie could be a generous Scot because of geological processes that took place more than a billion years ago in the Upper Great Lakes region of the United States. This geological circumstance of long ago affected the lives of many thousands, perhaps millions of people…a remarkable GeoDestiny.

Cecil Rhodes — gold

A Rhodes Scholarship is one of the highest honors and most valuable awards a student can receive. By means of this fund, some of our most distinguished leaders have obtained their higher educations. These scholarships were established by Cecil Rhodes, who founded the British South African Company, to rework old gold mining areas in what ultimately became known as Northern and Southern Rhodesia (now Zambia and Zimbabwe). These regions were probably the richest gold fields of the ancient world. The gold was discovered in an area 500 miles long and 400 miles wide. The mines had long produced large quantities of gold. But so much gold remained that about 90 percent of the approximately 130,000 newly registered claims were staked on the sites of old workings. Rhodes, through his British South African Company, brought in miners and other settlers in the 1890s. By 1905, this area was once again a world-class gold producer.

Rhodes made a modest fortune from his gold mining interests. In his will, he provided enough money for about 200 scholarships for a term of three years each on a perpetual basis. The British South African Company went out of business in 1923 after the gold deposits were depleted. However, the intellectual legacy from the gold will survive as long as Rhodes Scholarships exist.

Guggenheim — gold, silver, copper, diamonds

The Guggenheim family made their several individual fortunes from the silver of the Leadville, Colorado, area; gold in the Yukon; copper in Alaska, Utah, and Montana; and diamonds in Africa among other mineral resources. Branches of this family set up a number of foundations and made a variety of charitable contributions including $12 million to the Mayo Clinic and $22 million to the Mount Sinai Hospital. Guggenheim money established a number of art museums in the United States as well as in Germany, Italy, and Spain.

The most famous of these foundations is the one set up by Simon Guggenheim in 1924, in memory of his late son. The John Simon Guggenheim Memorial Foundation, sponsors Guggenheim Fellowships that are awarded to artists, scholars in the liberal arts, and to scientists. More than 10,000 individuals have benefitted from this endowment that gives encouragement, particularly to promising young talents. One beneficiary was the late Linus Pauling, who often gave credit to his Guggenheim Fellowship for helping him out at an important time in his life. Pauling later won two Nobel Prizes (in Chemistry and Peace), the only person ever to do so.

Hearst publications — silver and gold

The Hearst publishing empire is yet another legacy that originated in mineral wealth. A substantial part of the Hearst family millions was built on the silver-rich Comstock Lode discovered in 1859 at the present site of Virginia City, Nevada. It was here that George Hearst of San Francisco made his first fortune. He did the same thing again in the South Dakota gold strike of 1877. With this money he established the Hearst publishing empire. The remarkable Hearst Castle, now a state park open to visitors on the California coast, is another result of mining wealth.

Many Other Legacies from Mineral Wealth

Carnegie, Guggenheim, Hearst, Rhodes, Rockefeller, and Stanford stand out as individuals who left large cultural monuments. Additional thousands of people whose identities have been lost to history also have built lasting monuments through their collective contributions. Mining and oil boom towns soon brought families with the desire for something besides saloons for cultural centers. The now-famous San Francisco Opera came to San Francisco as a result of the gold rush. The Alaska gold rush also brought opera briefly to that northern land, but it did not last.

It is a rare university or college in the United States and Canada that has not received money, equipment, or scholarships from a mining or oil company. With an endowment of more than $3 billion, chiefly derived from oil revenues on state lands, the University of Texas is the world's richest educational institution. To fill its fine campus buildings, the university used its money to hire outstanding faculty. With oil revenues now declining and the endowment no longer growing as it once did, the institution is being challenged to see if it can maintain itself as it did in the more opulent oil-supported past. The fund trustees are well aware that oil is a one-time benefit and are working to invest its money wisely for the long term.

The Province of Alberta — Oil

Although minor oil fields such as the Turner Valley field existed in the 1920s and 30s, the first major discovery of oil in Alberta was Leduc No. 1, discovered shortly after World War II. This precipitated a rush of oil and gas exploration and the cities of Edmonton and Calgary greatly expanded. The Calgary Philharmonic, now one of the premier orchestras of Canada, is housed in a beautiful facility paid for largely through the prosperity that oil brought. An examination of the back of any Calgary Philharmonic Orchestra program where benefactors are listed, is a quick way to find out which oil companies have offices in Calgary. Almost all of them do.

In Canada, with very few exceptions, all mineral resources belong to the government (the "Crown"). Alberta has rich oil and gas fields, which have made Alberta by far the richest province in Canada. Other provinces are far behind in growth and per capita income. Alberta also has the lowest corporate taxes in Canada, which help attract population and industry. It has a rainy day fund of C$2.5 billion. Alberta is the only debt-free province in Canada, and over the past several years, has had annual income surpluses (*The Economist*, 2004).

Alberta has enjoyed prosperity considerably beyond that of the other provinces. With the oil revenues, it established the Alberta Heritage Fund, from which bequests are made each year to a variety of cultural and artistic organizations. The fund also provides various financial advantages to Alberta residents with respect to taxes and loans. Presumably, if carefully managed, this fund will survive long after oil.

In 2005, flush with royalty income and taxes from the high price of oil and natural gas and from the increased production of oil from the Athabasca oil sands, the Alberta government sent a $400 check to every resident of the province. Alberta, and especially the oil capital of Canada, Calgary, are the fastest growing province and city in Canada. The province is the envy of the rest of Canada, which, through various legislative means, has tried from time to time to seize some of Alberta's resource wealth. It is a continuing battle between Alberta and the central government in Ottawa.

Even dinosaurs benefit

In 1985, Alberta opened a magnificent structure to house some of its most spectacular ancient residents. In the scenic badland topography on the northwestern edge of the old coal-mining town of Drumheller, about 70 miles from both Calgary and Edmonton, stands the world-class Tyrell Museum of Paleontology. There is no better paleontology museum anywhere, and the star attractions, the dinosaurs, are wonderfully well displayed. Responding to a question about the funding for this facility, the museum's director, Dr. Emyln H.

Koster, put it this way: "As one of the more costly cultural facilities of the Alberta Government, the Tyrell Museum capital project coincided with an affluent early part of this decade due to a very buoyant oil and gas industry." It was money very well-spent and is worth a visit.

Alaska

This has become the richest state in the union on a per capita basis, due to its small population and the presence of the largest oil field in the United States. However, because it is so dependent on the fluctuating price of oil, Alaska has seen some briefly depressed times. At present, Alaska is rich, but North Slope oil is being depleted.

Since the 1967 discovery of oil on the North Slope (chiefly the Prudhoe Bay Field, as well as other smaller fields nearby), the State of Alaska has received more than $40 billion in taxes and royalties from oil to date. How have these monies been spent or invested?

With the completion of the Alaska pipeline, oil and money from Prudhoe Bay began to flow in quantity. Strohmeyer (1993) describes what happened then:

> The state did not know what to do with the gusher of money that poured in after oil began to flow from Prudhoe Bay in 1977. Alaskans had expected the royalties would ease the lean state budget and flesh out capital expenditure. But even the most optimistic projections did not foresee the world events that would send oil prices into orbit. By 1981, oil had reached a high of $34 a barrel, an increase of more than 1,000 percent in thirteen years. As owner of the Prudhoe Bay oil fields, the state collected about 12 percent royalties from the sale of every barrel piped to Valdez. During the Iranian crisis alone, Alaska's revenue tripled to $.5 billion.

Alaska increased its state spending 20-fold. As a result, Alaska currently has the lowest personal tax burden and highest per capita state government spending in the United States. With the new wealth, a number of state programs were set up, including a loan subsidy program for farmers growing barley, which resulted in $70 million of unpaid loans. As an interesting footnote, it was reported that "many of the farmers who were taking money from the state to grow barley were double dipping, simultaneously taking money from the federal government to not grow barley" (Jackstadt and Lee, 1995). Several hundred million dollars also were lost in loans to other economically doubtful enterprises including a venture to produce a dog-powered washing machine. A performing arts center in Anchorage cost $70 million to build and loses one million dollars a year. High school students have been sent on European field trips.

An oil royalty trust fund, the Alaska Permanent Fund, was set up in 1976 and now has investments totaling $27 billion. In 1982, Alaskans voted to give themselves an annual dividend from the fund which takes most of its earnings. That year, each Alaskan man, woman, and child received a $1,000 dividend check. A University of Alaska report says that the state is now spending about $1.2 billion more than it can afford in the years ahead. It has been calculated that if Alaska had increased its spending at just the average rate of other states over the past 25 years and earned a very attainable 5.15 percent on its excess oil income, it would have had a $75 billion fund at the end of 1993. This would have earned it about one billion dollars more in annual interest than Alaska spent in 1993. Thus, Alaska appears to have missed the opportunity to enjoy permanent financial security (Jackstadt and Lee, 1995).

Alaska's citizens have demanded the annual dividend payment in spite of the declining revenues from the Prudhoe Bay Field. The record payout was $1,964 to each person in 2000, and in 2002, the dividend was $1,541. In 2004, the dividend was $1,860 per person. As oil production inevitably declines, the oil dividend will dwindle, and Alaskans will have to go back to depending entirely on whatever current income their non-oil economy can produce. Previously this was chiefly marine products, crabs, and fish. Many Alaskans want to delay that eventuality by drilling in the Arctic National Wildlife Refuge, and building a natural gas pipeline south from Prudhoe Bay.

It is hard to wean citizens off this oil welfare and make them think of the future. The present generation of Alaskans is living off its oil inheritance in several ways. Alaska has no sales tax, no income tax, and the lowest property taxes in the United States. A survey of the 50 states by *Kiplinger's Personal Finance* magazine in August 1995, reported that for a retired couple with a $50,000 a year income, living in a 2,000 square foot house, the annual tax burden in Alaska would be $253. The highest tax burden among the states was in oil-less Wisconsin at $9,528. Oil makes a big difference.

No other oil fields the size of the approximately 12 billion-barrel Prudhoe Bay Field are expected to be discovered in Alaska. About 60 miles to the east of Prudhoe Bay, the geology suggests that perhaps a field or fields not as large as Prudhoe Bay might exist in a small portion of the coastal plain of the Arctic National Wildlife Refuge. The idea of developing it has split Alaskans and other Americans over its environmental effects, such as its possible impacts on the 125,000-strong Porcupine caribou herd and the wilderness solitude that reigns north of the Brooks Range.

Alaska's oil revenues are certain to decline in the long run, to the point where there will be little or no such income. If future generations of Alaskans are to be considered, then the abundant but transient oil revenues of today must be used differently. The political process has allowed this generation of Alaskans to capture benefits at the expense of future generations by plundering much of the wealth of its nonrenewable oil resource.

Of the initial 12 billion barrels of oil reserves in the Prudhoe Bay Field, seven billion have been produced. Production has peaked, and is now declining. Estimates are that even if new oilfields are put into production on the North Slope, sometime within the next ten years, oil production from that region will fall to only half of what it currently is. The economic impact this will have, given Alaska's current spending habits, will be severe.

Countries

Mineral wealth not only funds institutions and endows states and provinces, it has transformed entire countries. However, the use that oil-rich countries have made of their wealth is a very mixed bag. Pope (1996) commented, "If oil wealth is like winning the lottery, nations act like lottery winners: They tend to blow the money." Some do, and some don't. Examples of both follow.

Indonesia

This archipelago is the fourth-most populous nation in the world with 240 million people. Until 2009, it was a member of OPEC. Its oil deposits were developed by Shell Oil Company, which began as a trading company that actually dealt in part in seashells when Indonesia was a Dutch colony. This is how the Shell companies got their start, and they still retain the shell symbol. Indonesia was the prize the Japanese needed to keep their war machine going, and they occupied it for a time during World War II. After the war, Indonesia gained independence from the Netherlands, and continued to be an oil exporter. It has now become a net oil importer, with domestic oil demand now exceeding production. During the early post-war period, a virtual dictatorship ran the country and there is no visible evidence of where its oil revenues went. Under the present government, all oil revenues support the daily economy.

Saudi Arabia — petroleum

The discovery of oil dramatically changed Saudi Arabia and the life of its citizens. In part, this was already covered in Chapter 5, but additional information is included here. Saudi Arabia's enormous oil wealth presented some formidable investment challenges. Before oil was discovered, the country's economy was mostly simple local oasis agriculture, some fishing and pearl diving in the Persian Gulf, and nomadic herding of sheep and camels. Additional income was generated by Muslim pilgrims visiting Mecca.

In 1932, the Saud family united the various tribes of the Arabian Peninsula into the Kingdom of Saudi Arabia. As recently as 1940, the port city of Jeddah was a walled city of about 50,000 inhabitants. Jeddah today is a thoroughly modern city with plazas decorated with sculptures, high-rise apartments, wide boulevards, and one of the tallest buildings in the Middle East, the 44-story National Commerce Bank. At one time during its development, there were 355 ships waiting to unload cargo at Saudi ports.

As recently as 1962, there was only one radio station in all of Saudi Arabia. The first railroad did not reach the capital, Riyadh, until 1951. In 1950, there were no paved roads in Saudi Arabia. But by 1982, there were more than 7,000 miles of main highways, and more than 6,000 miles of paved secondary roads. More than 15,000 miles of earth-surfaced rural roads were built to some 7,000 villages, which, for the most part, had never previously seen a road.

The International Airport at Jeddah, constructed at a cost of four billion dollars, covers more than 40 square miles, is 50 percent larger than Kennedy, La Guardia, O'Hare, and Los Angeles airports combined. It is capable of receiving as many as 100 aircraft an hour. There are four grades of terminals, the most lavish of which is the Royal Pavilion designed for the royal family. It has a copper roof, white marble walls, and its main reception hall has Thai silk wallpaper and gold embroidered tapestries. Adjacent is an ultra-modern press room with complete radio and television equipment.

This airport at Jeddah was soon overshadowed by the airport built 22 miles north of Riyadh. This facility is more than twice the size of Jeddah airport, covering an area of 94 square miles.

In 1978, there were only about 125,000 telephones in Saudi Arabia. By 1985, just seven years later, there were more than a million phones in operation, serviced by equipment supplied by major communications companies in the Netherlands, Sweden, and Canada. Saudi Arabia today has the most advanced computerized telephone exchange system of any country in the world. Because the entire system was built so recently, there is no old obsolete equipment in service. As part of its communication system, Saudi Arabia has a domestic satellite system of 11 mobile and three fixed Earth stations, which allows anyone with a telephone anywhere in the Kingdom to dial directly to anywhere in the world. For a villager who 40 years ago had no roads, no lights, no sewer, no telephone available anywhere in his village, and spent the day herding sheep or camels, this is quite a change.

Schools through the university level and hospitals were built. The Saudis spent vast sums of money to speedily bring themselves into the twentieth century and beyond. Although inefficiencies are inherent in such a mammoth and rapid undertaking, much of the oil money has been employed wisely. The Saudis know that even the world's largest oil reserves are finite. However, some of the money has been spent supporting a growing number of Saudi princes in lavish lifestyles, a source of increasing discontent in the general population that may spell future trouble.

Along with the production of oil and the development of large shipping facilities for the resource, Saudi Arabia realized that, rather than being just a raw material supplier for foreign markets, it should process more of its petroleum (oil and gas) into added value finished products. To do this, Saudi Arabia has developed and is expanding a large petrochemical complex located in the newly established cities of Jubail and Yanbo. The cost is about $45 billion, and the project uses the technical talents of more than 40,000 people from 39 countries. These facilities may ultimately rival those for which the Houston, Texas, area has long been known. The inevitable shift in emphasis from being a raw material producer to upgrading the resource to the finished petrochemical end products will have a large economic impact on other such facilities around the world. Saudi Arabia has the oil and gas reserves to support these plants for many decades, at least long after the reserves of the United States and of the North Sea (Britain and Norway) have been exhausted.

Losing the capability to produce raw energy materials or metals is much more important to a domestic economy than the simple percentage the raw material represents in the gross national product. This point is largely unrecognized by politicians, economists, and the public at large in the United States, where there has not been a lot of support for the oil and mining industries. Indeed, these enterprises, fundamental to the economic well-being of the country, have been treated rather unkindly at times. But in the meantime, Saudi Arabia, Qatar, and other oil and gas producers are putting up refineries and petrochemical plants in their lands. Some metal producers are also doing the same thing by building plants to upgrade their raw materials before shipment abroad. Chile is smelting copper ore and Venezuela is using its gas to set up aluminum smelting facilities for its own ore and that of neighboring Suriname.

Water was a limiting factor in the economic life of Saudi Arabia, but petroleum came to the rescue there too. Using the abundant natural gas supplies produced along with the oil, the Saudis developed desalinization plants, that now produce more than a billion gallons of fresh water a day from the sea, by far the largest such enterprise in the world. Electric power is generated using waste heat from these and other facilities — all based on petroleum.

The story of the electrification of Saudi Arabia is perhaps the most spectacular of all. The first public electric generating plant was opened in Taif in the late 1940s. Since then, nearly the entire country has been electrified, and all major buildings are now air-conditioned. So Saudi Arabia went from nomad tents in the desert to air-conditioned multi-story office buildings in less than 50 years. There has probably been no greater transformation of a country of such size anywhere in the world than Saudi Arabia. Without petroleum, the entire region would have remained simply an obscure, arid land.

One of the interesting items that oil brought to Saudi Arabia is a 60-ton solid granite bathtub. In 1983, King Fahd ended his worldwide hunt for the perfect bathtub in a granite quarry in Manitoba, Canada. A flawless piece of granite was cut, hauled to Montreal, and then shipped to Italy where some of the world's finest stone workers sculptured and polished it, including giving it the final touch, the crest of the royal family carved on the tub. It then was shipped to Riyadh and installed in the palace.

Another positive result of the Saudi oil bonanza has been the training of Saudi young people. At one time, virtually any male (women were generally excluded then) who could qualify academically could study abroad at government expense, in almost any subject he wished. Educated people will be the country's ultimate greatest asset — paid for by petroleum.

Regardless of problems that have arisen from the sudden great wealth of oil money for Saudi Arabia, the country has energetically transformed itself into a thoroughly modern nation, to the immense benefit of its citizens. Probably no other government or country has done so much to spread the benefits of the oil wealth to all its people.

In some relatively oil rich countries, the oil wealth seems to "disappear" before it shows up in projects and services for the general public. But in Saudi Arabia, the benefits of the oil riches are more widely evident.

Kuwait — oil

On a smaller but similarly impressive scale, the story of Saudi Arabia has been repeated in Kuwait. Kuwait is a very small nation located at the northwestern end of the Persian Gulf. It was a British Protectorate until 1961 when it was given full independence. Prior to the discovery of oil, Kuwait was an insignificant land of sand whose principal exports, such as existed, were skins, wool, and some pearls. The discovery of oil changed all that.

With an area of 6,880 square miles, Kuwait is smaller than some counties in the United States. For example, Harney County, Oregon, has an area of 10,166 square miles. Yet its proved oil reserves (already discovered) are larger than the reserves of the entire United States including Alaska, with a total area of three-and-a-half million square miles.

The discovery and development of oil has meant free education for all Kuwaiti citizens as far as they want to go. It means no income taxes, subsidized housing and utilities, free medical care, and a government grant of more than $7,000 to every couple upon their marriage. The country has its own airline, Kuwait Airways, which flies Boeing 747s on regularly scheduled service from New York and London to Kuwait. The Kuwait government and private interests share ownership in Mobile Telecommunications Company, which now has 110,000 mobile telephone subscribers, and 150,000 pagers. Among numerous minor facilities built by the Kuwait government, is an Olympic-size ice-skating rink, a novel luxury in this hot dry land.

To develop Kuwait as rapidly as it has, a large number of workers were imported. At the peak of activity, 75 percent of its workers were foreigners. They outnumbered the Kuwaitis. There is obviously an internal threat inherent in this situation. But it has merit also because when times are slow economically or for security reasons, the country can simply decree that foreign workers return to their homelands. Recently, that is what they have done. After the first Gulf War, the number of foreigners in Kuwait was greatly reduced. Nearly all the Palestinians, for example, were forced to leave.

Although the current Kuwait population is estimated to be three million, less than one million are Kuwait citizens; the rest are foreign workers. With this small number of people sharing the income from some of the largest oil reserves in the world, the standard of living is very high. Understandably, Kuwait makes it difficult for anyone to become a Kuwait citizen.

Rich as it is today, Kuwait has a keen eye on the future. Since gaining independence, Kuwait has invested its large oil revenues in a great variety of assets, including $2 billion in the most respected stocks listed on the New York Stock Exchange. Kuwait also has established the Kuwait Reserve Fund for Future Generations. This organization and the Kuwait

Petroleum Corporation bought 14 percent of the West German carmaker, Daimler-Benz, 20 percent of the German mining complex Metallgesellschaft, and about a quarter of the giant German chemical company, Hoechst.

Perhaps taking the saying "there will always be an England" to heart, even after oil, Kuwait bought 5.1 percent of British Midland Bank and also invested heavily in English real estate. They own a one million square-foot complex of restaurants, shops, and offices along the Thames in London, and about nine percent of British Petroleum Corporation (BP). Kuwait has invested more than $2 billion in Madrid, Spain, and is looking at other possible investments in Australia, Singapore, Malaysia, and Hong Kong. In the United States, Kuwait purchased Santa Fe International, a California-based drilling company, and it also has a large portfolio of United States real estate including 100 percent ownership of the Kiawah Island Resort in South Carolina. It owns several New York skyscrapers, but have kept this hidden in deference to the Jewish tenants of some of these buildings.

In order to assure a good market for its oil, Kuwait bought most of the European marketing and refining operations of the former Gulf Oil Corporation, and they are adding to this system by building more gasoline stations of their own. The Kuwaitis have a brand of gasoline they market as "Q8" that is distributed through more than 4,700 retail stations in a number of countries including Italy, Denmark, Sweden, Belgium, the Netherlands, and Luxembourg.

Kuwait earns more money (about $7 billion annually) from these enterprises than from the sale of its oil. Once the oil is gone, Kuwaitis hope and believe that these investments will continue to allow them to pursue a reasonably affluent lifestyle. Clearly, Kuwait is very conscious of the finite nature of its oil riches, and has been working hard and quite successfully to put itself in a position to survive beyond petroleum. A Kuwait government economist states, "Our investments will be the main source of income for generations after the oil runs out." In late 1989, Kuwait announced it was drawing up plans for multi-billion dollar petrochemical and petroleum refining industries to upgrade its end product rather than just shipping out raw crude oil. By 1995, this program was well established. Of the two million barrels of oil produced a day, 1.2 million was exported as crude. Of the other 800,000 barrels, part was refined and shipped as finished product, and part was further upgraded to petrochemical specialty products by Kuwait's Petrochemical Industries Company. The gas is used to produce fertilizer. Kuwait continues to expand its petrochemical operations.

Since the invasion of Kuwait by Iraq, Kuwait is even more conscious of the great wealth it holds and the need to carefully preserve it in some fashion for future generations. The first Gulf War temporarily modified some of Kuwait's financial plans. The true cost of the war to Kuwait was that it used most of the cash it had accumulated (approximately $20 billion) for further investments. Kuwait also spent $11.7 billion on military equipment, including 200 U.S.-made tanks, 40 fighter planes, and 200 British armored personnel carriers — a regrettable tribute to the instability of the Gulf region. Since the first Gulf War, Kuwait has spent about $12 billion for arms. Its financial reserves before the war were $100 billion. War costs greatly reduced that but they have now built back their reserves to more than $50 billion, and they currently generate a budget surplus of $3 billion.

Mostly, however, Kuwait has figuratively spent its oil money on butter, not guns. In view of the vital interest that the western nations have in protecting Kuwait's oil, as demonstrated by the first Gulf War, Kuwait's emphasis in using its oil money for long-term investments seems a wise course.

Along with not using most of its money for armaments, another encouraging trend is that Kuwait's natural population increase has been reduced from 2.7 percent in 1990 to 1.9 percent in 2007 (Population Reference Bureau, 2007). Duncan and Youngquist (1999) projected an oil production peak at 4.6 million barrels a day in 2018 and a 38 percent decline in production by 2040. Projected population growth and oil production figures are on a collision course, so it is good that Kuwait made extensive investments elsewhere for the future. However, it may be that Kuwait will not admit so many foreign workers in the future, and decide to make more investments at home, involving their own citizens. Militarily, as long as a modest amount of oil production exists, the West will look after Kuwait.

Bahrain

Oil was discovered in 1932, one of the first in the Persian Gulf. But oil production is in decline. Recognizing the problem early, the government of Bahrain built a huge aluminum smelter that uses the energy from Bahrain's gas deposits, which is a longer-term reserve than its oil. The large number of oil tankers and other vessels related to the development of the Persian Gulf region made Bahrain's island location an ideal place at which to build large dry dock facilities. Bahrain's location was also strategic for an offshore international banking center. This was developed and has thrived. Also thriving are the recently introduced western-style entertainment attractions, facilitated by relaxation of some of the strict social rules of the adjacent Muslim states. The 22-mile causeway to Bahrain from the mainland allows for easy access to Bahrain's attractions (Bulloch, 1984).

United Arab Emirates — oil

Dubai, of the United Arab Emirates (UAE), in six-page ads in American business magazines, quotes Sultan Ahmed bin Sulayem saying, "We knew the oil boom would not last forever, and that a more stable and diversified source of capital was required." Dubai's answer has been to create what they call the "Hong Kong of the Middle East." This is a mammoth free-trade zone which first required a 2,500-acre harbor to be dug at the edge of the desert. Around it, on 25,000 acres, they built an industrial and warehouse complex.

They hope that their location at the lower end of the Gulf gives them a geographic advantage making them the trans-shipper of goods from the Middle East into Africa and Asia. The free-trade zone imposes no inconvenient tariffs, and offers a number of other financial advantages. Also, Dubai has a first-class airport, its own international airline, four hospitals, and a golf course. A $14 million cricket and hockey stadium, tennis and squash courts, and a bowling green have been built. They also advertise that beyond golf, tennis, and the like, tourists can watch camel racing from a special viewing building. They further note that, "One popular pastime pursued in Dubai that is found nowhere else in the world is 'wadi bashing'. Its rules are deceptively simple. It involves nothing more elaborate than driving in wadis, which are dry river beds that flow from the Hajar Mountains into the desert, or, on the East Coast, toward sea." So far, this "free-trade zone" project seems to have been a success.

Dubai is the most rapid and amazing development in the Gulf region. A "sudden city" has appeared on the desert sands. Where less than 20 years ago there were donkey carts on an unpaved road, there is now an eight-lane paved highway. They built the world's largest mall, Mall of the Emirates, with 2.4 million square feet, including an indoor ski jump and "mountains" with snow where children throw snowballs at each other. It is patronized by the world. Direct oil revenues now account for only about six percent of Dubai's income.

Skyscrapers with businesses, condominiums, and hotels fringe the waterfront and extend inward, making corridors for increasing traffic. A striking structure of Dubai's development is the Burj Al Arab, a high-rise luxury hotel, built on a man-made island off the beach at Dubai, designed to resemble the sails of an Arabian dhow. Built out in the shallow Gulf, there is a "palm tree" formed by dredging, with palm fronds carrying houses — a structure visible from space.

Dubai has become the commercial center of the Gulf, a vacation spot and, for some, the new home for wealthy Europeans. Nothing like this change in a desert has ever been seen and in such a short time. Indeed, Dubai is a "Sudden City."

Along with its useful developments, however, in 1995, the UAE began to spend money on armaments. They embarked on a large military purchase program, which included the purchase of 12 ship-based helicopters, at a cost of about $350 million. The UAE also negotiated contracts for the purchase of up to 80 long-strike warplanes, patrol aircraft, helicopters, and frigates. It is questionable how effectively this small country can defend itself in a major military engagement, even with this new equipment.

The two faces of Dubai

All this transformation has come at a cost. Behind the skyscrapers is a world of fleabag hotels and prostitutes, Indian and Russian mobsters, money launderers, and smugglers of everything from guns to human beings. More than half of Dubai's population lives in foreign workers' camps. Asian workers sleep in dormitories that open on to standing sewage.

Dubai has only modest reserves. But their new economy is still dependent on oil, especially from the adjacent oil-rich nations, and also a world economy based on oil. Will desert sands eventually reclaim the paved streets and abandoned skyscrapers by the end of the twenty-first century, or will Dubai survive on some other economic base not now foreseen? In the meantime, Dubai presents two faces of the miracle in the desert.

Oman — oil

This is the only nation in the Gulf region where the rulers bear the title of "sultan," which indicates a Muslim sovereign combining political and religious authority. The present sultan came to power in 1970. Oman began commercial oil production in 1967. Oil production peaked in the first decade of this century, and is expected to drop 84 percent by 2040 (Duncan and Youngquist, 1999). With this in mind, the country's emphasis has been on diversifying the economy as quickly as possible by developing agriculture, fishing, and tourism.

Oman has also seen a large shift in population from rural to urban areas and is experiencing a severe housing shortage. Providing the infrastructure of electric utilities, water, and sewer in these increasingly densely populated urban areas is a priority and has taken a great deal of money. Oman, like the other Persian Gulf countries, has also been spending its oil money to buy military equipment. In view of the fact that its present population of 3.1 million is expected to increase to 5.3 million by 2050, it may be that armament money could be better spent on developing the country's infrastructure.

Iraq

This nation has tremendous oil resources, much of which remain undeveloped. Otherwise, Iraq is a rather poor country. Its population has grown to the point where much of its food must be imported. Yet under Saddam Hussein, Iraq spent huge amounts of money on weapons, which were first used in a futile eight-year war with Iran. The total cost of the conflict came to about $500 billion. Much of this money was used to buy massive amounts of military hardware, which at the time of the first Gulf War, included 4,000 tanks and 2,500 heavy artillery pieces. Using Iraq's diminishing oil income to finance failed military adventures will go down in history as one of the greatest mistakes ever made by a national leader, and a tragedy for his people.

After the invasion chiefly by U.S. forces in 2003, and their departure in 2011, the future of Iraq is unsettled. It will take a great deal of work to establish a sustainable political and economic footing in which oil income can pay for the increasing food imports needed for the rapidly growing population. Hopefully, in the new Iraq that will emerge, big spending for weapons like Saddam Hussein did is past, and the oil income can be used for constructive purposes to benefit all Iraqis.

Iran

This country has also used its oil wealth to buy military equipment. Initially it was the Shah of Iran (1941-1979) who began the military buildup because he was determined to make Iran the dominant nation in the Gulf. He also wanted to defend Iran from its long-time enemy, Iraq. He bought so many planes and tanks that it was estimated at one time there were three planes for every qualified Iranian pilot. Iran's military buildup continued after the Shah's overthrow with Iraq. Eventually, war with Iraq broke out. During its eight-year span, Iran used virtually all its oil income for military expenses. Nothing was put in place for the future. Now that the Iraq war is over, perhaps its substantial oil income will be used for domestic improvements.

Although Iran passed its peak oil production in 1973, it produces six million barrels a day, and still has the second-largest oil reserves in the world. Its gas reserves are huge, estimated to be 940 trillion cubic feet. This is even larger than the gas reserves of Qatar. Both Iran and Qatar share the huge geological structural dome containing gas, which lies across the lower portion of the Gulf. Iran appears to have a slightly larger share of the structure (Bahktiari, 2004a).

With the rising worldwide demand for natural gas, Iran stands to greatly benefit from its huge gas reserves. It already ships gas abroad in the form of liquefied natural gas (LNG).

Iran, however, continues to spend considerable oil income on armaments. It has obtained two submarines and will get a third. It also purchased five Chinese-made patrol boats, which can be armed with missiles, and has obtained surface-to-air and surface-to-surface missile systems. These armaments have been placed at the mouth of the Persian Gulf, the strategic Strait of Hormuz, through which 50 percent of the world's oil flows. Using its oil and gas revenues to purchase more armaments seems unfortunate since Iran has the most diversified economy in the Gulf region. Properly nurtured, a diverse economy can sustain the country well beyond the petroleum era. Additional money to develop its water and agricultural resources would be a wise investment. Iran has spectacular mountain scenery and its tourist industry has excellent potential. Investments in tourism could yield a high return as well as provide employment.

The economy, however, is not producing enough jobs to employ its slowly rising population. Unemployment is about 30 percent, and 40 percent of its citizens live below the poverty line. The Iranian clerics control considerable oil income, leading to unrest in the younger population. Although the continuing development of the South Pars gas field as well as higher oil and gas prices are helping to maintain petroleum income, the best days of Iranian petroleum are past. Trying to advance its economy, and provide social welfare needs related to housing and unemployment can absorb all the oil income that may be generated in the future. Like many other countries, including the United States, military spending diverts money that could be used for better purposes.

Among the Gulf nations, Iran has by far the longest and most distinguished history. Its archaeological sites are numerous and varied, and many are well preserved. Iran has contributed in many ways to both science and literature, and has been a leader in the region in culture and education. To a considerable degree Iran still maintains that position. In contrast to the other countries, women in Iran were given the right to vote in 1963. Iran has potential for a good future. It will continue to have oil income for a considerable time, allowing it to make the transition to a post-petroleum economy. Oil income spent on military hardware will not be useful to that end.

Libya — oil

Libya is yet another example of an initially very poor nation catapulted into the twentieth century by oil, and oil alone. Libya has an area of about 680,000 square miles, about one-fourth the size of the 48-adjacent United States. Arable land is a very small part, and most of it is desert. Without its oil, Libya would still be living on the fringes of the world economy, remaining mainly a country of nomads and small farms.

At the time oil was discovered in 1950, Libya's population was about two million. With only a narrow strip along the coast suitable for conventional agriculture, the land, in an agricultural economy, could not support many more people. Libya's impact on the world economy prior to the discovery of oil was slight indeed. But now it has oil revenues from production of about 1.4 million barrels a day, and its population has tripled to about 6.4 million.

Libya has a mixed record for spending its oil wealth. Early after the discovery of oil, under the leadership of the wise old desert chieftain, King Idris, it spent money on roads, sewers, wells, and other generally useful public enterprises. But when King Idris traveled to Greece for medical attention, a colonel named Gaddafi led a coup to depose Idris and seized power. Government spending soon shifted from civilian projects to military hardware. Gaddafi bought ground equipment for 20 tank battalions, modern missiles, trucks, and artillery mostly from the Soviet Union. For his air force, French Mirage fighters were purchased. Six ex-Soviet submarines and numerous small surface craft make up the Libyan navy. In 1989, Libya was found to have built a chemical weapons plant. Some public works were continued, but planning became haphazard. In part of a major road system, where cloverleaf interchanges were built, the project was less than well thought out. In several places, it was necessary to make a U-turn against on-coming traffic in order to get on another road.

Funded by oil revenues, Libya engaged in exporting terrorism, and invaded neighboring Chad to the south. Its terrorist adventures were discouraged by a U.S. Air Force bombing attack, and by the presence of the U.S. Navy off the Libyan coast, which led to the shooting down of several Libyan fighter planes and the sinking of torpedo boats. French military forces dispatched to Chad helped defeat the Libyan invasion. That inland country was officially part of France's African empire until 1960.

However, Libya has made a few constructive investments to keep it going beyond the time of oil. These include a one-half interest in an oil refinery in Hamburg, Germany. Libya also owns a small airline, Libya Arab Airlines (LAA). What may or may not turn out to be a good investment is a grandiose scheme to pipe water from deep below the sands of the Sahara to the coastal areas. Col. Qaddafi stated that his $25 billion Great Man-Made River Project would convert the country, which is now 95 percent desert, into "a garden of Eden." The plan called for 12,500 miles of pipeline to carry water to all areas of the coast. However, as the wells were drilled in a desert area where there is no appreciable recharge, it is likely that any water there has accumulated over a long period of time. Heavy pumping from the aquifer will far exceed the recharge and water levels will drop. There is, in fact, geologic evidence to indicate that the water is what is sometimes called "fossil water" — water preserved from the geologic past that cannot be duplicated again (Gardner, 1995). The water must make a 9-day, 750-kilometer trip through a pipe four meters in diameter. Expectations are that it will make the desert bloom and new lands will be opened for rapidly increasing Libyan population. With considerable flourish, Col. Qaddafi opened the valve of the initial stage of the project. Unfortunately, thanks to a minor engineering error, nothing happened — no water. It was a bit embarrassing, but was later corrected.

Just as money spent on the current military will eventually be of little or no value, this project is likely to have a limited life. Contrary to the expectations of Muammar Qaddafi, rather than being a monument to great thinking, it is likely to become a monument to folly. Groundwater sparingly used in isolated Libyan oases could last for many thousands of years for the scattered peoples of the desert. But with the proposed heavy pumping, it will be a short-lived resource. It will provide only the illusion of a sustainable future. Expanding the economy and population based on that illusion will come to grief.

It is sadly apparent that tanks, guns, planes, and second-hand Soviet submarines will be a large part of the legacy Libyans inherited from their once-affluent oil era. Production peaked in 1969 at about three million barrels a day and is now down to 1.4-million barrels a day.

Qaddafi later appeared to have had a change of attitude. He acknowledged spending substantial sums to obtain materials to build an atomic bomb. He agreed to give up all the materials for the bomb he had purchased. What a small country like Libya would want with an atomic bomb is unfathomable, except perhaps for terrorism. This is a classic example of money wasted in a country urgently in need of improved infrastructure — better roads, educational and health facilities, and a sound economic base to survive beyond oil. With the uprising of 2011, and the violent end of Qaddafi's rule, hopefully the country's future oil income can be put to constructive purposes for the benefit of all Libyans.

Oil buys arms

Military spending by oil-rich countries, principally in the Middle East, has overshadowed all other investments. In the 12 years following the first Arab oil embargo in 1973, with the subsequent huge rise in oil prices and concurrent huge increase in revenues for oil producers, the Gulf nations spent more than $640 billion for military purposes. Iraq and Iran spent billions, which served only to finance an eight-year war of attrition ending in stalemate. An estimated million people were killed and many more were wounded. Without the oil money to finance the advanced weapons of war, it is probable that at least the casualty figures would have been less. What a tragic way to waste forever the proceeds from a non-renewable resource. Oil has been a mixed blessing to many countries. In 2007, the Persian Gulf countries spent another $20 billion for arms.

Now these countries have the latest state-of-the-art weaponry including all sorts of missiles, tanks, jet fighters, helicopters, warships, and other hardware. But there is a question whether or not these nations are safer or happier with all these devices of destruction. Arms shows in the Middle East have become regular events. It is big business. The judgment of history on the way in which some of the temporary oil riches are being spent is likely to be severe.

Mexico — oil

Mexico is another nation that geology destined to have rich mineral resources. Initially, this may actually have been a curse. It lured the Spaniards looking for gold and silver who plundered and ultimately destroyed much of the native civilizations, and brought smallpox and other diseases which further decimated many communities.

More recently black gold, oil, has become Mexico's most important mineral resource. Oil was discovered quite early in Mexico but only in modest quantities. What was probably the world's largest producing oil well was drilled in Mexico, yielding some two to three million barrels of oil a day for a time.

It wasn't until the second half of the twentieth century that the great oil fields of the Tampico-Vera Cruz area, mostly offshore, were discovered. Unlike Saudi Arabia, Mexico's oil has not done much to transform the country. The government-owned oil industry has been ineffective in using oil wealth for general social improvement. True, it built the tallest building in Mexico City, the Pemex building, which houses the Mexican national oil company, Petroleos Mexicanos (Pemex). However, Pemex is not run efficiently, and is grossly overstaffed with more than 108,000 employees. This contrasts with ExxonMobil, which has five times the revenues, yet employs fewer people. Pemex did bring local prosperity to some of the coastal communities where the oil fields are located. For the vast majority of Mexicans, the oil has had little effect except to keep the price of gasoline from being as high as it might be if Mexico did not have the oil resources. The oil revenues have not been used to raise the Mexican standard of living. Pemex provides the government with 40 percent of its revenues and pays 70 percent of the cost of running the national electric grid. Exactly where the rest of that tax revenue goes is uncertain.

Pemex is Mexico's cash cow and the state-run company pays over 60 percent of its revenues in taxes and royalties to the central government. Because of this heavy tax burden, Pemex has lost money for the past five years and has had to borrow by issuing bonds and using various other devices to keep going. It now owes a "… staggering $42.5 billion" (Smith, 2004). Pemex's debt is four times that of ExxonMobil. There is trouble ahead. The Cantarell oil field that supplies 62 percent of Mexico's total production has peaked and is in steep decline. Just to maintain Mexico's oil production, the government will have to invest as much as $100 billion in the coming decade. Taxes prevent Pemex from retaining enough of its earnings to finance needed expenditures. Francisco Rojas, who ran Pemex from 1987 to 1994, referred to Pemex's decaying infrastructure and lack of money for exploration saying, " … we are looking at a time bomb…." The Mexican government has recently announced it would leave more money in Pemex. It remains to be seen if they will keep this promise.

An ironic result of the big Mexican oil discoveries may be that Mexico will wind up deeper in debt because of them. On the basis of its oil finds, foreign banks were persuaded to loan Mexico the large amounts of money, now totaling more than 100 billion dollars. Where most of this money wound up is uncertain. What clearly remains is a huge foreign debt. The value of the Mexican peso collapsed to about 2,500 to the dollar. Subsequently, it was replaced by a "new peso." The new denomination collapsed, reaching an all-time low against the U.S. dollar in February 1995. The resulting economic crisis led the Mexican treasury to issue another "new peso."

By borrowing against their oil reserves, Mexico's oil riches, in effect, have been spent before its oil is pumped. There is also some question as to whether or not the oil reserves actually are as large as the government claims for collateral on their debt.

Nauru — phosphate

This little Pacific island nation once had (past tense!) a single but very rich mineral deposit, phosphate. It also appears to be the nation that had the mineral resource with the shortest economic lifespan. By 2000, all its phosphate was mined. The challenge, while phosphate income was available, was to make investments, which would continue to support the population. To manage these investments, the country formed the Nauru Phosphate Royalty Trust. One such investment is Nauru House, the 52-story, tallest office building in Melbourne, Australia. The building is big enough to accommodate the entire population of Nauru (about 4,000 citizens) if they chose to convert it into a hotel.

Nauru also issues very colorful postage stamps, which attract collectors. But how significant and sustainable that income will be is highly questionable. Recently Nauru sued the Australian government, claiming Australia had not paid as much as it should have for the phosphate.

Nigeria — oil

This is the largest African nation in terms of population, with 162 million people and a growth rate projected to increase its population to 237 million by 2025, and 437 million by 2050 (Population Reference Bureau, 2011). Nigeria is now a major oil producer and a member of OPEC. When Arab nations cut off oil supplies to the United States in the 1970s, it was fortunate that Nigeria at that time rather than Saudi Arabia was the principal foreign supplier of U.S. oil from the Eastern Hemisphere. Nigeria had an oil surplus to make up in part for the oil that the Arabs did not supply. There was a shortage, but Nigeria continued to make regular oil shipments to the U.S., without which the U.S. situation would have been much worse.

When President Shagari, who was from the northern part of the country, came to power in 1979, he had barely enough votes from other regions in Nigeria to win the office. In order to create a political consensus for his regime, he tried to spread the oil bonanza money throughout the country in the form of large public-works projects. The effect of these projects was that the percentage of the Nigerian population living on farms dropped from 85 percent to 65 percent, as people moved to the cities. They also changed their tastes from homegrown millet, yams, casaba, and sorghum to imported foods, so that some advantages of the oil income for providing foreign exchange were lost simply to fill the new demand to buy foreign foods. Also, international salesmen, seeing large amounts of oil money, arrived on the scene and sold projects to Nigeria that, in some cases, were not well-suited to the economy, and some have been outright economic disasters.

Nigeria has made some effort to invest its petroleum revenues in enterprises for the long-range national good. One example was the completion of a world-class fertilizer complex at Onne, Rivers State, near Port Harcourt. The $800 million project serves domestic as well as export markets. For over-cropped, nutrient depleted soils in many parts of Nigeria, this fertilizer will be most useful. But the problem with this project in the long term is that the feedstock for the plant is natural gas (from which the ammonia fertilizer is made). So it is still dependent on petroleum and cannot last beyond the life of Nigerian petroleum. However, the project, which now gets its gas from the Aalakiri Field about nine miles away, will save Nigeria about $100 million a year in fertilizer imports. This is a substantial help in the near future, and for a number of years to come. But if agriculture and population expand on this non-renewable resource, what is the ultimate outcome? Can the much larger population continue to be supported after the petroleum is gone?

Unfortunately, overall, Nigeria has not managed its petroleum wealth carefully. In 1995, *The Wall Street Journal* reported, "And Nigeria, after squandering its petrodollars, is now bankrupt. It needs $20 billion of oil company investment to keep its industry running, the World Bank estimates. Production from its huge fields discovered in the 1960s is now slackening." The political economy of Nigeria remains one of gross indebtedness, inefficiency, and mismanagement. An irreplaceable resource which could have done much more for the country is being largely squandered.

Nigeria remains beset with problems. It is rated as one of the most corrupt regimes in the world. Lack of civil control has reached the point that Shell Oil Company says it may not be able to continue operations there because of the ongoing sabotage of equipment. With corruption, lack of civil order, growing religion-based terrorism, a fast-growing population – already the largest of any African nation — the future for Nigeria is dim. A jihadist terrorist organization — Boko Haram — whose name translates from the Hausa language to "Western education is sacrilege," and which began attacking Christian targets in 2010, is only the latest threat to Nigeria's fragile stability. Oil revenues surely have not been used as wisely as they might have. Nigeria has about 37-billion barrels of oil reserves. And if civil order can be maintained, there are fair prospects for additional discoveries. But Nigerians themselves lack the ability to conduct oil operations, so foreign technology and investments are required. The country's production is expected to peak about now.

Norway

This is a land of mountains, beautiful fiords, and lots of rock. About two percent of Norway's land is arable. There is not a drop of oil in Norway's largely igneous rock terrain. Norway has always had to live in considerable part from the sea. It continues to do so thanks to oil and gas discovered in 1969 by Phillips Petroleum in the Norwegian sector of the North Sea. Today, almost half of Norwegian government revenues are derived from petroleum. Norway is currently one of the world's largest oil exporters, with a small population and limited domestic demand for the large amount of oil it produces.

How have its oil revenues been spent? Norway has used a lot of it to keep unemployment low. Billions of dollars of petroleum revenues have been poured into what turned out to be money-losing projects in agriculture, iron mining, smelters, and fishing in order to keep people employed. This is a temporary fit, and does not build a sound economic base for the long term.

Norway did change some of its priorities for spending its oil money, and has been putting more into research. Hallvard Bakke, Minister of Cultural and Scientific Affairs, said, "Our main objective is to expand the possibilities of the Norwegian economy and to give it more feet to stand on so that it does not have to rely on oil and oil-related industries." An example of this is the decision to pursue genetic engineering and apply it to one of Norway's new and rapidly growing enterprises, aquaculture. Money is being invested to study the Norwegian fiords as places to raise a variety of fish such as halibut, salmon, and cod. Perhaps by genetic engineering, some fast-growing fish species can be adapted especially to fiord ecology. Roads and bridges have also been built and these are the best in Scandinavia. However, much of the money seems to have been spent subsidizing a generous social welfare system (Seabol, 2005). Health care and higher education are free, and farmers enjoy very high crop subsidies.

Norway's oil reserves are about 5.3 billion barrels. Production peaked in 2001 and is now in decline. The resulting decline in oil revenue will be a problem, but not so much as in countries with a high population growth rate. Norway's population of 5.0 million has a very low growth rate of about 0.4 percent annually bringing its projected expected population to 5.6 million in 2025 and 6.6 million by 2050. Looking toward that future, Norway has set up a Petroleum Fund with various investments now totaling nearly $200 billion (Seabol, 2005). In 2005, a new government was elected pledging to spend more of the oil wealth on social programs. How much this means a change of direction in spending is not yet clear. Norway already has the most comprehensive welfare program in Europe.

Argentina

This country has been a long-time modest oil producer, with estimated reserves in 2010 of 2.5 billion barrels. Revenues have been used chiefly for current government expenses with some going into private pockets, a common fate of oil revenues throughout Latin America.

Brazil

Brazil's oil reserves are now about 14.2 billion barrels, mostly located offshore in the Campos and Santos basins. Brazil is a relative newcomer in the oil business. With the largest population and economy in South America, Brazil has been chronically short of transport fuel so the oil, which it produces goes to supply domestic demand. If recent discovery trends continue, Brazil may soon be an oil exporter. Currently, its modest oil and also iron ore and bauxite revenues have been used to support various government programs, and to improve the transport infrastructure of that largest of all South American countries.

Venezuela

This country is by far the largest oil producer in South America, with most of its conventional oil in two areas, the Lake Maracaibo basin on the northwest coast and in southeast Venezuela in the greater Oficina region. A very heavy oil deposit is also known and being produced in modest amounts in the Orinoco River basin of southeastern Venezuela.

Venezuela has had a fairly turbulent political history right up to the present time. Its oil fields were nationalized many years ago. Given the huge importance of oil to Venezuela, the oil workers' union is a strong element on the political scene, even going on strike occasionally against the government oil company PSVDA, for which they work. During their most recent strike, President Hugo Chavez fired many of the workers. In doing so, he lost some much needed oil field expertise.

Venezuela has a rapidly growing population, which has benefitted from oil in modest ways through schools, roads, and other public facilities. Some money has been used to subsidize the price of gasoline and the cost of public transportation. Various social welfare programs have been established in many parts of the country in the form of subsidized food markets that help to support the Chavez regime politically.

With a current population of 29 million expected to increase to 35 million by 2025 and

41 million by 2050, oil revenues are urgently needed simply to provide for basic education, the infrastructure of safe water, sanitation, and medical facilities, and provide housing for the large segment of the population that is poor.

Venezuela has made one substantial long-term investment. The government-run oil company established refineries and built gasoline service stations in the United States, which is its main market for exported oil. Not many people in the United States know that "Citgo" stations are Venezuelan-owned.

In spite of Venezuela's rapid population growth and associated social needs, President Hugo Chavez purchased seven Russian MIGs, and a fleet of Russian attack helicopters in 2004. In 2005, he bought 100,000 Russian AK-47 rifles. Flush with the money from high oil prices, President Chavez spent over four billion dollars (equivalent) in 2005 and 2006 buying additional military equipment, making Venezuela the most heavily armed country in Latin America. Since 2005, Venezuela has signed contracts with Russia for 24 Sukhoi fighter jets, 50 transport and attack helicopters, and 100,000 more assault rifles. Venezuela also has plans to open Latin America's first Kalashnikov factory to produce rifles in the city of Maracay.

Venezuela is hardly threatened by its neighbors. If it was, it seems certain that the United States, with a considerable interest in protecting Venezuela as a source of oil, which it very much needs, would intervene on Venezuela's behalf. Likewise, if Venezuela embarked on conquest of its neighbors, the United States would be likely to intervene to deter such action. How seven MIGs and a fleet of attack helicopters contribute to Venezuela's well being is not apparent. These purchases instead may be related to the recent civil uprising against President Chavez and the strike by the oil workers against his government, during which Chavez was briefly out and then back in office. The arms purchases may be to protect the existing government. Since revolutions are one of the recurring features of South American history, having the support of the military has generally been a good idea for those in power.

The Overall View

We have seen one mineral-dependent country, Nauru, face the fact that its one and only mineral resource and basic source of income is completely gone. In contrast, Saudi Arabia has petroleum that will last for many decades. But all the oil-rich countries have built their economies on a depletable resource. Some have invested portions of their income wisely for the future. These are mainly the countries with small populations and a large resource such as Kuwait. They have had a surplus of cash from their oil income, which they could invest either within their own countries or abroad.

Other countries, generally with larger populations, have used their mineral income to meet current expenses, and they have not been able to put away significant investment money for the future. Brazil is one such country. In other countries, graft and corruption have siphoned off substantial oil income for the benefit of a few. Nigeria has the dubious distinction of being one of those countries. The mineral and oil wealth of a number of countries, some undeveloped, has disappeared into Swiss bank accounts and in other ways gone into relatively few pockets rather than being used for the general good.

Thus, the legacy of how these mineral monies are used will run varied courses. Some run their course as soon as they are received – they are spent immediately in one fashion or another for current expenses or projects of varying political or social merit. But mineral income that is invested wisely by governments today, will markedly influence the lives of their citizens for the better probably for many generations to come. In retrospect, such leaders will be remembered and honored for their foresight and integrity.

One thing is clear. Governments spend far too much money on armaments. Too little money is spent looking toward the future. The one-time window of opportunity for wise use of the money from mineral riches slowly closes as income declines from depleting resources.

Individuals seem to do it better

In contrast to governments that get money from taxes on oil and other minerals and buy military hardware costing of billions of dollars, some individuals who have gained from the mineral bonanzas have benefited the future by using their money in a variety of long-term constructive ways. On a much smaller scale than governments' expenditures for arms, but with a far greater lasting and positive effect, these people have left legacies of great value.

By forming universities, museums, scholarships, research foundations, medical facilities, libraries, and other institutions, these gifts will do much more for future generations than fighter planes, missiles, tanks, submarines, and assault rifles. Such carefully administered and specifically designated uses of mineral riches are likely to be the most efficient employment of these funds, rather than those subject to the political hazards of being dispersed through governmental agencies where graft and corruption in many places are rampant in many places.

We all benefit

Most people who benefit from these mineral legacies don't know they are benefiting, nor do they know the sources from whence their benefits come. Those who receive named bequests such as the Guggenheim and Rhodes grants may know the source. Most of us have had our lives touched in some way by mineral endowed legacies. But how many visiting Grand Teton National Park or Acadia National Park know that portions of these parks were donated by the Rockefeller Foundation? The sources of bequests to medical research facilities are also often not apparent to those who benefit.

Hopefully, more of the Earth's resource wealth will be invested for long-term good. There are many opportunities to do so, and many programs and projects are ongoing. Both oil and mining companies contribute to educational institutions. ExxonMobil recently gave $100 million to Stanford University for unrestricted basic environmental research. One particular need for wise investment of current income derived from mineral development, and indeed, from general government tax revenues, is to prepare for the time when we no longer have the use of nonrenewable Earth-derived energy and mineral resources. As we enter a new and much different world, new technologies to support that future need more support now than they now receive. These include everything from developing renewable energy resources to learning how to crop land while retaining its fertility. Greater government and private funds must be directed toward these future needs. The future is built on what is done today.

Money from minerals carefully invested now by governments or individuals can help many people in the future.

> "We have all drunk from wells that others have dug."
>
> —Author Unknown

Chapter 7

Minerals, Money, and the "Petro-currencies"

This chapter might well have been titled "Minerals *as* Money" because during many centuries, the two were one and the same. Pieces of gold and silver, and sometimes copper, lead, tin, and zinc were used as money. When people first began to travel relatively long distances from their homeland, they encountered barter systems different from what they had known and there was a need for a common medium of exchange. Copper ingots were used, as well as smaller pieces of gold, silver, and bronze. Gradually, gold and silver became the preferred metals for exchange even before coins were invented. Pieces of these metals were passed back and forth among merchants, who kept scales for weighing them. In the eyes of many people, gold and silver still remain the only valid forms of money, and are called the "currencies of last resort." As long as politicians have the records they do in managing nations' finances, good reasons for that view will remain.

In India and China, gold and silver are still used as stores of wealth and exchange. There are significant amounts of silver that reside under mattresses in India. Arabs have long placed their ultimate trust in gold. Early oil leases in Saudi Arabia negotiated by foreign companies (when foreign companies were allowed to lease Saudi oil rights) were paid for in gold at the insistence of the Saudis.

The Chinese were the first to use paper money as early as 1023 A.D. Governments have continued to issue paper money at various times, often with mixed – indeed, unfortunate results. Devaluations of paper currencies continue around the world, as governments print more money in an attempt to keep their economies going. All too frequently, people who save paper money are the financial losers, as their bank deposits continue to devalue.

Frequently, the plot of the depreciation of currencies is a declining exponential curve, dropping slowly at first and then accelerating toward the end, and finally becoming a vertical line down, as paper currency becomes worthless. This occurred in modern times to the German mark after World War I when workers were had to be paid twice a day. German wives would meet their husbands at the plant's gate at noon to get their pay for that morning so they could immediately spend it before it lost value by nightfall. More recently, described later in greater detail, the Zimbabwe currency dramatically reflected the same exponentially declining curve in its paper money debacle. The devaluation of the currency led the German printer who printed Zimbabwe's money eventually to refuse to do so because the money was worthless. In 2003, the exchange rate was one Zimbabwe dollar (ZWD) to one U.S. dollar. It then inflated to 30,000 ZWD to one U.S. dollar. The government of Robert Mugabe continued to print money until the annual inflation rate reached 11.2 million percent. At that point, the people of Zimbabwe were forced to engage in a barter system of exchange. The use of the Zimbabwean dollar as an official currency was effectively abandoned on April 12, 2009, when the Reserve Bank of Zimbabwe legalized the use of foreign currencies for transactions. The South African Rand, Botswana Pula, British Pound Sterling, and U.S. Dollar are used instead. This ignited an economic boom in the once-prosperous African country.

Honest Money = Store of Value

To be money in the true sense, money has to be a store of value whereby one person's goods or services can be exchanged for money and that money later can be exchanged for goods or services of equal value. If inflation intervenes between these two transactions, paper money fails to retain its value. Inflation is the order of economic life today. It is one way that governments finance themselves—by selling bonds fixed in denomination. When bonds mature and are paid off in whatever currency they were issued, it is almost always a depreciated currency. The original value is lost. The noted Swiss financial expert, Franz Pick, publisher of *Pick's World Currencies*, defined a government bond as "assured confis-cation of your money."

On the other hand, gold and silver have proven to be much more dependable. Paper money, at times, has actually seen its value decrease by half or more in just a matter of days, as in the German inflation of the early 1920s. In Brazil, Peru, Chile, Mexico, Zimbabwe, and a number of other nations, inflation has often exceeded 100 percent a year. The extent to which paper money can become virtually worthless is striking. When I visited the Soviet Union shortly before its breakup, the ruble's official exchange rate was U.S. $1.60 to 1. After the breakup of the USSR, the ruble went to 5,000 to the dollar. Then the Russian government issued a new ruble whose current exchange rate is 31 rubles to the dollar.

A number of years ago in Chile, I took a local bus ride through Valparaiso to see the town. I had some local currency, but not knowing the bus fare, I simply handed the driver a couple of large denomination bills. His cash register was just the dashboard of the bus. He reached over and grabbed some bills and handed them to me without counting them. It was a windy day, and at the next stop, two people got on and some of the money on the dashboard blew out the door. Nobody bothered to chase it. The old peso at that time was worth approximately 15,000 to the dollar. It was later replaced by the escudo, which suffered the same inflationary fate as the peso. Chile is now using a "new" peso, and the U.S. dollar currently buys 550 Chilean pesos. Such wild fluctuations do not happen with gold or silver, which are as true a store of value as anything we now know. The Chilean peso value today benefits from the high price of copper Chile exports.

Printing paper versus mining minerals

It takes energy to wring gold, silver, copper, and zinc from the Earth, and to smelt and refine them. It takes much less energy to cut down a tree, process it into numerous pieces of paper, and then print some number on the pieces of paper and call it money. Unlike a gold coin that has a fixed gold content, one ounce, for example, a piece of paper can be printed in any denomination. No other figure than "one ounce" can legitimately be stamped on a one ounce gold coin, but governments can and do print any number they wish on a piece of paper. It has no tangible backing.

Johannes Gutenberg, with his invention of the printing press, greatly facilitated paper inflation. Every politician who votes for deficit spending should have a shrine to Gutenberg in his office. His invention, in the hands of fiscally irresponsible governments, has destroyed the life savings of many people around the world, continues to do so, and will inevitably do so in the future as national debts become so large that they cannot be paid off honestly.

Metal coins

Barter was the original means of exchange; things such as shells, precious and semiprecious stones, and sacks of grain were used. But the value of various barter items was not fixed, and therefore it was difficult to use them to trade in different places. Pieces of gold and silver were also used, but their random sizes made it difficult to easily deter-mine their value. They had to be weighed, and their purity varied. Eventually, the con-cept of coins made of a valuable metal with a fixed amount of metal in each coin and the amount of the metal in the coin made known created a consistent value and stable medium of exchange for goods.

The time when metal coins were first used is uncertain. They may have started in China as near as history can tell (a likely possibility as the Chinese seem to have been first in many things). Interestingly enough, soon after the Chinese began issuing precious metal coins, other Chinese began to make them wholly or partially out of lead. So it may be also that the Chinese can be given credit for inventing the lead nickel, and counterfeiting in general. This counterfeiting became so rampant that Chinese officials ultimately decreed that anyone caught operating a lead mine without government sanction would be executed.

The first coins, in what is now Europe, were struck in the ancient Greek city-state of Lydia during the seventh century B.C. Whenever they originated, coins have a varied history. Once coins began to be accumulated along with precious metal ingots, they became mili-tary objectives. They were rich booty in a convenient form. The capture of state treasuries such as the Persian, the Babylonian, and the Greek were major military objectives. Along with slaves, the gold and silver booty was paraded through the streets of the victors. The parade of precious metals and slaves vividly illustrates the importance of two things that are still vital for civilization—mineral and energy resources. Slaves at that time represented energy in useful form.

Sal-ary

After Greece, Rome became the dominant power in the Mediterranean area. Rome did this by developing a large and well-disciplined army. The soldiers were given a ration of salt as part of the monthly payment for their services. From this we have the expression "is he worth his salt?" The fact that payment was partly in salt and delivered in regular installments, also gave rise to the term "salary" derived from the Latin word *sal*, for salt.

Rome, Precious Metals, and Money

The Italian Peninsula has a fine climate but it is markedly deficient inprecious metals. To pay the army with something besides salt, Rome needed gold and silver. Some was obtained from looting the Greek treasuries, but that source ultimately dwindled. However, when Rome defeated Carthage, among the spoils of the wars was a province known as Spania, now called Spain. The Roman military returned with much gold and silver from Spain. Rome also took possession of the mines that produced these metals. At one time, the Romans had 40,000 miners working Spain's silver deposits, sending all the metal to Rome (Frank, 1927). Silver ultimately became the main metal of Roman coinage, and the unit of exchange was the denarius. The Italian Peninsula, as noted, had very little in the way of precious metals, so it was the Spanish mines as well as the Greek gold and silver that financed Rome's armies, making Rome the dominant power in the then-known civilized western world.

Wealthy Romans had luxurious villas overlooking the various bays of the Mediterranean. They also had beautiful homes on the south shore of the Mediterranean, for they had taken over parts of North Africa including what are now Libya and Tunisia. The Romans loved luxury, and the gold and silver captured by their armies, and that produced from the mines worked by slaves in conquered lands, provided the money to pay for the imports that Rome needed. Paper money had not yet been invented, so Rome could not run a deficit in its balance of trade as nations do today. Precious metals were the only medium of exchange. Ultimately, the precious metals from the Spanish mines became the chief source of money for Rome, and continued to be for many decades.

Gradually, a difficulty arose. The mines got deeper and deeper, and the problem of water flooding in the mines became increasingly hard to manage. The Romans were quite ingenious about solving this for a time. Ultimately, they were unable to invent adequate systems or pumps to remove the water. Finally, the ore that could be reached in the mines was exhausted.

There were many causes for the fall of the western Roman Empire, but one contributing factor surely was the erosion of the value of Roman currency. For three centuries, the great gold mines of Spain produced more than 300,000 ounces annually. Spain's silver mines produced even more metal. With the depletion of the mines, Rome's treasury emptied. Rome continued to issue debased coins to pay the army, which became an entirely mercenary force. Rome's sons were no longer drafted as they had been during the Republican era. Roman emperors hired others to take their place.

Debasing the coin of the realm

The loyalty of Rome's mercenary army had to be purchased, and the army insisted on being paid in something of value. In 9 A.D. the Emperor Augustus was unable to replace the army of his General Varus which was destroyed by the Germans (Lovering, 1943). The Roman answer to the lack of silver and gold for their coins was to begin to debase the coins by adding other metals — chiefly lead and copper. In a period of only 50 years, the denarius fell from being about 70 percent silver to only about 10 percent silver. As the denarius was losing its standing, a new coin, the "Antonianus" was issued and also the "double denarius" but the later contained only 50 percent silver. When civil wars broke out, the expenses caused a monetary crisis, and the silver coin was further debased and dropped to 5 percent silver content. In fifty years, the denarius had fallen to less than a tenth of its original value.

But the citizenry and army were not deceived. If you visit the museum at Sabratha, site of the ancient Roman city a short distance west of modern Tripoli, Libya, you will see an interesting display of Roman coins. The earlier coins are pure silver and gold. But later coins, although carrying the same stamped face value were debased. The citizens, the merchants, and the army all knew about the cheapening of the coins. To compensate for the inflation of their money, they clipped the earlier, more valuable coins to, in some cases, merely narrow pie-slice-shaped pieces, to equal the value of the later debased coins. On the wall where these coins are mounted, you can see narrow slices of earlier pure precious metal coins that remained in circulation and which were equal in value to the silver content of the later still round but debased coins. It is a visual display of inflation and currency debasement. The same display could be mounted in many other countries today. As Will and Ariel Durant wrote: "History is inflationary."

The earlier Roman coinage, with its pure precious metal content, was the most highly prized and valued currency of its time in the Mediterranean region. However, as precious metal supplies dwindled, the debasement of the coins proceeded. As the government continued to try to pass these debased coins at full value, Roman currency became a despised currency and the prestige of the Roman government also declined. This is a lesson not to be forgotten, and may have contemporary parallels.

By the fourth century A.D., the situation was so bad with Roman coins of varying degrees of debasement in circulation, that it was necessary to weigh and assay each coin. In these circumstances, Roman currency became virtually worthless. The mercenary Roman legions could not be properly paid, and their loyalty to the government was undermined with the sharp reduction of silver and gold content from the coins. With a debased currency no longer accepted by merchants, Roman citizens could not import the luxuries they once enjoyed. Rome's chief export had long been money accumulated during earlier centuries when they had acquired access to precious metal through conquest. Romans surrendered this wealth because they had few other exports of value with which to trade. Rome depended on plunder instead of on creating wealth, and when this policy began to fail, Rome went into decline.

Poss (1975) makes an interesting observation, perhaps with modern parallels:

> This imbalance in trade contributed greatly to Rome's ultimate ruin. Paying for lavish quantities of imports, in amounts that exceeded exports, with a currency that had been depreciated since the Punic Wars and further debased by such emperors as Nero, Aurelius, Commodus, Caracalla and Severus, Rome's currency was becoming unacceptable. The Empire's trading capital, the basis for its economic life, was being destroyed.
>
> With Rome thus facing economic disintegration, nothing could have added greater distress than the withering of her metallic supplies. Germanic hordes everywhere were rising in constant revolt. They began to overrun provinces of the Empire, pillaging Gaul, Spain, Macedonia, Cyprus, and Asia Minor, long the storehouses of Rome's invaluable mineral deposits.

By 218 A.D., the Roman Emperor Elagabalus decided to make the denarius wholly of copper. This coin was not accepted by the eastern merchants, which was a great blow because Rome had been the empire's trading center and the focus of its economic life (Poss, 1975). By the year 220 A.D., silver was so scarce that the debased currency could no longer be supported, and the government repudiated its debts. This resulted in Rome's fall as a trade center of consequence, and the inability of the government to pay for itself or the military (Lovering, 1943).

Finally, with northern hordes beating on its doors, and no money of value to pay for defense, the Roman Empire collapsed. The debasement of the currency was only one of the reasons for the fall of Rome, but it was an important one. It may have been the single most important one. The Roman historian, Antonius Augustus, wrote "Money had more to do with the distemper of the Roman Empire than the Huns or the Vandals."

The Gold Standard

Allowing paper money to be freely converted to gold is called the gold standard. This prevents governments from printing paper money that does not have gold backing and thus restrains politicians from excessive spending. By the 1870s, most major nations of the world had adopted the gold standard. The United States was one of the last, adopting it in 1900.

Until the Great Depression of the 1930s in the United States, the dollar was tied to the price of gold. That is, the dollar could be converted to gold at a fixed rate. As long as the price of gold remained fixed (which it was for many years, first at 20 dollars an ounce and then briefly at 35 dollars an ounce), there was confidence in the U.S. dollar because it could at any time be redeemed in gold. Because of this the government could not simply print money because the money had to have gold behind it.

But the many government programs the Roosevelt Administration in the United States initiated during the 1930s required that more dollars be printed. The Gold Standard Act in the United States, passed in 1900 and officially repealed in 1971, was for all practical purposes, invalidated when President Roosevelt signed the Gold Reserve Act of 1934. This measure provided that the dollar could no longer be converted into gold, and the government prohibited the manufacture of gold coins. This meant that a private money system based on gold could not be established. It now (2012) takes about $1700 to buy an ounce of gold. Gold has maintained its value while the paper dollar has not. The price of gold simply shows how much the government has inflated the currency since it left the gold standard.

Silver continued to back some U.S. currency with the circulation of silver certificates. However, in 1965, the United States offered to redeem all silver certificates with silver, and then took silver out of the coinage. Silver coins were becoming more valuable in terms of inflated paper currency than their stamped face value. Gresham's Law took over — "bad money drives out good money." Silver coins at the time speedily were taken out of circulation as people searched their change for these bits of real money. The new coinage was nickel and copper and later even the copper in pennies was replaced with much cheaper zinc. Try to find a U.S. silver coin dated 1964 or earlier in circulation today! With copper-coated zinc pennies, how far down can the debasement of a metal currency go? Ultimately it may be that even zinc is too valuable for pennies. Then what? The paper dollar no longer has any precious metal restraint as inflation since that time clearly shows.

There is currently little prospect that a gold standard resulting in some financial dis-cipline will be instituted. The official U.S. government link between precious metals and money is gone. No other nation maintains this link either. A gold standard might have avoided several debacles of currencies around the world, but the political environments make such monetary restraint impossible.

Budgets based on paper money can be financed easily with the printing press. By voting for generous public spending, politicians in effect use the public treasury as a cam-paign fund, the "pork" in the budget. Largesse gets them re-elected and most incumbents retain their seats in elections. Paper money ensures continued inflation — depreciation of the currency.

Abandoning the gold standard

By calling in all gold coins held by its citizens, the United States abandoned the gold standard in 1934. Foreign governments could still buy U.S. gold at the official price, which at the time was $35 per ounce. France started doing so and began draining U.S. gold reserves. To stop this, the U.S. officially left the gold standard in 1971, removing the last remnant of any precious metal backing for the U.S. dollar for any person or government.

The Federal Reserve System

The U.S. Federal Reserve System was established in 1913 by an act of Congress. It is a private entity composed of 12 Federal Reserve Banks owned by regional banks. No longer constrained by the gold standard, Congress can now vote for any expenditure. Money needed for various social and economic programs as well as military costs can be financed by the sale of government bonds to individuals, domestic banks, and foreign governments (notably China). Money not raised otherwise can be obtained from the Federal Reserve, which, upon buying the bonds, then prints money in payment to the government. The government uses that printed paper for its "money." Many people do not know this but the fact can be verified by simply looking at any U.S. paper currency and seeing that it is a Federal Reserve Note.

In this fashion, the government can finance its needs simply by printing bonds and selling them to the Federal Reserve. Abolishing the Federal Reserve System has been a plank in the platform of at least one presidential candidate who denounces it as the greatest existing threat to sound money.

Congress determines what to finance, and since social and economic programs ("entitlements") are more popular and win more votes than raising taxes does, the national debt, now more than $15 trillion, increases as we continue to live beyond our means. The same is true for many countries, and is the cause of the financial crisis that swept across the Euro-zone countries beginning in 2010.

The problem is that borrowed money should be paid back in money of equal value. But it rarely, if ever, is. The American Institute for Economic Research has shown that if the 1945 U.S. dollar is taken at face value for purchasing power, by 2009 its purchasing power shrank to six cents.

What backs the U.S. dollar now?

If anything backs the U.S. dollar now, it is the country's manufacturing capacity, the ingenuity of its people (e.g., advanced electronic and medical devices, sophisticated forms of heavy equipment, airplanes), and its natural resources. Chief among these are its remaining minerals, its forests, and especially its fertile soil and freshwater supplies related to agricultural productivity. The United States is the world's largest source of corn. China is a major buyer of corn, for which they need U.S. dollars.

Alan Greenspan, who later became Chairman of the U.S. Federal Reserve Board (1987-2006), commented on the gold standard:

> Under a gold standard, the amount of credit that an economy can support is determined by the economy's tangible assets, since every credit instrument is ultimately

> a claim on some tangible asset, but government bonds are not backed by tangible wealth, only by the governments promise to pay out of future tax revenues...Thus, government deficit spending under a gold standard is severely limited.
>
> The abandonment of the gold standard made it possible for the welfare states to use the banking system as a means to an unlimited expansion of credit...there are now more claims outstanding than real assets. In the absence of the gold standard, there is no way to protect savings from confiscation through inflation. There is no safe store of value...The financial policy of the welfare state requires that there be no way for owners of wealth to protect themselves. Deficit spending is simply a scheme for the hidden confiscation of wealth. Gold stands in the way of this insidious process….If one grasps this, one has no difficulty understanding the statist's antagonism toward the gold standard.

Gold, in mid-June, 2012, was selling for over $1,600 an ounce, its price reflecting how the market values the dollar. As printing paper money continues, the price of gold will serve as an index of inflation — the depreciation of the dollar. Viewing the current scene, some investment advisors suggest gold will be $3,000 an ounce by 2030, or earlier, and silver will be $100 an ounce, as turbulent economic times continue. Borrowing and print-ing money allows nations to live beyond their means, but it cannot continue indefinitely. Debts must be recognized and either repaid or defaulted. The result is likely to be a lower standard of living.

The danger from ever-growing debt is that the amount of money needed to pay the interest on the debt eventually becomes so large that it crowds out financing needed for basic government services. The options are three-fold: (1) reduce the debt by austerity measures, including higher taxes imposed on the public; or, as has nearly always been the case, to either (2) print money to the point of high inflation to pay off the debt in cheap dollars, thus destroying citizens' savings; or, (3) repudiate the debt (i.e., default). The latter two options amount to the same thing, causing collapse of the economic system and resulting in economic, social, and political chaos.

The dollar now is backed only by "the full faith and credit of the United States." China has a multi-billion dollar trade surplus with the United States. To keep the U.S. as a strong market for their products, China has been buying about 30 percent of all U.S. government issued securities. But there are signs that may change. The Chinese are using their surplus U.S. dollars to buy tangible assets, which recently included the purchase of IBM's personal computer business and oil and metal deposits around the world. They would rather have technical expertise and oil than U.S. paper securities. This trend could eventually have serious repercussions for the U.S.

Paper as "Money"

The end form of "money" is paper; there is nothing cheaper to use for a medium of exchange. In Hong Kong, before its reunification with China, when you exchanged your money for local currency, and the final figure had some pennies left over, you received slips of paper (Hong Kong pennies). How much longer will pennies be minted in the United States? Only until the dollar depreciates to the point where there is no metal that can be produced the size of a penny and still be worth less than a penny. Copper did not survive and zinc will be the next to go. Analysts are now calling on the federal treasury to abandon the metal penny and round off purchase prices to the nearest nickel.

Worldwide use of paper money

Gradually, around the world, paper money has taken the place of gold and silver. Some countries still cling in various small ways to precious metals for their currencies, chiefly by issuing special coins for special events or occasions. But now all countries, including the major nations, issue paper money not backed by gold or silver. Unfortunately for the general public, paper money as a store of value has a very poor history. Not only is paper money subject to government printing press inflation, but it can also be more easily counterfeited than precious metals currency.

As governments no longer back their currencies with precious metals, the evidence of inflation is incontrovertible. It is estimated that if the paper money now in circulation in the world were backed by gold, that gold would be worth $32,000 per ounce. Governments have abandoned precious metals as currency backing because it restricts the government's ability to print an infinite amount of "money." *Miami Herald* humor columnist Dave Barry has analyzed the situation precisely, stating:

> Over the years all the governments in the world, having discovered that gold is, like, rare, decided it would be more convenient to back their money with something easier to come by namely: nothing.

How Other Minerals Back Currencies

Besides precious metals, other things can and do, in effect, back a nation's currency to some extent. The ability to produce food, cars, refrigerators, medicines, medical equipment, and many other items tends to support a nation's money and, therefore, the materials from which these things are made, including soil, iron, and copper, and energy resources in the ground (coal, oil, gas) are valuable. Japan, which has very few natural resources, nevertheless has a strong currency. The yen has been strong because of what the Japanese can do by processing and upgrading the natural resources they import. But their economy is precarious. For without basic raw materials within their borders, they are vulnerable. And they know it.

Before World War II, Japan invaded Manchuria, China, and Southeast Asia to establish a colonial empire from which to obtain raw materials. They were defeated in this endeavor. Now they are buying mineral resources abroad, either by 100 percent ownership or, more often, through joint mineral resource developments. China is doing the same thing.

Noting of the strength of the Japanese yen in international markets, the U.S. Bureau of Mines (1994) reported:

> Japan has intensified its overseas mineral exploration and development projects for copper, gold, lead, silver, and zinc since 1992. Significant joint exploration and development projects were undertaken in Australia, Chile, China, Mexico, Mongolia, and the Republic of South Africa, and in the United States. In 1992, Japan successfully launched its first geological observation satellite with the world's most advanced sensor and radar equipment to aid in the worldwide search for copper, gold, iron, lead, silver, zinc, and other metals. The satellite began transmitting data in 1993 covering 10 portions of the earth's surface, including 2 targeted areas in the U.S.

In this way, Japan is working to establish, through legitimate economic means, a worldwide network of mineral supply sites to replace colonies it could not seize by military force. Despite that, what really backs the Japanese yen is Japan's industry — its ability to process Earth materials into useful items, many of which now offer keen competition to the American automobile industry.

"Petro-currencies"

There is no better example of how the possession of mineral and energy mineral resources supports the value of a nation's money than the case of oil. As oil became more and more important in world economies and clearly was the only thing making the money of some countries valuable in world trade (Nigeria, Qatar, United Arab Emirates, Kuwait, Libya, and others), the concept of "petro-currencies" developed. When Kuwait's chief resource lies beneath its desert sands in the form of oil several times longer than the amount of oil in the United States, there can hardly be a better reason for holding the Kuwait dinar.

Among the Gulf states, oil provides about 80 percent of government revenues. In North Africa, Libya has virtually no other resources than oil, and the Libyan dinar floats on the surface of the ocean of world currencies because it floats on oil. When the oil is gone, the value of the Libyan dinar will likely vanish.

Oil and the British pound

The same is true to some degree for the British pound since the discovery of oil in the British sector of the North Sea. With that discovery and subsequent British self-sufficiency in oil (and, for a brief time a net oil exporter), the British pound did a great deal better than in times past. It has had its problems, however, which were clearly tied to oil. In the 1980s, when the price of oil declined, the British pound dropped to the point that it almost equaled a dollar. Then, as oil prices rose, so did the pound, a clear example of the importance of possessing that energy mineral resource to the value of the British currency.

Former British Prime Minister Margaret Thatcher's greatest stroke of good luck was probably the coincidence of her early tenure with the surplus foreign exchange account the government ran on the basis of oil production and export. This helped Mrs. Thatcher become the Prime Minister with the longest tenure in recent British history. Without North Sea oil revenue, the government's budget deficit would have been much higher, and it would have required income tax increases of between $30 and $35 billion (pounds converted to dollar equivalent). There would have been another million people added to Britain's jobless lines, which undoubtedly would have contributed to considerable civil strife.

Over the longer term, North Sea oil has given Britain a lasting legacy in the form of some 80 billion pounds of foreign investments that Britain made at the time it had the oil money to do it. This was earned as new oil fields were discovered and oil prices went up and up. When oil prices slumped in the mid-1980s, the income from oil declined to the point when, in 1986, the income from investments made earlier from oil money exceeded the income directly received from oil. This again tended to support the British currency and economy.

Britain, however, has come close to killing the goose which has been laying the golden, or in this case, the oil-filled egg. The average tax rate, when adjusted for inflation, is about 78 percent of the profits of the oil companies. For some oil fields, the rate is over 90 percent. With such a high tax, companies refused to develop the many small field discoveries that were made, with the result that Britain passed the peak of its oil production in the late 1990s. The hope for future development lies in more than 40 smaller fields, some with only one-twentieth the recoverable oil of the larger oil fields. As one observer said, "The government milked hell out of this industry, and the cow nearly fell down." Recently the British Government reduced its tax rate on all new fields with the result that some of the smaller discoveries are now being developed.

However, this additional production cannot make up for the decline in the larger fields and production continues to drop. In 2004, Great Britain recorded the steepest drop of any oil-producing country, with oil extraction down 10 percent. The downward trend has continued. Forecasts are that oil production will fall one third from its peak by 2020. Such a dramatic change is certain to cause budget problems for the future prime minister. Britain is now a net importer of both oil and natural gas. At the moment, the pound is fairly strong, but will it remain so with increasing imports of petroleum? Margaret Thatcher picked the right time to be prime minister!

Canada

It seems odd to think of the Canadian dollar as a petro-currency. It would be the only such currency outside of the Gulf countries and Venezuela. But Canada is the largest exporter of oil to the world's largest importer of oil, the United States. The Canadian dollar has been slowly increasing in value against the U.S. dollar. With the world's largest deposits of oil sands, and conventional oil more difficult to find, billions of dollars are pouring into these resources from investors in several countries. Oil sands are likely to be the last surviving oil industry in North America. With oil, timber, and metals, Canada's dollar is now a natural resource dollar.

Oil and U.S. Balance of Payments

The United States unfortunately is increasingly on the wrong side of oil balance of payments relationships. In the late 1980s and into the 1990s, the value of the U.S. dollar plunged to a record post-war low against other major currencies. The main reason for this was the large balance of payments deficits combined with a huge budget deficit at home. A significant part of the trade deficit resulted from the cost of importing oil and other raw materials.

The situation became even more acute in the first decade of the twenty-first century. At present, the United States imports about 11 million barrels of oil a day. No refineries have been built in the United States in over 20 years. With limited U.S. refining capacity, an increasing percentage of oil is imported as more costly refined products — gasoline, jet fuel, and diesel. About eight percent of U.S. oil imports are now finished product. At 11 million barrels of oil a day, at an average cost of over $80 a barrel, the U.S. oil import bill is more than three-quarters of a billion dollars daily.

The United States' dollar sensitivity to oil was illustrated when a rumor came out that an exploration project had struck oil in the Baltimore Canyon area off the East Coast of the United States. This had long been a major exploration target. The dollar immediately jumped in value. When the rumor proved false (and the Baltimore Canyon area has now been one of the great disappointments in East Coast off-shore drilling), the dollar fell.

Just as oil-rich countries are kept afloat by oil, insufficient oil in a country that uses 25 percent of world supply as the U.S. does, depresses its currency. This is likely to be an increasing problem for the United States because oil remains the largest single component of the U.S. deficit in international balance of payments.

It is true that some of the money sent abroad to buy oil comes back to purchase goods, or assets of various sorts. But the United States is in a losing situation. As the petrodollars get recycled, the U.S. may not see much benefit, because U.S. exports to the OPEC members remain weak. Also, the U.S. may not gain from new capital flows. Although there are no hard data, some reports suggest that in the current geopolitical climate, petrodollar investments are flowing increasingly to euro-based assets. The dollar is under stress as oil figures into the cost of nearly everything.

Money and International Prestige

As the U.S. dollar falls, some politicians and industrialists applaud because presumably it makes U.S. exports more competitive. But the low value dollar is a two-edged sword. If the U.S. has a big balance of payments deficit, that is, it imports more than it exports, the cheap dollar makes imports more expensive, and the single main import is oil. If the United States dollar weakens, the prestige of the United States weakens too. No one respects a country in which it takes a handful of money to buy a loaf of bread. Citizens traveling abroad want to have a currency that is respected and in demand, and has reasonable buying power relative to similar goods at home. The disaster that overtook the Russian ruble after the Soviet Union disintegrated certainly did not enhance Russia's international prestige. Now, with Russia becoming a major gas exporter, especially to Europe, the ruble is strengthening.

The value of a currency, and how it is respected, is a considerable measure of that country's political strength and economic influence around the world. It has been said that the market valuation of a nation's currency is an "international report card" on how well that country is managed. Testifying before the United States Congress in 1995, Felix Rohatyn, a senior partner of the investment firm Lazard Frères stated, "We are gradually losing control of our own destiny; the dollar's decline undercuts American economic leadership and prestige. It is perhaps the single most dangerous economic threat we will face in the long term because it puts us at the mercy of other countries." Since then the U.S. economic situation has continued to deteriorate.

The dollar has been the reserve currency of the world since the end of World War II. Most international accounts including the purchase and sale of oil and all other commodities are now settled in dollars. But there is an ominous trend emerging. In 1965, 80 percent of the world's foreign-currency reserve holdings were in dollars. By 1995, that figure had declined to about 58 percent.

Oil Priced in Dollars

Because of the continued weakness of the dollar, the oil-producing countries have suggested that oil should be priced in terms of a basket of currencies — that is by using the average value of several currencies. If oil is no longer priced in U.S. dollars, it will be a severe blow both to U.S. prestige and to the dollar. The fact that the most important commodity in world trade, oil, is priced in U.S. dollars is a major reason why the dollar is the most widely accepted currency in the world. Although the huge oil import bill for the United States is not the only culprit destroying the dollar's reputation as a strong currency, it is an important one. If, at some point, a major oil exporting country decides to price its product in some other currency, the international repercussions would be large, and could set off an unfortunate train of events for the dollar.

In fact, there is already a "basket of currencies" in the form of the euro, a currency in use by most European countries, markets important to OPEC. Oil will continue to be the largest single item in the U.S. import bill for the foreseeable future. Continuing to price oil in dollars is very important to the United States. For Muslim countries, which hold most of the remaining world oil and are disenchanted with the United States, switching to the euro or some other monetary system for pricing their oil would give them another economic weapon besides oil itself.

Oil Backs Local Credit

In some states of the United States, oil is also a proxy for money in the way state bonds are rated and how easily they can be sold. A brokerage house titles one of its investment publications "General Obligation Credits in the Oil Patch," which indicates oil production remains a strong factor in the economies and budgets of states such as Louisiana, Texas, Oklahoma, New Mexico, and notably, Alaska. In the first three of these states, bond ratings were lowered when the price of oil dropped and oil production and exploration activity declined.

Alaska's Good Fortune — For the Moment

Thanks to Prudhoe Bay's strong oil production, Alaska's bond ratings were raised in 1980, and have not been reduced since. But as Prudhoe Bay production declines, and if no other substantial oil fields are found in Alaska, its bond ratings will be reviewed. More than any other state, Alaska's budget is tied directly to the petroleum industry. Revenues from oil and gas make up about 86 percent of total state government income. Bond ratings are important because they determine the interest to be paid on bonds. A good bond rating is worth money to the organization that issues them. If it is oil that gives the bond a good rating, then oil is worth money to the bond issuer.

Oil via Dollars = an International Currency

Oil, as noted, is priced and paid for internationally in dollars. As long as the dollar is strong enough to be wanted around the world, the dollar makes a country's budget easier to handle by providing universally acceptable foreign exchange and reduces pressure on the local currency to carry the load. If the oil money were not there, it would almost certainly take much more of a local currency to buy anything on the international market. Oil, being priced and sold in dollars, gives each oil-producing country money that is recognized as money around the world, despite the condition of its own currency.

Oil money benefits other countries

Oil money not only aids the Middle East countries that have the oil, but also benefits the people that work in that region who come from countries that do not have much oil themselves. Indian, Pakistani, and other foreign workers in the oil-rich Middle East nations send substantial sums back to their home countries.

Egypt has some oil production, but with a rapidly growing population of 83 million, it is increasingly dependent for its survival on foreign aid, from neighboring friendly oil-rich Arab countries, chief of which are Saudi Arabia and Kuwait. But when the oil revenues of its rich neighbors begin to decline, Egypt will no longer be able to be supported as it is now.

Perhaps this situation will not be played out for some time, since both Kuwait and Saudi Arabia have very large oil reserves and they have been generous to their Muslim

Arab neighbors. However, as the oil begins to run out in these two countries, they will no doubt look to their own interests first, as will all other oil-endowed countries.

Another oil-deficient Arab state benefiting from its oily neighbors is Jordan. It gets a little export income from some small phosphate deposits. It has become a gold-trading center in the Arab world. On the streets of downtown Amman, Jordan's capital, robed Arab men and women may be seen frequenting gold shops. Arabs have long put their confidence in gold. Many have gotten wealthy on oil, but taking a longer view, they invest in gold as something that will last beyond the oil. Perhaps they rightly do not trust any of the currencies of the world as a reliable store of value. The gold trade in Amman is brisk.

Minerals Provide Foreign Exchange for Small Economies

Many smaller countries whose economies are not big enough to justify the presence of an automobile plant, an electronics complex, laboratory facilities for the production of vital medical supplies, or other sorts of manufacturing which must have a reasonably large domestic market to survive urgently need foreign exchange. Without a diversified industrial base, foreign exchange has to fill the gap to pay for imported items. Where oil is not available to earn money, metals and other minerals may provide the foreign exchange so urgently needed. Peru, Bolivia, Zaire, and Zambia, for example, do not have a diversified manufacturing base. Many things have to be imported. These countries are not highly developed technologically, and, therefore, cannot sell technology or the things technology produces. Accordingly, these lesser-developed countries must fall back upon the production of raw materials, commonly minerals, to earn much of their foreign exchange.

Bolivia earns its foreign exchange from the sale of tin, oil, and gas. Peru earns most of its foreign exchange from exports of gold, silver, copper, and a little oil. It will soon earn more foreign exchange from the sale of gas from its large Camisea gas field east of the Andes following the completion of the trans-Andean pipeline and the export terminal on the coast.

Zambia's copper provides more than 80 percent of its foreign exchange. Chile's currency, like most Latin American currencies, has been volatile. But its volatility would have been even greater if it were not for the fact that it has some of the largest and richest copper deposits in the world. Copper exports currently account for 54 percent of its foreign exchange income and copper will earn valuable foreign exchange for Chile for many years to come.

The dire need to export "something" to earn foreign exchange also tends to disrupt mineral resource markets. Chile, with its relatively rich copper ores and low-cost labor, can produce that red metal at an average cost of less than 60 U.S. cents a pound, substantially below current production cost in the United States. Even if Chile had to sell its copper at a loss, it would do so because it needs foreign exchange at almost any price. At times, Chile has dumped large amounts of copper on the market despite low prices and demand. The result has been that many copper mines in the U.S. had to close. On the other hand, the money Chile earns goes in part to pay interest on the $20 billion foreign debt owed by Chile, much of it held by U.S. banks. It is a complicated interlocking financial world that mineral resource economics creates.

Another aspect of some countries' dependence on the export of minerals or energy minerals is that as the price of these materials drops, they need to export more to maintain the same level of income. However, by exporting more, they cause lower prices, and so on it goes. Countries often need to export minerals not only to obtain foreign exchange, but also to provide internal employment. By having to produce more because of declining prices to earn the same amount of foreign exchange, there is some compensation because they create more employment. This has the advantage of keeping the local population reasonably content and benefits the political regime in power. Even if the price of the product falls below the cost of production in a given country, that country is still likely to continue production. At first glance, this does not seem logical, but the economics were neatly explained by a minister of mines of one African nation, who commented on a gold-mining project, that was uneconomic by most standards, "You do not understand. As long as the metal brings in more dollars than we have to spend for supplies from the outside, it is economic. The labor, power, and other supplies are obtained locally and paid for in our currency, the value of which we control. We need the thousands of jobs to keep the people quiet. Therefore, the project is economic."

So it is not just the matter of earning foreign exchange that causes fluctuations in the price of minerals and energy minerals, it is also politics. The amount of the resource produced is increased simply in order to "keep things going." The "things" in many cases is the current political regime, which may involve considerable graft to keep the present politicians in power. If the graft is not kept properly fueled with money, there are likely to be changes. Heads may literally roll. Some of the cheating on OPEC production quotas may have its origin in these circumstances.

Domestic Oil Saves Foreign Exchange

Being self-sufficient in oil does make a difference — a lot of difference. If the United States were still self-sufficient in oil and had not sent billions of dollars abroad to pay for oil, it would not be such a huge international debtor as it is now. It was the increasing dependence of the United States on foreign oil that enabled the OPEC countries to raise the price of oil as high as they did in the past. This resulted in a great transfer of the western world's wealth to them, causing tidal waves in international banking.

No doubt the price of oil would have increased anyway, but the extent to which it rose would have been less if the United States, the world's largest consumer of oil, had been self-sufficient in oil. This is another example of oil as money, and the problems that beset a highly industrialized, high oil-consuming nation.

Oil Money in the Banking System

Minerals, oil in particular, have had a far more profound effect on the world economic system and its structure than simply influencing the value of a particular currency or providing a foreign exchange medium. When the price of oil was raised from less than \$3 a barrel to more than \$35, the world witnessed the biggest transfer of wealth in all of history, and it continues with oil at \$80 a barrel and higher. Unable to absorb this flood of money locally (denominated in U.S. dollars), the oil-rich Arab world had to deposit it where it would earn income until it could be used internally in various projects. The money had to go somewhere and the main places it went was to the major banks of Europe, and particularly the large banks of the United States.

Faced with this huge influx of money, banks in turn needed to loan the money out so it could earn the interest the banks had to pay on it, plus a profit for the bank. The places that needed money the most and were willing to pay for it, or so they said, were chiefly developing countries such as Mexico, Brazil, Peru, Argentina, and several African nations. The Arab oil money poured into the banks, and the banks in turn poured it out to needy undeveloped countries. It seemed to be a happy arrangement all around.

But apparently many bank managers did not take time to realistically consider how these debtor countries would pay back the money, given their social, economic, and political situations along with the dishonesty of some government officials — almost a tradition in certain areas. Some of these loaned dollars were siphoned off by graft and corruption. Some money escaped the corruption and was invested in projects of various sorts, but many were poorly managed at best. Some were bad ideas to start with. Peru was one of the first countries to delay its debt repayment with the excuse that "these projects were so bad you should have known better than to lend us the money we asked for on them." (This is literally what they said!)

The Longer-Term Balance of Payments Problem

Unfortunately, unlike Japan, which knew long ago it had to export to survive, the United States was content with its own large internal market and sufficient domestic mineral and energy mineral resources (oil, gas, coal, iron, copper, and others in initial abundance) for its own use. It did not need foreign exchange. But as U.S. oil self-sufficiency disappeared, and the demand in the U.S. increased for fuel-efficient cars, Japan was able to build and export them to the U.S. In the decade of the 1980s, the U.S. went from the world's largest creditor nation to the world's largest debtor nation, with a huge foreign trade deficit. This was almost an unbelievable change of circumstances. Unable to sell enough to meet its import bill, the U.S. is running a large deficit in its international balance of payments. How long this situation can last is a serious question. Getting out of this economic hole will be a very large task. The U.S. balance of payments deficit for now exceeds $600 billion a year, with an internal debt of more than $15 trillion. The economic position of the United States may be as large an Achilles' heel as its oil supply problem, and the two are closely related because oil imports (finished product and crude) are the largest single item in the deficit.

U.S. domestic production helps keep its oil bill from being even larger. Alaska's Prudhoe Bay Field alone has saved the United States about $150 billion in oil import costs. Unfortunately that field is already in production decline.

Continuing Transfer of Wealth

The worldwide payment for oil from consumer to producer is the largest transfer of wealth the world has ever seen. It will continue for decades to come. When or how it will end no one can say, but the world's money and the world's economic structure will never be the same again. Oil turned it upside down. It made some nations rich, and others poor. The locations of the largest oil deposits will continue to have profound effects on the economic futures of industrialized countries and those trying to enter the age of oil. Because it is the largest user of oil on a per capita basis, the United States is particularly vulnerable.

This continuing transfer of wealth to the oil producing countries affects all citizens of resource-poor nations even though they may be industrialized nations. It will ultimately be the citizens of these nations who will have to pay the bills in various ways through higher oil and mineral costs, and perhaps through having to rescue their banking systems. Higher taxes, a depreciated currency, higher prices for daily living needs, and a lower standard of living may accompany these costs. Oil — who has it, and who does not — was and remains a major factor in these situations.

It is important to consider the profound effects of a single commodity — oil — which less than 200 years ago was of no great importance to anyone. At that time, as it had been for several thousand years, one of oil's chief uses in the Middle East, where numerous oil seeps existed, was the treatment of camel mange.

In Summary

Minerals in the form of precious metals have served literally as money during much of modern civilization. In the form of oil and coal, iron, copper, uranium, and the many other minerals that modern society needs, these materials are now responsible for an enormous transfer of wealth. Minerals are money in a fundamental sense. Who has them, and who does not will continue to influence the course of national economies, and in turn, the destinies of nations.

Because there are not enough precious metals in the world to back world currencies, paper money will continue to be the medium of exchange. Its value will fluctuate over time and from country to country as it is perceived by the world community to be backed by something of value. Other than gold and silver, important metals like iron and copper, or fossil fuels, or even agricultural products can help to support a currency. Money can also be backed by the intangible, but important, technical ability of a country to use raw materials to make things of value. The value of currency is a measure of a nation's ability to effectively manage both its internal and external finances. When a government inflates its currency, citizens tend to convert currency paper into almost anything tangible. Natural resources are the most common refuge from inflation. Land is another tangible inflation hedge. Both of these shelters are evident in various economies.

It will take a nimble investor to successfully manage money in the decades ahead. Governments will struggle to finance the economic demands of increasing populations. Diminishing resources in many countries will subject them to the problem of having to find a way to finance imports, or to invest in costly, less economic substitutes for the cheaper resources of the past. The world's monetary systems are likely to be even more chaotic in the future than they have been in the past.

Chapter 8

Energy and Population

Energy is the key that unlocks all other resources. It mines our minerals, and transports, smelts and processes them into useful forms. It plows our fields, transports our crops, processes them, and distributes them to consumers.

Energy powers our factories, and lights, heats, and cools our homes, businesses, factories, and public spaces. In electric form, energy is used in myriad useful ways. Energy supplies have determined the outcomes of wars. The amount of energy used and the way it is used defines different cultures today and will in the future.

Two problems certain to dominate worldwide concerns this century are energy and population. The most basic source of energy for humans is food. More than oil, natural gas, coal, or any other form of energy, food is the first concern of everyone. In some regions, it already is. Eventually this concern will be universal. Unfortunately, as Roberts (2008) warned, the basic foundations of food production, soil and freshwater are being depleted. He says, " … because water, unlike energy or fertilizers, has no alternative, this emerging scarcity poses a constraint on food supplies that in some ways is more final than that of oil or climate."

How much energy each individual commands, either directly or indirectly, does much to determine that person's physical standard of living. Beyond energy, the size of the population (country or region) where an individual resides also influences the standard of living in many ways. Both these factors are considered here.

The drivers of energy demand are population growth, increasing industrialization, and rising in per capita income. These pressures are most apparent in populous, developing countries such as China, where a rapidly growing middle class aspires to have motorized transportation and other consumer goods. Automobile sales are experiencing annual double digit growth, as all of Southeast Asia is industrializing.

> Now energy use is rising most rapidly in the developing world, partly because this area of our world is experiencing faster economic growth than the developed world and partly because developing countries use energy less efficiently. In fact, the developed world uses only one-third the energy of the developing world per

unit of gross domestic product…. We see overall global energy use growing by about 40 percent by 2020 (Raymond, 2004b).

End of cheap energy, tightening supplies

The rapid rise in jet fuel and gasoline prices during 2004-2007 in the U.S. was exacerbated by hurricanes damaging and destroying offshore drilling and production platforms and by reduced refinery output. It showed just how thin our spare capacity cushion is. Recent price increases in heating oil and electricity further educated the public that energy supplies underlie the whole economy and that the age of cheap energy is history. These realities make discussions of energy urgent in the halls of Congress and the subject of special speeches by the president and politicians of every stripe.

The energy-population connection

People use energy. More people use more energy if per capita physical standard of living is to be maintained. To raise the low standard of living in many nations takes more energy. It is as simple as that. Almost all deliberations about future energy are concerned with obtaining more and more energy from every possible source. The idea that population growth is the main, underlying problem does not seem to be generally recognized. Duncan (2001), in his study of energy and the future, clearly connects population and energy demand, as did Grant (2005). But neither the press, the public, nor politicians seem to understand this critical tie, fundamental to our future.

Energy and population to a considerable degree are one and the same problem. Richard Smalley, a pioneer in nanotechnology and winner of the Nobel Prize for his research, was concerned in his later life with energy. He said, "Energy is the single most important problem facing humanity today." But taking a longer view of the two, population is the variable that may be the more important. Transition to a renewable energy economy will be forced upon us. Studies indicate renewable energy resources cannot, at any reasonable standard of living, sustain the seven billion people on Earth today, much less the 9.4 billion expected by 2050 (Trainer, 1995). As the production of oil, gas, and coal, now the main energy sources for developed societies inevitably begin to diminish, human societies will again be more dependent on the local environment. Instead of living off past environments that gave us the inheritance of fossil fuels we use today, we will have to depend on local renewable energy resources such as biomass, wind, and solar. Expansion of nuclear-fueled electric power generation can offer a somewhat wider scope of energy supplies, but it can't replace today's fossil fuels, because uranium, like fossil

Table 8-1. Growing World Energy Demand. Projected percentage growth of energy demand by geographic sector in barrels of oil energy equivalent: 2004 to 2030

Region	Percent growth	Millions of barrels of oil equivalent per day 2004	2030
North America	25	55	69
Latin America	85	13	24
Europe	18	39	46
Russian/Caspian	40	20	28
Middle East	64	11	18
China	100	26	52
Japan	9	11	12
India	164	11	29
Africa	58	12	19
Other Asia/Pacific	73	12	38

Source: *The Lamp*. ExxonMobil publication v. 87, n. 1, 2005
Note: This is not just barrels of oil, but includes all energy sources converted to barrels of oil energy equivalent.

fuels, is a nonrenewable resource.

The high ratio of energy used to put a calorie of food on our table today is approximately 10 to 1; that is, for every calorie on our plates, it took 10 calories of fossil energy to put it there. Future agriculture is not likely to be as mechanized as it is today, and transport of foodstuffs from far places will not be as easy or inexpensive. Chilean grapes, Brazilian orange juice, and Australian oranges will show up less frequently on American and other nations' tables, and ultimately not show up at all. Estimates are that the total distance food now travels to the average American dinner table is now about 1,500 miles.

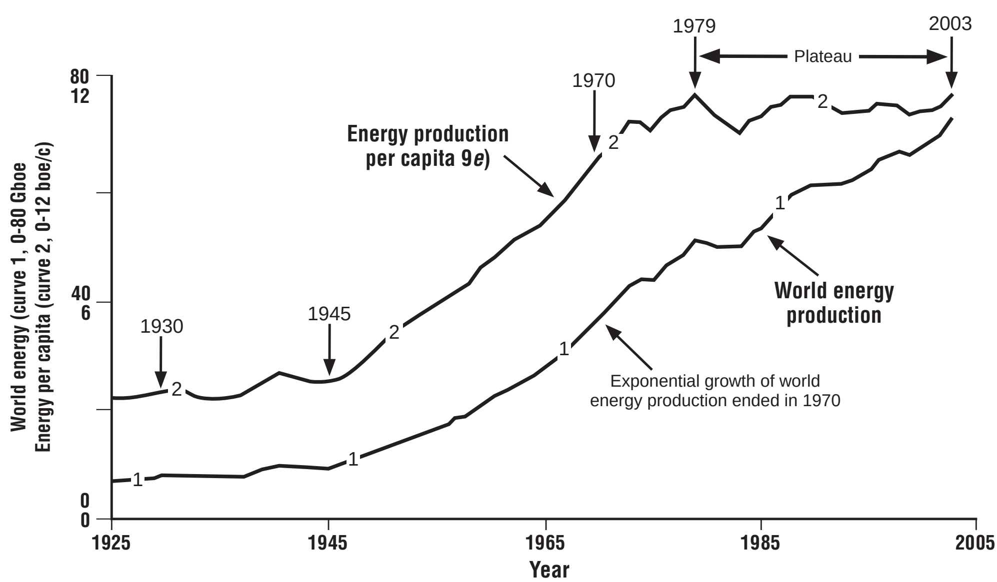
When the local environment again has to provide our basic support, it will have to provide relatively more than it did before the hydrocarbon "bubble" if population continues to increase. Then it will be clearly evident that population size is the deciding factor in our standard of living.

Population growth outraces energy growth

Coincident with, and in large part because of the exploitation of oil following the Drake well discovery of 1859, there has been a huge expansion in world population. Initially, energy production exceeded population growth and per capita energy production increased worldwide until 1979. Although energy production continued to grow, population grew faster. After l979, per capita energy consumption leveled off and is now decreasing (Duncan, 2001).

In Figure 8-1, Duncan graphed what happened to the relationship between energy production and per capita energy consumption per year: it peaked at 12 barrels of oil equivalent). With oil a primary source of energy, Deffeyes' comment (2005) is pertinent: "Global per capita oil production peaked in 1979. Since 1979, the world has been producing people faster than we have been producing oil." This will be a major problem this century.

Figure 8-1. World Production of Energy and Energy Production Per Capita in Barrels of Oil Equivalent (boe)



Courtesy of R.C. Duncan. Figure not previously published.

Against the rising tide of world population, nonrenewable energy supplies are being exhausted.

Commenting on the looming energy supply gap, R.W. Tillerson (2006), Chairman and CEO of ExxonMobil Corporation, said:

> Fundamentally, the energy gap we speak of is the divide between growing energy demand worldwide and global energy supplies. On the demand side, world consumption of energy in all forms is expected to increase 60 percent by 2030. To put this in perspective, it requires new supplies of energy equivalent to 125 million barrels of oil a day, or over 40 times Norway's current rate of oil production.

Energy use defines civilization as we now know it. Abundant cheap energy from fossil fuels has been the basis for the rise of industrial civilization. But a future, without ample fossil fuels will be difficult. Some of that energy will have to come from low-grade agricultural sources (the biofuels) that depend on the environment, chiefly soil and fresh water. But soil and fresh water are also being depleted at an alarming rate.

Population still growing for decades ahead

Although some hold the view that population growth is leveling off, and therefore energy demands will stabilize, statistics do not bear this out. The Population Reference Bureau says population is still increasing with an additional 80 million people annually.

"Population growth is leading us to a world that we do not want. It is the most fundamental of the engines of change, and the most ignored" (Grant, 1996). More recently, Grant (2000) emphasized this point: "The whole world is engaged in a pell-mell race to grow faster — driving toward an impossible objective. It is a daunting prospect: the idea of a race to increase economic activity in a world already under stress."

Broader Aspects of the Population Problem

In 1978, British scientist S.R. Eyre wrote:

> There are too many people. Even to begin to advance toward a new utopia we must reduce our ranks…. But the direct route to such a goal is blocked by a rising tide of humanity — there is no way to it by our present road. And if they reach the new utopia, they will number far fewer than the number of souls who populate our present world…. Let the powers and potentates who have a hankering for bigger markets, more rate payers, ever-swelling numbers of the faithful, reflect on this and then hold their peace.

Lester Brown, founder of the Worldwatch Institute, with a down-to-Earth view of things from his early farming experience, states, "… for the first time, growing human demand is crossing the sustainability threshold of global ecosystems."

These truths have had almost no effect in changing the existing unsustainable course of humanity. Since Eyre wrote in 1978, world population has increased by 50 percent, and is projected to grow another 45 percent by 2050. TV screens display the plight of population — the children of Niger, for example — with heartbreaking pleas for immediate food aid. Yet the Population Reference Bureau (2004) says, "Niger is expected to be the fastest growing country between now and 2050, rising from 12 million to 53 million." It also notes that Niger has the highest number of children per woman of any country in the world — eight.

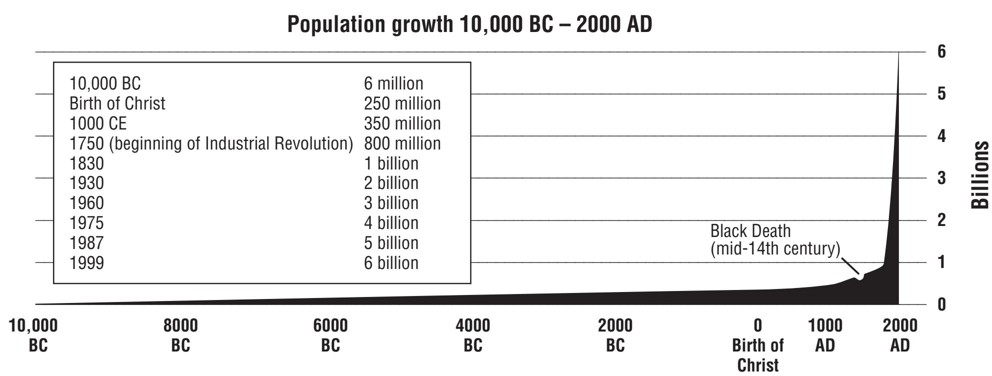
If food aid is continually sent to Niger, already unable to feed itself, the population may well reach 53 million by 2050, at which time the food crisis may be beyond solution. If it is not sent, millions will die of starvation. Surely if food aid is given, family planning should accompany it, if there is any hope for that country. All countries need to confront the issue of population growth, including the United States.

A 1972 volume entitled *The Limits to Growth* was recently updated (Meadows, et al., 2004), and reaffirms the validity of the original arguments. Population control is a major theme. In 1993, noted human biologist and ecologist, Garrett Hardin, published *Living Within Limits*, in which he detailed the collision of population growth with the limits of Earth resources, stating: "The rapid growth of human population during the past two centuries is very exceptional. It must soon come to an end. The experience probably will never be repeated."

The growth of population is a biological matter. The normal growth pattern of an organism is to grow to a mature size and then stop growing. A person does not grow indefinitely. Unending growth in the size of human population is not a normal situation. Like an individual, it eventually must stabilize in size. No organism can continue to grow indefinitely. Otherwise, the world would have been covered in bacteria, houseflies, or codfish long ago. The population growth trend of the past three hundred years is not sustainable.

The rapid rise in human population is set forth in a monumental study by Stanton (2003). This sudden rise within the framework of previous centuries of very slow growth is graphically illustrated in Figure 8-2.

Figure 8-2. World Population 10,000 B.C. – 2000 A.D.



Graph reprinted with permission of *Understanding Global Issues*, London

Geophysicist/petroleum geologist, M. King Hubbert, who correctly predicted in 1956 that United States oil production would peak in 1970, had a broad interest in the rate of human exploitation of energy sources. In his 1976 paper, "Exponential Growth as a Transient Phenomenon in Human History," he noted that the past two centuries have been marked by exponential growth both of population and exploitation of Earth resources. This is clearly a once-in-human-history event, which is coming to an end and will never be repeated.

Population growth — not in the political agenda

Despite clear evidence of the need to restrain population growth, governments, with few exceptions, make little or no effort to address the problem. It appears to invite political self-destruction to do so. The United States makes no effort to resolve the problem. Bartlett (2004) notes: "Our population growth rate of more than 1percent per year is the highest of any industrial nation. The U.S. can't preach that other countries should limit their population growth unless we are willing to set an example and do so first."

In 1800, the world population is estimated to have been about 906 million. World population now is over seven billion. This growth was made possible largely by the extraction and use of cheap and initially abundant energy in the form of fossil fuels. It greatly increased food production and provided other essentials including adequate space-heating against the elements in higher latitudes, allowing larger populations to survive. The five million people now living in my native Minnesota, where temperatures below minus 60° F have been recorded, are an example. Medical advances along with related sanitation advances have been a beneficiary of abundant and cheap energy, and enabled more people to survive. It is, therefore, important to note again that the world per capita energy consumption peaked in 1979. Population is outrunning available energy resources.

Table 8-2. Population of World's 10 Largest Countries and Selected Others, 2008 and Estimated 2050 (population to closest million)

2008		2050	
China	1,324	India	1,691
India	1,149	China	1,312
United States	304	United States	438
Indonesia	240	Nigeria	433
Brazil	195	Pakistan	314
Nigeria	148	Bangladesh	226
Bangladesh	9	Brazil	222
Russia	164	Dem. Rep. Congo	149
Japan	58		
Selected Others			
Mexico	108	Ethiopia	173
Ethiopia	79	Mexico	144
Saudi Arabia	28	Angola	48
Angola	16	Saudi Arabia	47
Guatemala	13	Guatemala	28
Haiti	9	Haiti	14

Source: Population Reference Bureau World Population Data sheets, 2008 and 2011

Population grew to approximately 1.5 billion by 1900 when wood was still the chief source of energy. But, when petroleum began to be used in countless ways, the population rocketed to 6.3 billion in just over a century. The increased use of cheap fossil fuel and growth of population are surely the two most important phenomena of the twentieth century. The United Nations median world population projection is for the 2011 population of nearly 7 billion to grow to approximately 9.6 billion by 2050. The Population Reference Bureau (2011) estimates a lower world population in 2050 of 9.27 billion and says:

> Developing countries in Africa and Asia will account for about 90 percent of the increase in world population projected by 2050, while the population of most developed countries will decrease. Among developed countries, only the United States is likely to see significant growth, a result of immigration and a birth rate higher than other developed nations.

Population in 2007 and estimated population in 2050 for the ten largest countries is shown in Table 8-2.

The Population Reference Bureau states, "Three of the world's most populous countries in 2004 are the United States, Russia, and Japan. By 2050, only one, the United States, is expected to remain in that top 10 list." Some 32 countries have essentially achieved population stability or are actually declining. All 32 are in Europe.

The fallacy of financing social security by immigration

It is sometimes argued that because people live longer, we need to bring in more young immigrants to maintain the base of financial support for the Social Security System. Otherwise there will be too few younger workers to support the expanding older retired population. This may work for a brief time, but it is a self-defeating solution because this larger group of young workers will eventually retire themselves, requiring an ever larger intake of a younger population. It would be, in effect, a population Ponzi scheme. At some point, the system has to face the reality that population growth cannot continue indefinitely.

Immigration problem in broad perspective

There is currently considerable furor about illegal immigrants in the United States. Laws are not being observed and enforced. But immigration should also be viewed in the simple context of an increase in population. In the United States, immigration is central to the population problem because most U.S. growth (83 percent) is due to immigration. The question should be: Can we support more population with a declining resource base? This is also the world's most basic problem.

The U.S. grew from being a wilderness to the third most populous nation in the world in less than 400 years. It has a population growth rate well above other industrial nations, many of which are losing population. The U.S. growth rate is six times that of the United Kingdom. Japan, Germany, and Italy have negative growth rates. Austria has a zero growth rate. Only France approaches the U. S. in growth rate, but the U. S. is still 50 percent larger. (While two other English-speaking "settler nations," Canada and Australia, have faster grow rates than the U.S. — that is, their annual percentage increases are higher — in both cases due to extremely high immigration rates, at 34 million, Canada has little more than one-tenth the U.S. population, and Australia, at 22 million, a mere one-fifteenth.) The Population Reference Bureau projects that between now and 2050 (not very far away) the U.S. will add another 110 million people. This is more than the combined current population of Canada, Great Britain, and Austria. Rarely, however, does population growth get critical attention in the media, and the discussion of population growth by politicians is taboo, especially during election campaigns.

Ignored or not, inevitably the basic issues of population, population growth, and sufficient energy to support the expanded population will be critical in this century. Population growth drives energy demand. Recent higher costs of energy have resulted in some public policy attention, but the factor of population growth driving energy demand and its role in rising cost gets little political notice. No substantive discussion of future energy can ignore the matter of population.

Combining population growth trends and probable future energy availability, vital for industrial use, Duncan (2001) concludes that the Olduvai Theory " … states that the life expectancy of Industrial Civilization is less than or equal to 100 years: from 1930 to 2030. The theory is tested against historic data from 1920 to 1999." The current generation will find out whether Duncan is correct or not. He might be. In any case, the point he makes is that the present trend of rising energy demand and rising consumption required our industrial civilization that is built on the premise of continual growth is unsustainable in a world of finite resources. Well documented, Duncan's article makes for very thoughtful reading.

United States population has doubled since 1950. California, the most populous state, increased its population by 75 percent since 1970, and has a growth rate greater than that of India. With a population of 38 million now, California expects to add 20 million more by the year 2040. Can the "California lifestyle" be maintained despite this tide?

Retired physics professor Albert Bartlett has asked several times:

> Can you think of any problem in any area of human endeavor on any scale, from microscopic to global, whose long-term solution is in any demonstrable way aided or assisted or advanced by further increases in population, locally, nationally, or globally?

Answering Bartlett's question is critical to our future, but is seldom heard in any political discussion. The United States, Canada, and Australia are the only industrialized countries currently showing significant population growth, in all three cases because of exceptionally high immigration levels. The United States alone takes in more immigrants every year, legal and illegal, than all other countries in the world combined. The increase is estimated to be at least one and a half million a year, but with "porous" borders, there is no truly accurate accounting.

The U.S. does not have the resources to sustain its population in its present lifestyle, with a deficit in international balance of payments of more than $600 billion annually. It is true that some of this may be caused by unnecessary consumption, but the largest single item in this deficit is the cost of importing oil. A relatively simple index of a country's physical standard of living is to divide energy use by population. More people use more energy, as well as other resources such as water and soil, in which to grow crops.

Again, the question is whether the United States or any country needs more population. Population growth will require increasing resources to accommodate the increased population. If it cannot do so domestically, it must increase imports of vital materials. How soon the U. S. recognizes this depends on the rate of immigration, and the availability and affordability of imported resources.

If the basic resource needs of a population are not met, either in terms of quantity or cost (for example, enough fuel at affordable cost to keep the populace from freezing in the winter), social unrest could result on an unmanageable scale. The high-density energy forms of oil and natural gas we now use cannot easily be replaced by lower-energy density renewable resources. In some cases there is simply no substitute for oil. It is very doubtful that alternative energy sources can support the United States in the energy "style" to which it is accustomed. Even if that could ultimately be achieved, there will probably be a substantial time gap between the time sufficient alternatives are brought into use and when oil and gas are in short supply. The gap may not be bridged in time to avoid some severe problems.

The matter of declining energy supplies in the face of continuing population growth may seem like an academic discussion, but the time to try to mitigate the problem is now. When serious problems arrive, it will be too late and the adjustments are likely to be chaotic. Like the frog in the kettle slowly coming to a boil, we currently are ignoring an inevitable problem.

Demographic studies show most world population growth will be in developing countries, which, for the most part, are already straining their resources to take care of their present population, even at low standards of living. An increasing number of countries are not meeting their basic needs. With world population growing at the rate of about 80 million a year, the one and a half million or so entering the United States each year is insignificant in terms of alleviating world population pressure, but it does impact the United States. Admittedly, if one is on the other side of the border, the opportunity to improve one's standard of living by moving is a compelling motivation. Having lived, worked, and traveled in many developing countries, I am sympathetic to the desire to do better. But migration cannot be the ultimate solution.

The United States and every country face the same question: "How many people do we want?" More than 30 years ago a presidential commission was appointed to review this question for the United States. It concluded that even with a much smaller U.S. population (a bit more than 200 million, compared to 313 million in 2012), there was no advantage to having a larger population. The report was issued, then promptly forgotten. There is hardly a more fundamental question for any country than the size of its population. There is no indication that it has been seriously addressed in either of our nearest neighbors, Canada and Mexico, or anywhere else except China. Some attention has been directed to population matters in Great Britain, but not equal to the huge looming problem of how more than 62 million Britons, in an area smaller than the State of Oregon, can exist at a decent standard of living when the oil and gas they must increasingly import will be gone. Researcher Andrew Ferguson, of the citizen-sponsored Population Matters (formerly the Optimum Population Trust), based in England, has raised the issue, and examined prospects for alternative energy sources.

There is concern about declining populations in some countries. Japan, with 127 million residents crammed into an area about the size of California (much of which is mountainous and uninhabitable), now advocates population growth; the Japanese are promoting an increased birthrate because they have seen a slight reduction in population. It would seem that a crowded country like Japan with almost no resources of either energy or metals, would welcome a smaller population to make the coming world energy transition less traumatic.

Despite the absence of government leadership, there are a growing number of citizen-sponsored organizations concerned with population growth. In the United States these include Negative Population Growth, Population Environment Balance, World Population Balance, and Population Connection. Australia, a country very divided on the issue of immigration and population growth, has at least one organization — Sustainable Population Australia (SPA) — concerned with optimum population size. SPA's motto is "better, not bigger."

If populations everywhere in the world were matched in size with the resources available to effect a decent standard of living, migration would be minimal. Developed nations could wisely invest a lot of money in family planning aid to achieve such a goal. A fraction of the dollars spent around the world for military uses would be the best money spent, both short term and long term, if used for family planning. Birth control, religion, and racial animosity get all mixed up in the matter of population control. The challenge is huge, but it is imperative to confront it. The alternative is more war and starvation. The population problem is not a technological one but one of educating people worldwide on the relation of population size to standard of living. A few already realize this, especially where it has become tragically obvious. But in most places, it is not a priority. We have made great strides in technology, but we have made little progress on the population issue. It urgently needs to be addressed.

Population is a homegrown problem and can best be solved locally. Borders are important to maintain, but they are porous. Immigration will probably continue until the standard of living around the world generally equalizes. Unfortunately, without a substan-tial reduction in total world population, that standard of living is likely to be considerably lower than the industrialized world now enjoys.

One way or another population growth will end in this century. In my own lifetime, world population more than tripled! No other generation has witnessed such a thing. No other generation is likely to see such a thing again. There is neither land nor energy to triple the population once more, and probably not enough for a doubling. Present trends will have to change, either voluntarily or by natural realities. We have witnessed a remarkable era in human history, dominated by exponential growth in energy use and population, never to be repeated.

Some General Energy Facts

As background for examining future energy options, here are some general considerations. Energy comes in many forms. It has chiefly two sources. The Sun directly or indirectly produces solar energy, coal, oil, natural gas, wind, waves, and hydropower. The other important source of energy is from radioactive materials in the Earth, which includes uranium used in atomic power plants, and uranium and other radioactive materials that provide the heat of the Earth's interior that can be harnessed as geothermal energy. High grades (higher temperatures) of geothermal resources in a few places on the Earth's surface can produce electric power. Lower-grade geothermal resources are more widely available and can be used for space heating and related applications such as fish farming and industrial drying processes. A minor source of energy, tides, is caused by the gravitational effect of the Moon with a minor effect from the Sun.

Takes energy to get energy: the important energy/profit ratio

A very important fact is that it takes energy to obtain energy in usable form. The often referred to "free energy" from the Sun is not truly free (Hayden, 2004). To capture the Sun's energy takes numerous materials such as those used in photovoltaic cells to produce electricity, or in rooftop water heaters to augment space heating. These have to be mined, processed, transported, and manufactured. Every step takes energy.

To dig and transport coal takes energy. To explore for and drill for oil takes energy. These energy costs deducted from the energy produced create the concept of net energy recovery. This is called the energy/profit ratio. Sometimes it is called the EIOER — energy invested on energy returned, or EROEI — energy return on energy invested. All terms describe how much energy goes into producing or capturing an energy source (coal, oil, natural gas, biofuels, uranium, wind, solar) measured against how much useful energy is obtained from the activities. Obviously it is necessary to get slightly more energy out of an energy production system than is put into it or there is no net energy gain.

The energy/profit ratio differs considerably for various energy recovery systems. This concept of net energy recovery is exceedingly important but very often overlooked in common discussions about energy. It should be carefully considered whenever an energy project of any sort is proposed.

How wide the energy cost "circle"?

There is a problem in calculating the net energy recovery of a project. How wide do you draw the energy used "circle" to get the energy end product? Coal is an example. Coal in the western U.S. is mostly strip mined, so it is clear that stripping the overburden is an energy cost. The energy used to mine, load, and transport the coal to wherever it is going to be used is an energy cost. These are clear-cut energy costs. But do you include the energy cost of producing the machinery used to mine the coal? The machinery is made of various metals, mostly steel. That steel is made from iron probably mined in Minnesota, then transported by rail to Lake Superior where it is put on a freighter also made of steel and moved by energy (now a diesel powered ship) to the place the iron ore is smelted by using coal, which had to be mined, and with quarried limestone (takes energy to quarry) added for the flux. Some minor metals such as molybdenum also had to be mined, processed and transported to be added to iron to make the steel. This in turn had to be processed in various ways taking energy to finally make it into the machine that mines the coal we started with in this discussion. And then, of course, the machine had to be transported to where it will be used to mine the coal. The same can be said about the equipment that mined the iron ore and the ores of the minor metals used in steel making. All these processes use energy.

This illustrates how wide one might draw the circle to include the total energy cost of mining coal and bringing it to the place where it is finally burned. To compute the true energy cost of all that went into getting that coal is obviously a very complex problem. Some people say that just the energy cost of mining the coal should be included and not everything else. But if so, to what do we charge all the other energy costs to calculate the true energy cost of mining the coal? The point is that when everything is added up, there has to be a net energy profit to our energy capture operations, and this must be considered for any energy source we use. At present, the energy cost of obtaining various types of energy supplies differ widely.

More energy to get less

We are experiencing an unpleasant evolution in net energy recoveries, and the energy needed to produce non-energy materials. We have taken the easiest energy supplies first. Oil is a good example. Initially oil was drilled and produced onshore by shallow low-cost wells. Now a great deal of oil exploration has moved offshore into waters as deep as 10,000 feet. To do this takes more and more equipment and more and more energy to drill in deeper water to reach oil beneath the ocean floor. In some cases 30,000 feet or more of drill pipe is needed to reach the objective.

Other problems arise with oil. In general the oil we now recover is lower grade than previously. It takes more energy to refine the same high quality end product from lower-grade oil than higher-grade oil. Recovering oil from the Athabasca oil sands of Canada, for example, and then upgrading it to a product equal to what we can recover from conventional oil wells takes considerably more energy.

Second law of thermodynamics not subject to repeal

Another important fact about energy is that if energy is transferred from one form to another, a law of physics comes into play — the Second Law of Thermodynamics. It's a law even congress cannot repeal. One part of this law says that each time you change energy from one form to another, it cannot be done with 100 percent efficiency. Some energy is lost. We will see this in the production of hydrogen as the "hydrogen economy" is pursued. Hydrogen cannot be drilled for or mined as there is no uncombined hydrogen. Most of the world's hydrogen is locked up with oxygen in water. Hydrogen can be produced by the electrolysis of water, which requires electrical energy, but the energy recovered from the hydrogen is less than the amount of energy used to produce it from water. The production of hydrogen is a net energy loss. This is very different from the current production of oil, which has a fairly large net energy recovery, or energy/profit ratio. Natural gas production also has a relatively high energy/profit ratio. This has implications for the economics of the anticipated "hydrogen economy" that has been proposed to replace our oil economy in transport fuel.

Another example of the loss of energy in transition from one form to another is a coal-fired electric power generating plant. At best, a plant can achieve about 40 percent efficiency in converting coal energy to electric power. A combined cycle gas-fired turbine electric power plant can achieve about 55 percent efficiency. Fuel cells use hydrogen to produce electricity and can be up to 70 percent efficient. Recall that it takes more energy to produce the hydrogen than is available from the hydrogen. So using electricity to produce hydrogen from water and then using the hydrogen to fuel a fuel cell to produce electricity involves two energy form transitions involving a loss of energy.

A widely read financial newsletter dealing with energy reported that an energy system (in which you could immediately invest) would return 70 times the amount of energy put into the system. A physicist friend and I both wrote the editor to ask for specific proof. If what he wrote were true, we would have achieved the energy goal of the ages — perpetual motion. We have yet to receive a reply. But I have since obtained some energy by converting the newsletter to Btu units in my office fireplace one cool morning.

Entropy

This is a word one doesn't hear often, but we are all involved with it personally every day just by existing. A definition given by *Webster's Ninth New Collegiate Dictionary* is that entropy is "the degradation of matter and energy in the universe to an ultimate state of inert uniformity." To live we eat, and the food we eat is high-grade, low-entropy energy which goes into our system and is used by our body to keep things going. In the process, the high-grade energy (food) is degraded and dispersed into materials that have very little energy. We need about 2000 calories a day to stay alive and moving. If we did not have high-grade concentrated food energy to eat, our systems would gradually disintegrate.

In an interesting article in the British newspaper *The Guardian*, George Monbiot (2004), explains the problem:

> To understand what is going to happen, we must first grasp the core fact of existence. Life is a struggle against entropy. Entropy can be roughly defined as the dispersal of energy. As soon as a system — whether an organism or an economy — runs out of energy, it starts to disintegrate. Its survival depends on seizing new sources of fuel.
>
> They [our economies] evolved in the presence of a source of energy which was both cheap to extract and cheap to use. There is, as yet, no substitute for it. Everything else is either more expensive or harder to use. Without cheap oil the economy would succumb to entropy.

Monbiot goes on to note that getting oil from oil sands or from oil shale has a much lower energy/profit ratio than getting oil from wells, and this will be more costly energy. He suggests the higher costs of energy we are already beginning to encounter has a disintegrating effect on enterprises. Case in point: the struggle airlines are experiencing to survive against rising fuel costs. He concludes that as we deal with lower and lower grade sources of energy, our complex industries will be harder to sustain. It is a thought to consider as we examine current and future energy options in succeeding chapters. For a thought-provoking view of the future of population, energy, and our industrial civilization in this century, readers are encouraged to read the already cited Richard Duncan (2001), who suggests a time limit (to 2030) for the industrial economy we now have. The Industrial Revolution had a beginning. Will it have an end? Duncan presents a timeframe that you may not agree with, but the possibility cannot be summarily dismissed.

We have been living in a high-energy use age. People in some parts of the world still have nothing more than themselves and perhaps a donkey to provide the energy for their standard of living.

It is sometimes said that as we become more efficient in using energy, we will not have an energy problem. Although energy use per capita is declining, we still use more and more energy. Population growth is the culprit, and until population growth ends, we cannot solve the energy problem.

Energy in a changing spectrum

Since the Industrial Revolution, the energy mix has been changing. Wood was the dominant world fuel in 1800. In the United States, coal was the dominant fuel in 1900, and in 2000, the dominant fuel was petroleum — oil and natural gas. Nuclear power, although out of favor in the United States and much of Europe, is growing in Asia with at least 27 plants now under construction.

Table 8-3 shows the current sources of energy used in the United States.

For the past two centuries, we have experienced a continuing change in energy sources. In his book, *Energy at the Crossroads*, Smil (2003) makes the point that we are at an important energy decision point. The difference between now and before is that now the stakes are so much higher in terms of population size and in terms of the huge and growing quantities of energy needed to run our international industrial complex. Gasoline and diesel have fueled the machinery through which millions of acres have been put into cultivation. Pesticides and fertilizer derived from petroleum have greatly increased crop yield per acre. Unfortunately, there appears to be no adequate substitute for petroleum in the field of agriculture on the scale in which it is now used. Can the eight or nine billion or more people expected by 2050 be properly fed when oil and gas production may be down more than 60 percent (Duncan and Youngquist, 1999)?

Table 8-3. U.S. Energy Mix 2011

Energy	Percent of Total
Oil	39.45
Natural Gas	29.90
Coal	22.80
Nuclear	8.27
Biomass (wood and other)	2.90
Hydro	2.75
Geothermal	0.34
Wind	0.11
Direct Solar	0.078

Source: U.S. Department of Energy, Energy Information Agency

All industrial nations and developing countries that aspire to a better life are in competition for energy. The future course of civilization is at stake. Population giants India and China, with one third of the world's population, have joined the race.

The United States, with about four percent of the world's population, uses about 25 percent of the world's energy, and 43 percent of the world's gasoline. The U.S. is now urgently trying to determine what energy road to take. Domestic oil production peaked more than 40 years ago. Foreign sources are uncertain due to political and social instability. Even Russia with large oil deposits, the world's largest natural gas deposits, and large coal and uranium deposits, is trying to determine which energy policies to pursue.

Twenty-first century — Reality check on population and energy

Fossil fuels powered the great industrial and population expansion of late nineteenth and entire twentieth centuries. But they are unlikely to see us through to the end of this century as we now use these fuels. How long will fossil fuels last? Then what? Population growth and declining energy sources will collide this century. Sunlight and wind are a far cry from the high energy density, easily transportable and widely used energy in the form of oil, natural gas, and coal. The challenge is to transform to a society of sustainable size at an acceptable standard of living in the new energy paradigm and do it in an orderly fashion.

Most people living today depending on their age will see the beginning and a substantial part of this critical transition. The ultimate resolution will determine the course of humanity. Present trends have to change — they will change. Population size is the principal variable.

Solving The Energy Problem?

Always playing "catch-up"

The energy problem can never be solved as long as we face a moving target — population growth. If population continues to grow, we will always be playing "catch-up" and the problem will never be solved. In his classic work *Living Within Limits*, Hardin (1993) titles one section: "Human Population: Growth Outruns Solutions." Even transition to renewables does not solve the problem because wind and solar energy, although renewable, can provide only so much energy at any given time (Hayden, 2004). Will the problem be solved rationally or will it precipitate chaos? (Kaplan, 2000).

The NIMBY (Not in My Backyard) factor

It is increasingly difficult to find a place to put a power plant. In the U. S. there is hardly an acceptable site left because of population density. The NIMBY factor is very strong. Even small gas-fired turbine plant developments encounter opposition. Power plant siting is an especially acute problem in California, where 38 million people reside and millions more are expected in the next decade. Californians need more power, but many of them oppose building any power plants, and their "backyards" increasingly cover the landscape. An interesting example of the NIMBY factor is a recent conflict involving power needs for the State of Massachusetts. A prime location for windmills to generate power is Nantucket Sound off the south shore of Cape Cod. The community of Hyannis Port is on the near shore near the site of the Kennedy Compound. The late U.S. Senator Edward Kennedy strongly opposed this development saying it would mar the view. But windmills are a "green" energy source advocated by many environmental groups. One such group is the Natural Resources Defense Council for which Senator Kennedy's nephew, Robert F. Kennedy, Jr. serves as the chief legal counsel. This group endorses "green energy," especially windmills. Windmills are a fine idea, but apparently not in Kennedy's (in this case) front yard.

With 313 million Americans, finding a place to put a power plant that is not in some-body's backyard is difficult and such developments are opposed almost everywhere. The conflict has reached the point of being described as one stage beyond NIMBY called BANANA — build absolutely nothing anywhere near anything.

Population and adequate energy supplies are all one problem. Politicians propose all sorts of energy solutions at election time, but dare not touch the sensitive problem of population growth. Ignoring it does not make it go away. As energy demands from population growth rise, the problem becomes ever more acute.

Population growth and the future

As population grows and our nonrenewable energy supplies fail to meet the demands of our industrialized society, development of alternative renewable energy sources to address the realities of post-petroleum demands will be urgent. We are now out on a non-renewable energy resource limb, which is slowly being sawed off. The safety net below is the mix of energy alternatives. Is that net big enough and dependable enough to hold the population that will exist when the nonrenewable limb is fully sawed off? We will learn the answer in this century. A smaller population would make the transition to a renewable sustainable economy much easier. Any serious discussion of energy must be framed in the context of population size. This rarely happens now. Trainer (2005) is one who has given it serious study.

Somewhat surprisingly, at least one government agency has recognized the population factor relative to energy. In discussing electric power supplies, Bonneville Power Administration, the government marketing agency for the power generated by federal dams on the Columbia River system, stated in 2002 that due to population growth in the Pacific Northwest, there was no surplus power available to send to California. This government agency action is the beginning of future realities. As Garrett Hardin would say, it is not a problem of energy shortage, but of population "longage."

Earth resources still the control

With both nonrenewable and renewable energy sources, we are still bound by the limi-tations of Earth resources that control human destiny. It is easy to see that nonrenewables, the fossil fuels, and uranium are limited. When renewables inevitably have to take over, the materials to build equipment to capture renewable energies such as wind and solar still must come from the Earth. The current enthusiasm and move toward biofuels is based totally on one of the most vital of Earth resources — soil. Fertile soil is nonrenewable in the frame of human lifetimes, and unfortunately it is now being depleted faster than it can be generated by nature. Renewables do not make us independent of Earth's control over our destiny.

Destabilizing effects from population growth

In many places, population growth facing limited energy resources creates a destabilizing influence. In the United States, the ever-increasing cost and difficulties of importing more and more oil and gas are causing some industries to close or move abroad with the attendant loss of domestic jobs. So while U.S. population grows, the decline in availability of some natural resources is already causing job loss.

In other places, particularly in Africa, the loss of soil, degradation of soil fertility, and increased demands on limited water supplies are critical factors in political instability as growing populations press ever harder on the resource base. These problems have even resulted in genocide.

It is a simple tradeoff. With the world "full house" as Lester Brown writes, the more people, the lower the standard of living. This tradeoff will become ever more apparent even in developed countries like the United States. Madden, writing for the National Planning Association in 1972, states:

> There is no unique, optimal long term population. Rather, there is an entire set of tradeoffs between personal freedom, material and social standards of living, and the population level. Given the Earth's finite and diminishing stock of resources, we are inevitably compelled to recognize that more people mean a lower standard of living…there is a strong probability that the transition to global equilibrium between population growth, pollution, food production, natural resource depletion and economic development — will involve a traumatic decline in population.

The relationships between energy supplies, population size, and the quality of life should be given much more attention than they now receive. Ignoring the population growth issue will simply make the effects worse — more traffic jams, crowded parks, higher light, water and gasoline bills, and overwhelmed and poorer quality healthcare facilities. Some of these problems are already appearing.

The choice is between more population or trying to maintain the existing standard of living. Even if populations are stabilized, the continued decline of nonrenewable resources will almost certainly result in a decline of living standards. A renewable resource economy is very unlikely to support the present population, much less the increase projected at today's standard of living (Trainer, 2005).

The Population Reference Bureau projects nearly a 50 percent increase in world population in the next fifty years. This projected increase in global population over the next fifty years is a nightmare. It is equivalent to the entire population of the Earth in 1960.

There is an optimistic prediction that world population will level off at about 9 billion people in 2050. The idea that population growth will eventually cease is a comforting thought, but even this prediction is not cheerful. By 2050, oil and natural gas production will be less than what it is today and current trends in the development of alternative renewable energy supplies clearly indicate they cannot fill the gap attributable to the decline of oil and gas by 2050. Even now, with world oil production near or perhaps beyond its peak, more than half the world does not enjoy a standard of living very much above a subsistence level.

Twentieth century U.S. resource abundance

Twentieth century U.S. industry and population grew as abundant oil and gas, and coal resources were discovered. Huge groundwater reservoirs like the Ogallala Aquifer beneath the Great Plains and the Dakota Sandstone artesian system were also developed, but today are substantially depleted. Vast areas of prairie sod felt the plow for the first time. My father told of walking behind a plow and an ox turning up the virgin soil and occasionally finding arrowheads.

Twenty-first century: dividing less and less by more and more

This century will be the twentieth century in reverse. We will have more and more people to divide up less and less oil, gas, coal, diminishing groundwater resources, and less and less of that very basic material, soil. Looking forward to "more and more" of everything, as we did especially in North America, in the twentieth century, was a pleasant time. As we begin the reverse, there will be increasing social strains as fuel costs increase and food costs rise, and as land and housing become even more expensive.

The thin veneer we call civilization may begin to wear dangerously even thinner. Only when overcrowding becomes apparent to the general public, will serious concern about population growth and how to stop it emerge. That concern is long overdue. Hardin (1993) wrote: "Accepting the fact that the world available to human beings is a limited one will be one of the most difficult tasks ever tackled by our species. The immediate costs will be high; the ultimate reward will be survival."

Pimentel and Wilson (2004) summarize the present condition of the very fundamentals of civilization — food, water, and arable land:

> Increases in food production, per hectare of land, have not kept pace with increases in population, and the planet has virtually no more arable land or freshwater to spare. As a result, per capita cropland has fallen by more than half since 1960, and per capita production of grains, the basic food, has been falling worldwide for 20 years.

Living within limits and maintaining what we have

Around the world, we must live within Earth's limits. Stabilization and then reduction of population must occur if any reasonable standard of living is to be preserved. There will not be the resources to continue the international welfare that now support already distressed countries. With more countries needing more aid soon, this is an especially serious concern. Wealthier nations will be increasingly concerned with the cost of preserving their own infrastructure, and will have financial resources to send abroad.

The most recent engineering study in the United States on the cost of bringing the aging and deteriorating infrastructure of roads, bridges, schools, other public and private buildings, and various facilities up to satisfactory standards was $1.3 trillion. Expanding the infrastructure to keep up with a growing population will require substantial additional investment.

It is likely that more countries will turn inward to take care of domestic problems exacerbated by population growth and the rising cost of material resources. We are a "full house" and are using Earth's bounty at an unsustainable rate.

Ethics and aid

Another aspect of the recent rapid growth in population is the international responsibility countries share for the welfare of one another. "I am my brother's keeper" is an honored altruistic ethic. In earlier times, before we had a globalized economy and populations were much smaller, the matter of international (foreign) aid was not significant. But today's huge population increases in the context of deteriorating environment together with the worldwide visual display of humanity's problems, makes the question of aid a conflict between compassion and reality. Scenes of starving bodies, especially children on TV, are heart-rending. The immediate humanitarian impulse is to send food to the places stricken by flood and drought. But the reality is that this only compounds the problem. If a drought or a flood devastating a region was a one-time event, sending food and other relief would make sense. The problem would be solved. But the hard fact is that ~~by~~ preserving the population to continue to multiply only ensures that a recurrence of the disaster will affect even more people. Hardin (1996) suggests that aid can be counterproductive, and gives an example:

> Twenty-five years ago western countries brought food and medicine to Nepal. In the summer of 1974 a disastrous flood struck Bangladesh, killing tens of thousands of people. Was there any connection between feeding Nepal and flooding Bangladesh? Indeed there was.
>
> Nepal nestles amongst the Himalayas. Much of the land is precipitous, and winters are cold. The Nepalese need fuel, which they get from trees. Because more Nepalese are being kept alive now, the demand for timber is escalating. As trees are cut down, the soil under them is washed down the slopes into the rivers that run through India and Bangladesh. Once the absorption capacity of the soil is gone, floods rise faster and to higher maxima. The flood of 1974 covered two-thirds of Bangladesh, twice the area of the 'normal' floods, which themselves are the consequence of deforestation in preceding centuries.
>
> By bringing food and medicine to Nepal we intended only to save lives, but we can never do merely one thing, and the Nepalese lives we saved created a Nepalese energy-famine. The lives we saved from starvation in Nepal a quarter of a century ago we paid for in our time by lives lost to flooding and its attendant evils in Bangladesh.

I knew Garrett Hardin well. He was a gentle, sympathetic man. But, as a biologist, he also recognized the realities of the situation, pointing out that bringing food aid to countries already living beyond their environmental limits only compounds the difficulties, causing greater numbers of people to suffer in the future. That sort of aid does not attack the root cause of the problem. Countries supplying aid to impoverished areas should also support family planning for population reduction in those areas. The world, including the industrialized countries, has already overshot the environmental carrying capacity of the Earth on a sustainable renewable resource base. The United States, seen as a world leader in many respects, ought to set an example of matching population to its resources. But, more and more, it is living on imports.

"People never die of overpopulation"

Hardin observed that it is never said that people die of overpopulation. They die of floods, famine, typhoons, landslides, and other disasters. Bangladesh has an area of 55,126 square miles, about 1,100 square miles smaller than the State of Iowa. Yet, 151 million people now live in this area! Imagine 151 million people living in Iowa with a substantial part of the state consisting of a marshy deltaic area only a few feet above sea level. At times, typhoons from the Indian Ocean sweep in and flood the Bangladesh lowlands killing thousands of people. At other times, floods from the Ganges and Brahmaputra rivers, whose headwaters lie in the once heavily forested areas of the southern Himalayas, inundate the extensive lowlands. Stripping these headwater areas of vegetation to use for fuel caused by the overpopulation of the region, further compounds the problem, increasing the rate of runoff from the barren slopes.

Bangladesh suffered disastrous floods just a few years ago. School children standing outside grocery stores in Eugene, Oregon, where I live, put up tables and signs to collect contributions to send food to Bangladesh. How could I resist the pleas of our own children for the children of Bangladesh? But they were treating the symptoms of the problem and not the cause — overpopulation — and helping to ensure there would be more people next time to drown or be displaced by floods. I contributed anyway. The happy smile from the child who held up the contribution can as she thought of how this would help a child in Bangladesh was my reward. But I knew the futility of the situation. And it still bothers me. Overpopulation does indeed kill people. Those who are here, we should surely help. But continuing to multiply our kind invites disaster.

Haiti

Haiti is a country of 10,500 square miles inhabited by more than ten million people. It is projected to have 11.5 million people by 2025 and 14.3 million by 2050 (Population Reference Bureau, 2010). Haiti has no oil, natural gas, coal, or significant water power. Much of it is mountainous. To obtain fuel, the country has been almost entirely deforested. Roots of trees have been dug out to make charcoal. It experienced devastating heavy rains in 2004. I visited Haiti and observed the worst erosion I have seen anywhere during my travels in more than 70 countries.

In the 2004 rains, bare hillsides became huge debris flows. Several thousand people were killed, and thousands more were injured and left homeless. U.S. and French troops were sent in to keep order and provide help. In recent years, the United States has sent several billion dollars in aid. Additional funds were sent following this disaster to provide the basics of existence. Some of that money would have been better spent providing family planning education, and supplies to stop larger numbers of Haitians from suffering more casualties from floods of the future.

Haiti has been dependent on international welfare for many years. Given present trends, there is no apparent escape. The question arises as to how much longer such welfare can be provided, and who will provide it? The rest of the world cannot support Haiti indefinitely. Population problems are homegrown and ultimately must be solved there. In the meantime, when the next heavy rains come, more people will die from debris floods caused by the deforested hills. Clearly, overpopulation resulting in the destruction of the environment kills people.

The violent earthquake that struck Haiti in January 2010 should have brought the issue of overpopulation into clear focus. But in all the reports of the disaster, few mentioned that overpopulation greatly compounded every food, water supply, and medical problem. The media and most politicians find population issues taboo, although in Haiti and elsewhere, the problem is obvious. Without significant population control, Haiti will remain a struggling and impoverished nation.

Degree of vulnerability to the environment

Dense populations make the local inhabitants more vulnerable to the vicissitudes of the environment, torrential rains and landslides, earthquakes, and tidal waves. In every region there are minor fluctuations in rainfall amounts. If there are no long-term food storage facilities, then the annual rains are particularly important in regions with subsis-tence economies. Lamb (2005) notes: “ …man’s vulnerability to climatic fluctuations is bound up with, and intensified by the population explosion…this is now seen in particularly stark form in the drought-prone areas of East Africa."

In 2012, the United Nations warned that at least 13 million people in East Africa were in danger of starvation due to the failure of seasonal rains. Other nations were asked to send food to minimize starvation. But this is no solution. It simply becomes an endless cycle. Climate and its immediate manifestation called weather will continue to fluctuate. Until populations are reduced to comply with Lieberg's Law — adjust demand to the minimal survival conditions — populations will continue to starve.

With stable population at a much lower size, vulnerability to environmental changes would be reduced. Modest relief efforts could be more easily accomplished. At the same time, overpopulation's impact on the environment would be reduced and the environment could begin to heal, although in some regions this would take many decades. Nevertheless, it could be done. So there is hope if people make the decision to match population size to the minimum sustainable carrying capacity of the land. This applies worldwide, not just to the places where environmental degradation is obvious. The Earth can be preserved and restored if logic and resolve are applied. Given a chance, nature has enormous capacity to heal itself. But growing population pressures will not allow it to do so.

The United States?

Can people die of overpopulation in the United States? Today, California has 38 million people. Finding places to put them is a challenge as anyone traveling through California can observe by seeing the houses perched on steep hillsides, in narrow canyons subject to crumbling masses of rock debris, and on precarious sites facing the ocean where property commands a premium price. Multimillion dollar houses came crashing down in the heavy rains of 2004-2005. Increasing population puts more and more people in peril. Much homebuilding in recent decades has also occurred in scrub and chaparral habitats that are naturally and regularly swept by wildfires, inevitably placing the homes and their owners in harm's way. The wildfires that raged across San Diego County in 2007 burned half a million acres, destroyed at least 1,500 homes, killed nine people, injured 85, and forced one million residents to evacuate their homes, the largest such evacuation in California's history.

It has been California real estate agents' proud claim that "real estate is really moving" in the Golden State. That was certainly true in the real estate frenzy of the first half of the first decade of this century. Increasingly some of that movement was downhill, and some of that "moving real estate" killed people. After extensive forest fires in previous years, in 2003 and 2004, barren hillsides gave way during heavy rains. Dozens of people were killed and numerous homes and roads were destroyed. California expects to have 20 million more people by 2040. Where can 20 million more people be put in relatively safe environments where overpopulation will not kill people? The world over, increasing population is forcing more and more people to live in harm's way.

Self-sufficiency

As energy production and agricultural production becomes more regionally restricted, countries will increasingly have to depend on the resources they have within their borders. International transportation and sale of both oil and gas as we now know it will not exist. Population size will have to match available resources, local and regional, and will not be able to rely on other sources worldwide. When economies become more localized, the critical importance of matching population size to resources will become apparent. A lack of resources will not then be easily mitigated by imports. Lifestyles and existence itself will have to match the environment on a locally sustainable basis. In his monumental study of past civilizations in his book *Collapse, How Societies Choose to Fail or Succeed,* Diamond (2005) cites among other examples, the demise of the Mayan civilization. He notes that "one strand [cause] consisted of population growth outstripping available resources: a dilemma similar to the one foreseen by Malthus in 1798 and being played out today in Rwanda, Haiti, and elsewhere."

When we have transitioned to a renewable resource base, we will become aware that "renewable" cannot be equated with "unlimited." Crops are renewable, but they are not unlimited. Each year's production is only so much. The physical standard of living of a country or a region becomes a simple calculation of resources divided by population. The larger the population, the smaller the share, meaning the lower the standard of living. To a degree, the world is in that situation now, and only relatively cheap transport of energy supplies and agricultural products helps to even out natural differences. This prevents us from recognizing the problem. What would the U.S. standard of living be if it were not for the importation of oil? Or what about Japan, which has to import nearly all of its energy and minerals, and 70 percent of its food supplies? As nonrenewable resources become depleted, and unavailable for worldwide export, as they are now, the reality that each nation has to depend on itself will be more evident. International welfare will not continue indefinitely. Even now, the international welfare "bank" is being strained with only a few donor countries to support it. Surplus grain production is at the lowest level it has been in modern times.

It is unsettling to know that the United States is also beginning to experience the same problem. In a sense the United States is already on international welfare. The world loans the United States nearly two billion dollars a day to support its lifestyle. How long will that international goodwill continue? The U.S. has the third largest population in the world. "But because of its combination of huge population size and profligate per capita consumption puts enormous stress on the Earth's life support systems, it is fair to say that the United States is the most overpopulated country on the planet" (Ehrlich and Ehrlich, 2004). U.S. per capita energy and resource consumption in general is 30 times that of many undeveloped areas. The present situation of living on "imported affluence" is not sustainable. A few economists have pointed this out, but so far, policy makers seem unconcerned. It is not a topic likely to win votes.

Yet the United States must begin to think about living within its own resource limits. Its constantly rising population compounds the problem. Sharp cost increases for both oil and food over the past several years have created a socio-economic problem. Lower income consumers are unable to meet the basic costs of transportation and keep warm in the colder months. As the population grows and fuel costs increase, this problem grows. In 2004, more than 100,000 Colorado residents required emergency assistance with their home heating bills. Such public assistance is provided by both state and federal agencies. For that year, the federal aid for home heating cost was budgeted at $600 million, but proved to be insufficient. To fill this gap, which has been growing for several years, many utilities now ask their other customers to make some additional "payment" each month. An Indiana utility simply adds a percentage of each customer's bill to the total bill to help pay for those who cannot pay the bills themselves. More and more energy supplies to meet these growing demands have to be imported.

Subsidizing basic needs is undoubtedly a good cause. But realistically, as population increases, fuel costs rise, and more and more people cannot pay to keep warm, ever greater numbers will have to depend on the charity of others. There is a limit. In my native Min-nesota and across the northern tier of states, winter can mean "fatal cold." I have experienced -43° F. Heating homes is critical.

Alternative energy sources not easily transported

Petroleum can be readily transported, but many alternative energy sources cannot. Electricity is a valuable end product. However, hydrogen produced from water by electricity cannot be shipped half way around the world like oil is today. Alternative energy sources in the future will inevitably be far more regional than in our present global energy economy.

The potential of alternative energy sources including their transportability is the subject of Chapters 11 and 12. As we move through the brief nonrenewable hydrocarbon (oil, gas, coal) bubble, which now provides more than 86 percent of the world's energy, more people will change essential aspects of their lifestyle than ever before.

Beware of what you hope for

As we search for alternative energy sources, the apparent goal of some is to discover an infinite supply of renewable energy presumably to support continued growth. If that were to occur, eventually our entire ecosystem would be destroyed and we would not survive, because every human has an impact on the environment. Unlimited energy supplies would invite disaster. The environmental organization Population Environment Balance says our goal should be to balance the size of our population with what the environment can produce on a sustainable renewable basis, with a reasonable standard of living for all.

It is highly probable that alternative renewable energy sources cannot support the huge and growing population we have today. Lack of energy to continue our current headlong growth may be a blessing in disguise as it may act as a natural curb to population growth and the present onslaught on the environment.

A wealth of literature

Fortunately, it appears the public is becoming increasingly aware of the problem of producing enough energy to keep up with population growth. A number of studies and a wealth of literature on these vital topics is widely available.

A scant few of the multitude of such references are cited in the Bibliography. Some have been drawn on for general background without specific citation. The most recent and comprehensive energy study is Cleveland (2004) *Encyclopedia of Energy* in six volumes. There are now numerous volumes on various aspects of energy and population readily available in libraries and bookstores. More appear almost daily. An outstanding book on population is *The Rapid Growth of Human Populations 1750-2000* (Staton, 2003).He minces no words about our present and coming population problems.

This is the century of decision

Energy (including food) and population growth, with their related impact on the environment, are our primary concerns for the future. By the end of this century, these matters will be largely resolved, one way or another. And with the transition from our fabulous inheritance of fossil fuels and the profligate spending of our natural environmental capital, by the end of this century we will have established the framework of existence for all future generations. As Grant (2005) predicts, by then the fossil fuel bubble will have collapsed and renewable energy sources will be those on which the world will have to depend for all time to come. A statement Grant made earlier is an appropriate summary of this point:

> The debate has been cast in the wrong terms. The problem cannot be solved if we keep asking: 'What energy sources will be available to replace fossil fuels?' We should instead ask: 'What populations can be supported at a decent standard of living by the energy sources that will be available after the transition from fossil fuels?' There are such sources, but they won't be like the profligate fossil fuel era (Grant, 2004).

Electricity — the secondary but vital energy source

We have not yet touched on electricity in this energy discussion. Electricity, of course, is not a primary source of energy. It must be produced by other energy.

But, as Richard Duncan, a Ph.D. in electrical engineering, has pointed out to me, in our modern world, electricity is perhaps the most critical form of energy. It is the energy most of us use every day. We turn on the light when we get up in the morning; keep things cool in the refrigerator 24 hours a day; keep in touch with the world by telephone, television, and innumerable portable electronics; run our office machines; do the laundry; heat and cool our buildings; and enhance our lives in myriad ways. When blackouts occur, virtually everything stops immediately. Lights go out, water pumps don't run, elevators stop, communications stop, all our varied modern industries stop. This is only a partial list of all that makes civilization modern. Electricity can be produced by a variety of energy sources, but nothing can replace electricity. The use of electricity, which was not available just 200 years ago, is perhaps the hallmark energy of our civilization. Even after oil, natural gas, and coal are gone, we will probably still produce electricity by some means, but probably a lot less of it.

Table 8-4. Energy Sources for U.S. Electricity Production 2010

Energy	Percent of Total
Coal	50.30
Nuclear	20.37
Natural Gas	17.91
Hydro	6.88
Oil	2.35
Wood	0.95
Wind	0.95
Organic Waste	0.60
Geothermal	0.35
Solarvoltaics and solar-thermal electric	0.01

Source: U.S. Department of Energy, Energy Information Agency

Conclusions

Energy in the form of food is essential to life. Beyond that, how much energy we indi-vidually command either directly or indirectly determines our standard of living above the level of bare subsistence. Renewable energy is mostly energy "at the moment." At any given moment, there is just so much solar, tidal, wind, or other renewing sources of energy available to support the population. And there is no fossil fuel energy bank account to continue to draw on as we have done up to now. Energy supplies are also not distributed conveniently into all geographic areas, which accounts in part for the wide variations in standards of living around the world. Infinite energy supplies are not desirable if they encourage the population to grow beyond the environmental carrying capacity of the Earth. Having an infinite supply of energy would be the ultimate disaster for the human species.

Population, the variable factor in the future

When civilization has passed the hydrocarbon fuels era and has to depend on renewable energy resources, it will be limited by how much energy can be captured in usable form each day, and the amount technology, yet largely undeveloped, can enable it to store for a time. The amount will be relatively fixed. Therefore, the variable in this equation is the size of population. Population size will clearly determine standard of living when energy resources are more geographically limited. Making the transition to renewable energy resources is only half the problem. The other half is reducing population size to fit the new energy paradigm. Clearly, a smaller population is necessary in the future to insure a reasonable standard of living for all (Trainer, 2005).

Population, the ultimate problem

Fossil hydrocarbons in significant amounts will be gone well before the end of this century, but people will still be here. How many people there are will determine what sort of existence humanity enjoys. Today there are minor sporadic attempts to control population growth, but the three largest countries, China, India, and the United States, continue to grow. Against the background of declining soil, water, and the fossil energy supplies, population growth is both a short- and long-term problem. Yet, often the problem is frequently not even recognized. I have examined more than a hundred studies on future energy topics. Nearly all of them fail to consider population. A Danish environmental optimist, Bjorn Lomborg, edited a 648-page monograph entitled *Global Crises, Global Solutions* (2004), published by Cambridge University Press. It includes sections on Sanitation and Access to Clean Water; Migration; Malnutrition and Hunger; and others, but there is no section on population or population growth, the basic underlying cause of most of the "crises" the book cites.

By 2050, India is projected to have 1.7 billion people; China, 1.3 billion; and the United States, 439 million. Sub-Saharan Africa's population will at least double. Ethiopia, which already subsists on international aid, is projected to grow from 87 million to 174 million. It is very doubtful that these projected population sizes can be reached with an acceptable standard of living, or even to avoid starvation. If, as seems likely, by 2050 there are no food surpluses to export to Ethiopia and the growing number of other countries now seeking international aid, they will face starvation. The high consumption lifestyle of the industrialized countries, especially the United States, will be a thing of the past.

Family planning aid and worldwide equality for women should replace bombs and bullets as national and international priorities. By 2050, population problems will be front-page news. Earth's resources and the energy from the Sun are the ultimate popula-tion limiting factors. As early as 1983, the Worldwatch Institute studied the inevitable depletion of fossil fuels in a 431-page volume entitled *Renewable Energy* (Deudney and Flavin, 1983). Among other things, the Institute concluded that the challenge of relying on renewable energy supplies is daunting and population size would be a critical factor in what could be achieved.

Bumper stickers sometimes express great truth. Example: *Continued population growth = permanent energy crisis*. Competition for energy supplies to support our relatively high standard of living will increase. In 2050, gasoline may cost $6 (or more) a gallon in today's dollars. And gasoline may have to be rationed, as alternatives are still not likely to totally replace it. As a citizen waits in long lines at the service station with the U.S. population then at 439 million and world oil production less than half that of today's, the connection between population demand and scarce energy will be very apparent. Energy costs will surely consume an increasing percentage of our daily incomes. Competition for many basic elements of survival, especially food, will increase, hopefully in a civil, not violent manner. Human relationships are likely to be under increasing stress as the world becomes ever more crowded.

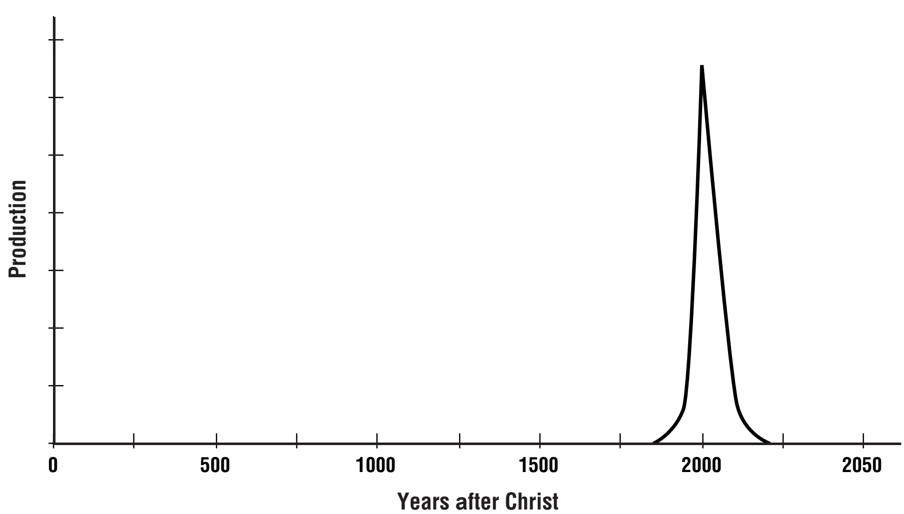
Up to now, human societies have often made local important decisions when their situation became critical. The energy/population problem, for the first time is global. At best, it will take the world many decades to transition to a new resource paradigm.

CHAPTER 9

The Oil Interval

THE TERM "INTERVAL" is intentionally used here in place of "era" or some other longer time term because the time of significant production and use of oil will be but a brief, bright blip in human history, never to be repeated (Figure 9-1). During this time, oil has rapidly changed the world in myriad ways never even faintly imagined by the few gathered around the Drake well near Titusville in northwestern Pennsylvania in 1859 who saw the liquid found by drilling to 59 1/2 feet.

Figure 9-1. The Oil Interval — A Brief Bright "Blip" in Human History



Source: Campbell, 2005a

Long before the Drake well, oil was known in many regions, most notably the Baku region of the Black Sea. Much earlier, Egyptians used oil to embalm their dead, and it is likely that the basket floating the baby Moses on the Nile was caulked with asphalt, used even then as a building material.

Since its inception, the oil industry has grown into a complex, constantly changing enterprise, essential to the industrial activities of nearly all economies, and greatly influencing the daily lives of many people. It fuels all air transport and nearly all ground and sea transport. The industry also provides chemicals, building materials, medicines, fertilizers, and countless other products.

Beginnings of modern oil industry

The beginning of the modern oil industry is generally identified with Drake's discovery that oil could be obtained by drilling. The technique soon expanded to other areas of the United States and then abroad. Oil exploration was greatly enhanced by technology, notably by the use of the reflection seismograph invented in the United States in 1921. Oil has been discovered in more than 80 countries, but only a few countries have significant deposits.

The historical growth of world oil production is shown in Table 9-1.

Table 9-1. Historical Growth of World Oil Production (Thousands of barrels/day)

Year	Production[1]
1859	Total year production approx. 7,000 bbls
1889	168
1919	1,523
1949	9,326
1970	46,808
1975	56,198
1980	60,108
1985	63,087
1990	66,514
1995	69,951
2000	74,893
2005	81,485
2007	81,455
2011	82,025

Sources: American Petroleum Institute, World Oil, BP Statistical Review

[1]All liquids including natural gas liquids (NGLs).

U.S. dominant for a time

In 1920, the United States produced 80 percent of the world's oil. In 1950, it still produced more than half and was completely self-sufficient in oil. This allowed the United States to become a military and industrial power while improving the economy and lifestyle of its citizens. These effects spread to other countries with their discovery and exploration of oil.

Peak of U.S. production

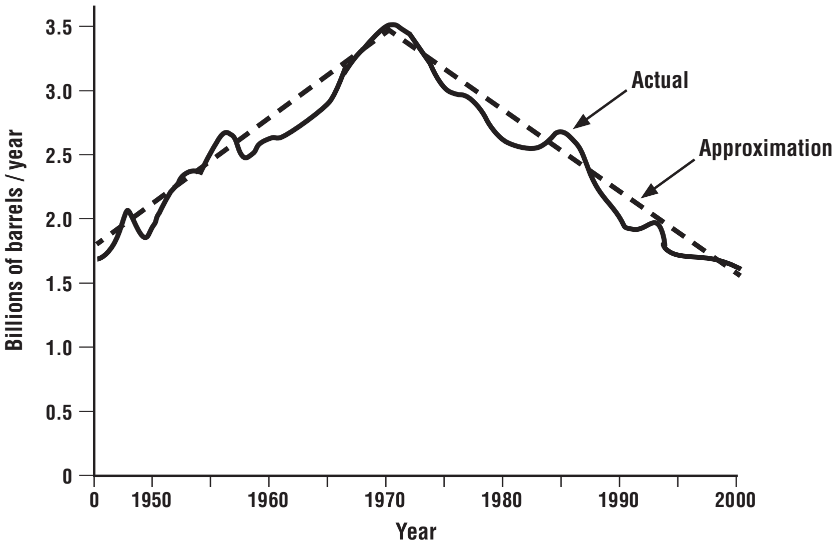
The mid-twentieth century U.S. oil production dominance was short lived. In 1956, M. King Hubbert predicted that the U.S. oil production would peak in 1970. His work generally was dismissed or ignored because in 1956, U.S. production was still rising and world dominant. However, Hubbert's prediction proved to be remarkably correct as shown in the plot by Hirsch (2005) in Figure 9-2.

Even before 1970, the United States could not produce enough for its own growing demands and had become a net oil importer. It was never again able to domestically produce oil equal to its demand. Unrecognized then, this turning point marked the beginning of the time when the economic destiny of the United States gradually passed into foreign hands. A clear and sad example of such power was the 2007 visit of a U.S. president to Saudi Arabia to ask the king to produce more oil to reduce the price of gasoline for U.S. consumers.

Arctic National Wildlife Refuge (ANWR) and U.S. oil supply

It is important to understand the realistic potential of getting oil from the Arctic

Figure 9-2. Profile of U.S. Oil Production 1945–2000



Source: Hirsch, et al., 2005

National Wildlife Refuge (ANWR) for solving our oil supply problem. ANWR's oil potential has been thoroughly studied (and much debated), including a 320-page U.S. Geological Survey report with five maps prepared by Bird and Magoon (1987). My later conversations with co-author Les Magoon, and one of my former students, affirm the limited oil realities of this region. Unlike Prudhoe Bay 70 miles to the west, the small area in ANWR that is expected to be productive consists of a number of small structures and numerous faults. Total reserves are estimated to be in the range of six to 11 billion barrels, produced over a period of 20 years. ANWR, at best, can be only a very modest help in the U.S. oil supply problem.

A lot of the concern about possible environmental impacts from oil activities on ANWR is unfounded. Of the more than 17 million acres in ANWR, only a small fraction is potentially oil productive, and of this coastal plain area, it is estimated that only about 2,000 acres would be involved using directional drilling from a relatively few drill sites. Also the experience at Prudhoe Bay shows that the original caribou herd of 3,000 has actually increased to more than 15,000. The caribou roam freely under the pipeline and over the oil field. Drilling in ANWR, like Prudhoe Bay, is unlikely to harm the caribou.

An argument favoring ANWR production, important to Prudhoe Bay's future, is that ANWR would provide additional oil for the 800-mile Alaska pipeline and would justify its continued use for some time to come. ANWR oil would help more Prudhoe oil be recovered. However, ANWR by itself would do little to ease United States oil supply problems, and the commonly used argument that ANWR would provide only a year or so of oil to the U.S. is not valid because the oil cannot be produced in a year or so, but only over some 20 years, with annual totals in modest amounts.

The impact of the use of oil

The impact of oil has been immense in world history. The oil industry has become the largest single commercial enterprise in the world. It uses more technology than any other enterprise from exploration to refining to its thousands of end uses.

Power source comparisons

Pimentel and Pimentel (2008) make useful comparisons of the power inputs in agriculture comparing the power of one person to other sources. One person is about one-tenth horsepower — that means one horse can do the work of 10 people in one hour. The use of animal power greatly improved agricultural production beyond the potential of using only human labor. But an even greater leap was achieved with energy from oil derivatives, chiefly gasoline. These authors point out that even with an energy conversion efficiency of only 20 percent, by using gasoline to power farm machinery, one gallon of gasoline can produce more power than a horse working at maximum capacity for 10 hours. "Further, 1 gallon of gasoline produces the equivalent of almost 3 weeks of human work at the rate of 0.1 HP, or 0.075 kW, for 40 hours a week." In another comparison, they estimate that a gallon of gasoline in an engine will generate the same work as 97 manhours of labor.

Andrew Nikiforuk (2008), cites David Hughes' (Geological Survey of Canada) calculation: "A barrel of oil, as analyst David Hughes often reminds me, equals 8.6 years of human labor. A human life span could produce about three barrels of oil equivalent energy." Using another measure of what oil does for us, Campbell and others estimate that current world consumption of oil is the energy equivalent of the work of 22 billion slaves, 24 hours a day. Most users of oil today have very little appreciation of the scale of the contribution oil makes to our everyday lives. Replacing this versatile, energy-dense, easily transported form of energy by any alternatives is likely to be much more of a problem than generally thought.

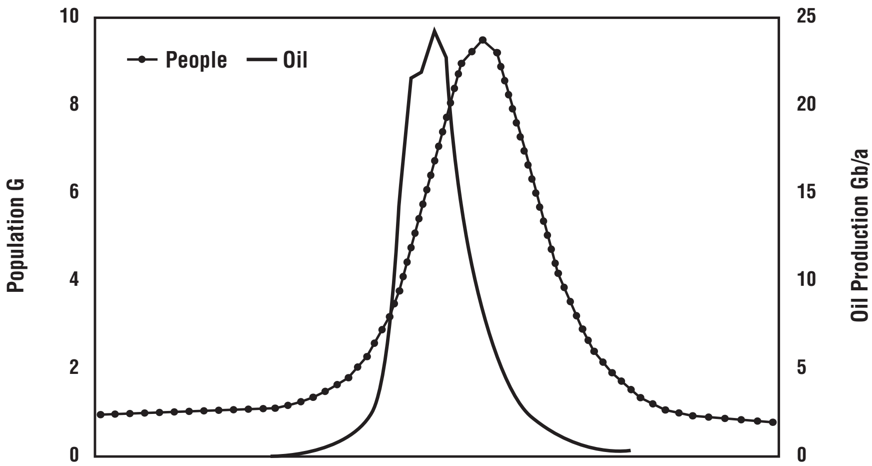
Advances in agriculture owe almost everything to oil. Oil has lifted the backbreaking dawn to dusk burdens of farming by what Stanton (2007) has called the "40 to 1 factor." By this he means that the use of oil in agriculture has reduced the need for human labor by a factor of 40 to l. In some uses, such as powering combines or tractors, the factor may well be in the vicinity of 100 to 1.

Probably the most important effect of using oil has been in the production of food. Oil-powered mechanized agriculture now allows one person to plow, plant, cultivate, fertilize, and harvest possibly a thousand or more acres of land. Petroleum (oil and gas) further benefits agriculture in the form of fertilizers and pesticides derived from it. The most important ammonia-based fertilizer used in modern agriculture is made by means of natural gas. Oil-powered tractors pull tanks with liquid fertilizer sprayers over farmland to enhance its productivity well beyond what the land could otherwise achieve. This creates what have been called "ghost acres" — extra production (as if from additional acres) that exist only because of the beneficial effects of fertilizer. When oil is no longer available for agriculture, finding substitutes for all its uses as labor, chemicals, and fuel will be an enormous challenge. Will agriculture return to intensive hand labor as in the past?

Food production is surely the most important of all human activities. Oil has greatly expanded the food supply and led to a huge rise in population. The plot of the curve of the rise in oil consumption is closely parallel with that of population growth. As oil declines, will the curves continue to be parallel on the downside or will population growth continue? Can even our current population be supported without the aid of oil in agriculture? Campbell has graphically expressed his view on the relationship of oil consumption to population growth in Figure 9-3.

Ferguson (2008d) has specifically addressed this problem, and his conclusions are similar to Campbell's:

Figure 9-3. Oil and Population



Source: Campbell, 2005a

> The end of fossil fuels, or the demise of cheap energy…will change nearly all aspects of our lives, but none is as fundamental as the food supplies needed to keep the human population alive…. Any farmer who continues with the practice of high (costly energy) input to agriculture will not be able to compete in price with those who decide to forego the high inputs and settle for a lower output…. The 'energy transition,' which people talk about so blithely, is likely to involve a total change of lifestyle with a much smaller population is almost beyond dispute when account is taken of such matters as those investigated above.

Many other industries besides agriculture are based on oil. These include the tourist industry with motels, hotels, resorts, and cruises all tied to transportation; the airline and automobile industries; and the huge petrochemical industry producing not only agricultural chemicals, but literally thousands of household products in everyday use. These include tires, cosmetics, paints, clothes, medicines, and roofing materials. Oil-based plastics are ubiquitous in every household, yet few people realize oil's many and varied roles in their lives.

From a Union Oil Company (now part of Chevron) information leaflet, Table 9-2 shows what might be produced from a "typical" barrel of oil:

How can this great variety of products and thousands of others be produced from wind, solar, or nuclear sources? Oil is not simply an energy source; 40 percent of oil goes into other uses. There are simply no known substitutes for oil in all these uses. Finding more energy to replace oil is the current focus, but that is by no means the complete answer to the decline of oil production. It will affect us in many ways beyond its use as an energy source.

One of the most fundamental uses of oil, rarely noticed by most people, is literally beneath our feet. Asphalt comes from the bottoms of oil refining operations. It is the residue left after the lighter parts of oil are distilled off. Nearly all our worldwide ground transport infrastructure depends on millions of miles of asphalt pavements. Try paving roads with ethanol, biodiesel, or hydrogen! Asphalt's availability will decline as oil production declines, and existing pavement will gradually deteriorate. The "pothole plague" now common in many areas is only the beginning of greater problems. Rising costs and asphalt shortages are already delaying maintenance of existing roads.

Table 9-2. Products Possible from a Typical Barrel of Oil

- Enough gasoline (medium-size car – 25 mpg) to drive 300 miles.
- Fuel to drive a truck (10 mpg) about 80 miles, or same fuel could be used for jet fuel, mileage different depending on size of plane.
- Liquid propane to fill 12 (14.1 ounce) cylinders for home, camping or workshop.
- 70 kilowatts of electricity from power plant generation from residual fuel oil.
- Asphalt to make a gallon of tar for roads or roofs.
- About four pounds of charcoal briquettes.
- Wax for 10 birthday candles or 27 wax crayons.
- Lubricants to make a quart of motor oil.
- After all this, there is enough oil left to produce petrochemicals sufficient to provide the base for: 39 polyester shirts, 750 pocket combs, 540 plastic toothbrushes, 65 plastic dustpans, 223 hula hoops, 65 plastic drinking glasses, 195 one-cup measuring cups, 11 plastic telephone housings, and 135 four-inch balls.
- Yet enough remains from by-products to be used in medicines, absorption oils, and fractionating oils.
- When we contemplate replacing oil with alternatives, as clearly shown in this table, oil is much more than transport energy. Forty percent of the barrel (42 gallons) is used for other purposes. How does one produce this great variety of products (and many others including very important agricultural chemicals) from wind or solar sources, or from nuclear power, tides, or currents? There is simply no known comprehensive substitute for oil in its multiple end uses, now numbering more than a thousand. Oil permeates our lives in many ways of which we are not aware. It is the major building block on which inevitable gradual departure will be an event in human history without precedent, adjustment to which will shape our future in many ways not yet foreseen.

Asphalt paves 94 percent of the roads in the United States. This is a total of about four million miles, and is the basis of our entire ground transport infrastructure, except for railroads. Its price is closely related to that of oil, and it provides ease of mobility in the industrial world and for some of the less developed world, regardless of what may power the vehicles that use it.

The U.S. transcontinental freeway system built during the Eisenhower Administration in the 1950s is almost entirely asphalt. When that goes, as a South Dakota road engineer told me, "There are a lot of dusty and muddy roads ahead." Whatever personal and freight transport may be developed by the automobile and truck industry, if there are no paved roads, gravel and seasonally muddy roads prevail, and will become large and inconvenient problems. Most of us do not consider how important "lowly asphalt" is to our daily lives, in just getting to the supermarket or having trucks deliver products that stock those shelves.

Origin of Oil

Accumulation of organic materials in basins

Through its geologic occurrence and chemical evidence, it is clear that oil is derived from organic material. Hunt (1996), probably the most widely experienced researcher in petroleum geochemistry, writes, " … the whole argument of biological origin of oil was settled with the discovery of optically active molecules deep in the source rocks. It is impossible to make optical activity from inorganic sources. Some gas … may be inorganic, but not oil." Some people still continue to believe and promote the idea that oil somehow originates deep within the Earth from inorganic sources. Hunt's statement should put an end to these erroneous and unsupported arguments.

This organic material accumulates with other sediments in structural basins in the Earth, both within continents invaded by the ocean, and along the continental margins. The central deep ocean regions do not have any significant accumulation of sediments and, therefore, have no oil.

Depending on how one defines the limits of a basin, there are about 600 sedimentary basins worldwide, most of which have been explored to a greater or lesser extent. Only about two hundred of them are oil productive, and of these, only a very few basins contain the huge oil fields in which most oil is located. The Earth has been fully explored and the larger and most productive oil basins have been drilled and are now in production.

The organic material from which oil is derived is mostly plants, with algae in many areas being the predominant source material. Campbell (2005a) notes that, "Isotopic examinations show that oil was derived from algae." Algae in ancient oceans furnished the basis for industrialization and for dramatically different lifestyles from previous centuries. The course of human history has been greatly influenced by simple algae transformed into oil.

Other sources of oil include the buried mangrove swamps found in offshore Angola and in Southeast Asia. Plankton, both floating animal and plant forms are also important. The unicellular animals, foraminifera, may be a major source of the oil found in the Sirte Basin of Libya.

Most oil is formed in marine environments. A few commercial deposits have been discovered in deeply buried organic materials (mostly algae) in lake basins in Nevada and China. Freshwater algae produce quite a different type of oil than does marine algae. There are about 30,000 species of algae.

Many kinds of oil

The kind of source material, how long the organic material and then the oil are "cooked," and at what temperatures, how deeply it is buried (pressure) and for how long, determine the many different kinds and qualities of oil. The *Oil & Gas Journal* lists prices for fourteen different oils produced just in the United States.

Classifying oil

Oil can be classified in various ways, but a common way is to designate it either as "sweet" (less than 5 percent sulfur) or "sour" (5 percent or more sulfur). It is also classed by how light (thin) or heavy (thick) it is. This is expressed by a "gravity" figure, inverse in numbers to how thick or thin the oil is. A 40 gravity oil is light, and a 20 gravity oil is heavy. At around 52 gravity, the oil becomes gas. Oil in the Maricaibo basin of Venezuela is heavy crude (around 20 gravity). It is so heavy that the oil storage tanks are not painted silver to reflect the Sun's heat, but black to absorb heat and keep the oil thin for pipeline movement.

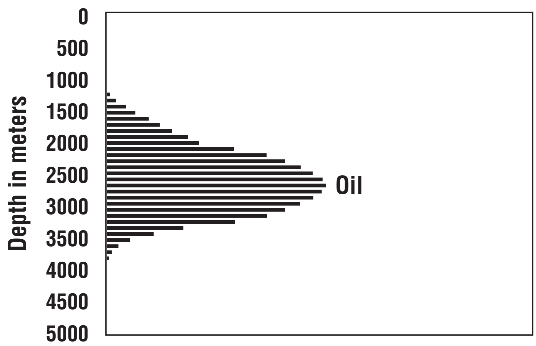
The "benchmark" oil in the United States is West Texas Intermediate (WTI), a good grade oil; its price is quoted every day. In 2009, Saudi Arabia switched, and Kuwait is considering switching to using the Argus Sour Crude Index. This is based on the fact that more oil supplies now come from medium-sour crude oil than from West Texas, from which the initial crude oil index was derived. Saudi Arabian oil exported to the U.S. is lower quality than the West Texas crude, containing enough sulfur to be classed as sour. Venezuela and other exporters to the U.S. of sour crude oil may also eventually use this index. In Europe, the "benchmark" oil quoted is North Sea Brent, which is a slightly lower-quality oil than WTI, and, therefore, usually sells for slightly less. Refineries prefer to refine light oils with a low sulfur content, since they can be more easily made into higher value end products. Worldwide, these oils have generally been produced first, so remaining oil is a heavier and lower quality crude. Refineries are gradually having to adjust to this new reality, with related higher refining costs.

The "oil window"

Once deposited in an anaerobic (oxygen-lacking) environment through which the organic material is preserved, it must be buried deeply enough so that the geothermal (temperature) gradient of the Earth is such that a temperature of about 156°F is reached (minimum temperature for the start of "oil window"). Together, with the pressure of the overlying sediments, the organic material is slowly "cooked" to produce oil.

Sediment containing oil is commonly an organic-rich black shale. After the organic material has been "cooked" into oil, it has to migrate into a permeable and porous sealed reservoir from which it can be economically extracted.

Figure 9-4. The "Oil Window." Depth Range at Which Oil is Most Commonly Generated



Source: Modified from Campbell, 2005a

Role of structure and stratigraphic traps

To prevent the oil from continuing to migrate and disperse, a "trap" is needed. Early in oil exploration, it was discovered that anticlines — upfolds in the Earth's crust — were excellent oil traps. If they were found at the surface by mapping or in subsurface by the seismograph, these obvious exploration targets were drilled first, as many California oil fields were. In the Persian Gulf region, it appears that the collision of continental masses resulted in many anticlinal traps for an echelon of elongate oil fields, most famous of which is the gigantic Ghawar Oil Field. This is the world's largest oil field and the most important in Saudi Arabia and, therefore, of world importance. Discovered in 1948, it still produces more than half of Saudi oil.

Another form of trap is the stratigraphic, such as a sandbar buried in shale, with both ends terminating in an impervious shale. This sort of trap lying at some depth, usually has no surface expression as many anticlines do. Therefore, they are more difficult to find than structural traps, which have both anticlines and faults. However, detailed and improved seismograph technology can find these traps. Earlier they would be found simply by ran-dom drilling, as was the great East Texas Oil Field. A classic buried stratigraphic sandbar trap, it was discovered in 1930, and is second only to Prudhoe Bay, the largest field ever discovered in North America.

In the Nigerian delta there are stratigraphic traps that are hard to detect. But Exxon-Mobil has developed an indicator of significant hydrocarbon subsurface accumulations they call "R3M," which is apparently quite successful.

Importance of a cap

The oil reservoir also has to be capped by impermeable strata to prevent the oil from leaking out. Many a highly prospective reservoir has been drilled only to discover that the oil had leaked out. This was the case with one of the most expensive wells ever drilled, the Mukluk No. 1, drilled offshore Alaska by the Sohio Oil Company. The great oil deposits of the Middle East owe their survival largely to the presence of very effective reservoir caps.

Amount of ancient plant material for one gallon of gasoline

Using plant material as the theoretical originating material, Jeffrey Dukes, biologist and biochemist at the University of Massachusetts, has calculated that it takes approximately 190,000 pounds (95 tons) of prehistoric plant material to yield 13.2 pounds of crude oil, including 6.2 pounds (one gallon) of gasoline. Thus, the production of just this one gallon of gasoline represents a huge distilling and concentration operation, which nature accomplishes for us in the Earth. Have you ever considered the amount of ancient algae, and the amount of heat energy and related "cooking time" it took to bring you that gallon of gasoline?

To sum it all up for its shareholders in *The Lamp,* v. 88, n. 1, 2006, ExxonMobil wrote:

> Here is the recipe for oil: Gather large amounts of organic matter in a sedimentary basin, compress under enormous weight, and cook it at moderate temperatures for millions of years. Seal it in a reservoir until ready to use.

To produce, preserve, and accumulate oil in large commercial quantities has taken a remarkable series and precise succession of geologic events, which have occurred in only a few places in the Earth during relatively few times in Earth history. It is a limited resource and one that controls the destinies of many nations. But this is only a temporary circumstance because oil supplies are finite and the world will have to move beyond oil in this century. The big question is "to what?"

Just drill deeper?

To prolong the oil interval we now enjoy, it is sometimes suggested that we should simply drill deeper for more oil. This might be true in a limited number of places, but if it was possible and feasible, oil exploration companies already would have done so. At 10,000 feet, and in some regions such as Kansas, even shallower, the drill bit would hit either igneous or metamorphic rock (so-called "basement rocks") where oil is not generated and does not exist. Oil is limited vertically by the depth needed for the "oil window" temperature to be reached, but oil occurrence also is limited at greater depth. In most of the Earth, below 15,000 to 16,000 feet, the geothermal gradient (increase in temperature with depth) is such that at these depths and related temperatures, oil is not stable and breaks into the simplest hydrocarbon molecule, methane. How deep oil occurs also depends on the type of source material and how long the organic material has been buried. In a few places, thick beds of salt alter the geothermal gradient, and oil can survive at greater depths, as in the Campos and Santos basins offshore Brazil. But there is an ultimate depth below which no oil, only natural gas occurs. So "drilling deeper" is generally not the answer to finding more oil.

Who Has the Oil?

Changes by discoveries, depletion, and price

Who has the oil has changed considerably over the years. Discoveries in some countries and the depletion of oil deposits in others, has altered the picture. This is illustrated in Table 9-3 in just 27 years between 1974 and 2003.

Another factor is the price of oil. When oil was three dollars a barrel, as it was for a long time, Canada was credited with having only a small amount. Higher prices for oil made the oil in the vast Athabasca deposits economically competitive with conventional oil, giving Canada, by some estimates, reserves nearly as large as those of Saudi Arabia.

Table 9-3. Comparison of oil reserves in selected countries, 1974 and 2010
(rounded to nearest 1/10th of billion barrels)

Country	1974	2010
Canada	7.1	4.8[1]
China	25.0	20.3
Indonesia	15.0	4.0
Iran	66.0	137.6
Iraq	35.0	115.0
Kuwait	72.8	101.5[2]
Mexico	13.3	10.4
Norway	7.3	6.7
Russia	67.0	60.0
Saudi Arabia	164.5	259.9
United Arab Emirates	33.9	96.2
Abu Dhabi	92.0	
Dubai	4.0	
United Kingdom	15.7	3.1
United States	34.2	19.1
Venezuela	15.0	99.3

Source: American Petroleum Institute; *Oil & Gas Journal*

[1]Conventional only. Does not include oil sands or other heavy oil. Added in, the total is 175,214,000 billion barrels.

[2]Other estimates lower.

Except for developed countries, almost all reserves unaudited.

Who has the oil, and the concepts of "resources" and "reserves"

With oil currently the major source of world energy, the important question is who has it? The Middle East (Gulf) nations are estimated to have something over 60 percent of world oil reserves, and Saudi Arabia alone has 25 percent of the world total oil reserves.

The terms "reserves" and "resources" are sometimes confused. The term reserves applied to any natural resource including oil, means the amount that can be produced with existing technology at current prices. Obviously, reserves may vary in size depending on the development of new and more efficient technology and current prices. This has certainly been seen in the case of both oil and natural gas, and in metals, with wide fluctuations in the prices of gold and silver and the size of "reserves" of these commodities changing.

Resources are the total amount of the commodity in the Earth, only a portion of which at any time can correctly be termed reserves. Also, the term "oil in place" is sometimes used in the oil industry to describe the resource. Press reporters and others may make the error of assuming oil in place (resource) is a reserve. An example is the oil in the Caspian region, where the oil in place initially was estimated at 200 billion barrels and the press reported an oil discovery "nearly equal to the reserves of Saudi Arabia." However, when geologists and engineers later reevaluated the Caspian reserves, they arrived at a figure of about 40 billion barrels.

The Athabasca oil sand deposits are another example. Estimated to have as much as two trillion barrels of oil in place, the economically recoverable oil (reserves) are estimated to be in the vicinity of 175 billion barrels. With the steep drop in the price of oil during 2007-2008, from more than $147 a barrel to briefly less than $40, part of the Athabasca oil reserves were relegated back to the status of resources. Development of some oil sand projects were put on "hold" to a time when the price of oil again rises, and some of the resources revert to reserve status.

"Political reserves"

Studies of world oil reserves, especially one by French geologist, Jean Laherrère (1995), indicate that in many countries, the "reserves" are "political" to some degree rather than actual. It is notable that reserve estimates by some countries have not changed in many years. For example, Kuwait reported the same reserves from 1991 to 2002, whereas others change dramatically in just one year. Oil reserve estimates are not independently audited and the figures published annually in the *Oil & Gas Journal* are simply those provided by the individual countries and may not be correct.

"Political reserves" may serve a couple of purposes. They may be inflated because the people in charge of oil field operations in a country are prone to report to the politicians in charge that they have found more oil that year than they produced, so reserves happily go up. Workers continue to keep their jobs and may even get a raise.

Also, in OPEC countries, agreed-upon production quotas are based on reserves. Some countries in OPEC can increase their production to increase their oil export by inflating the reserves. The end result is that unaudited reserve figures are suspect. In contrast, in most industrialized countries including the United States and Canada, reserves are inde-pendently audited and are probably fairly accurate. Even in these cases, how much oil can really be economically recovered from a well or field can never actually be known until the well is plugged or the field abandoned.

Unaudited reserves

Reserve figures from unaudited countries probably indicate the amount of oil each country has *relative* to others that can be economically recovered. On this basis, with the caveat that reserve oil estimates are much more reliable from independently audited countries than others, the following Table 9-4 indicates the probable relative oil positions of selected countries.

Table 9-4 (see page 156) makes the importance of Saudi Arabian oil reserves to the world economy clear. But there has been little transparency about the validity of these reserves. However, Matthew Simmons, after being on a group tour conducted by Saudi officials of their oil facilities, and learning very little, returned to the United States and made a shrewd discovery. American petroleum engineers who had worked in Saudi Arabia and returned to the States had published a number of papers about the Saudi oil fields. Simmons laboriously examined some 200 of these articles, putting his findings and con-clusions in the book *Twilight in the Desert: The Coming Saudi Oil Shock and the World Economy* (2005). Simmons concluded that the estimates put out by the Saudis were exaggerated. This was not well received by the Saudi government, which once claimed it could produce "15 million barrels a day for 50 years." Since Simmons' book, the Saudi claim has not been repeated. At a professional gathering, a Saudi oil official informally told me he

Table 9-4. Proven Reserves of Selected Countries by Region (billions of barrels, January 2012)

	Proven Resources
North America	
United States	20.7
Canada	173.7
Mexico	10.1
South America	
Argentina	2.5
Brazil	13.9
Colombia	1.9
Venezuela	211.2
Europe/Eurasia	
Azerbaijan	7.0
Kazakhstan	30.0
Norway	5.3
Russian Fed.	77.4
United Kingdom	2.8
Middle East	
Iran	151.1
Iraq	143.1
Kuwait	101.5
Qatar	25.4
Saudi Arabia	264.5
Africa	
Algeria	12.2
Angola	9.5
Libya	47.1
Nigeria	37.2
Asia/Pacific	
Australia	1.4
China	20.3
India	8.9
Indonesia	3.8
Vietnam	4.4
Total World	1,523.2
W. Hemisphere	443.2
OPEC	1,068.4

Source: *Oil & Gas Journal*

Note: Only the Canadian, Norwegian, United Kingdom, and United States reserves are independently audited. Others are from governments of respective countries unaudited and cannot be independently verified. Canadian reserve figures are for oil sand deposits now under production. Oil in place in oil sands may be as much as two trillion barrels. Conventional Canadian oil reserves are 4.5 billion barrels.

thought Saudi oil production might level off at "12.5 million barrels a day." This figure has appeared in various publications, and seems likely to be correct.

In 2005, Colin Campbell also published an estimate of Saudi (and other countries') oil reserves, and came to the same conclusion as Simmons — that Saudi estimated reserves were exaggerated.

Even if one applies reasonably estimated reductions in unaudited oil reserve estimates, the Middle East still has the major share of world oil reserves (Table 9-4) and will be a dominant factor in the economic future of many nations for decades to come.

The Role of OPEC

The move to form the Organization of Oil Exporting Countries (OPEC) was made by Venezuela in 1969. The goal was to break the long-held control over the price of oil by the investor-owned oil companies. Membership in OPEC changes from time to time, but it currently has 12 members. They are Algeria, Angola, Ecuador, Kuwait, Iran, Iraq, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates, and Venezuela. Indonesia, now a net oil importer, dropped out in 2008.

Periodically members meet and vote to set the size of their combined oil production and are assigned oil production quotas based on their claimed reserves. Since most OPEC countries like to maximize their oil production to raise their oil export incomes, there is a tendency to cheat on production quotas. Saudi Arabia has probably been the most diligent in observing its quota. Because it overshadows all other OPEC members in production, it is the "swing" producer. Theoretically, Saudi Arabia can "bring into line" any OPEC member not adhering to its quota, by increasing its own production and thus reducing the OPEC price. But this has rarely if ever been done. Saudi Arabia simply threatens to do this. The individual OPEC country production quotas have been only loosely enforced.

OPEC likes to promote the idea that it is concerned about the economic health of the oil-consuming countries and therefore might increase its production to reduce excessive prices. But when world oil price exceeded $145 a barrel in 2008, OPEC countries were not dismayed. However, when oil dropped below $60 a barrel (and briefly below $40) abruptly that same year, OPEC called an emergency meeting. Saudi Arabia announced a cut in production of 1.5 million barrels a day to try to stabilize if not raise the price.

OPEC intervenes through production when it suits their interests. When demand exceeds supply and market forces raise oil prices, OPEC is likely to let prices take their inevitable climb. It may be that Saudi Arabia's excess oil production capacity is unavail-able. The kingdom has increasing domestic demand, and may reserve some of its remain-ing oil for the long term. Therefore, oil price will be based strictly on supply and demand; a totally free market.

Oil Exporters

Gradually, as oil fields decline in some countries, they may grow in number and size in others. The long-term trend is almost certainly a decline in the amount of oil worldwide available for export. The Persian Gulf countries will probably be the last countries with oil available for export.

The United Kingdom has become a net importer of oil and gas, as its share of North Sea oil production has passed its peak and is experiencing a fairly rapid decline. Because oil is essential to its economy, the U.K. has lost control of its economic destiny. Indeed, all countries, who depend on oil to support their economies, and who lack sufficient oil to meet their domestic needs, have ceded their future to those who have oil.

Most other European countries have been oil importers for years. The United States imports the largest quantity of oil, 11-12 million barrels a day including refined products. This represents about 60 percent of total U.S. oil consumption.

In a belated response to the first oil embargo crisis of 1973, the U.S. established the U.S. Department of Energy (DOE) in 1977, with the stated purpose "to lessen our dependence on foreign oil." Now, the DOE has 16,000 federal employees and approximately 100,000 contract employees, and an annual budget of $24 billion, and the U.S. imports twice as much oil as it did when the agency was established.

U.S. oil imports now come mainly from six countries. Surprisingly to many people, the largest supplier is Canada.

China is the second largest oil importing country at 6.7 million barrels a day. This amount is certain to grow as China makes a major effort to motorize more of its citizens. Japan is third at 5.5 million barrels a day. Other Asian nations and India are increasing their demand for oil. This can only mean continuing higher prices.

Table 9-5. Six Largest Suppliers of Crude Oil to the United States (Thousands of barrels/day July 2011)

Country	m bbl/day
Canada	2,468
Mexico	1,758
Saudi Arabia	1,514
Venezuela	1,438
Algeria	803

Source: *Oil & Gas Journal*
Note: Mexico's main oil field, Cantarell, is in steep decline. Mexico may be a net oil importer within this decade.

Canada's declining conventional oil production is being replaced in part by oil from oil sands production. So it may continue for some time to be the chief oil exporter to the United States. However, oil sands production, as detailed in Chapter 11, will be constrained by limited energy and water supplies and may only reach four million barrels by 2030. If this happens, Canada may maintain its export volumes for some time to come, but eventually Canada's own population growth combined with increased indus-trial activity and the decline in conventional oil production will reduce the amount of oil available for export.

Mexico, the second largest source of U.S. oil import supplies, is experiencing sharp production declines in its Cantarell oil field, which is equivalent in importance to Mexico as the huge Ghawar Field is to Saudi Arabia. The rate of decline is above 15 percent (31 percent in 2008), and estimates are now that without major changes in its national policy of excluding foreign investment, Mexico may become a net oil importer within the next decade. The loss of imported Mexican oil would put Venezuela second and Saudi Arabia third as the largest sources of oil imports to the United States.

Venezuelan President Hugo Chavez was an outspoken critic of the United States, which China viewed as an opportunity to invest in Venezuelan oil operations, arranging to have Venezuelan oil supplied to refineries built by China both in Venezuela and in China. U.S. oil imports from Venezuela seem likely to be in an increasingly perilous position.

"Addicted to Oil"

It is frequently stated, by politicians in particular, that the United States is "addicted to oil." Campaigns promise to break that oil addiction, at least as far as imported oil is concerned. That is unlikely to happen until there is no longer oil for the United States to import.

Addiction to oil a mutual problem

"Addiction to oil" is a problem for many oil exporting countries as well. Almost all government revenues in Kuwait, Libya, Qatar, and Saudi Arabia come from the sale of oil. Other countries, such as Algeria, Angola, Ecuador, Iran, Nigeria, and Venezuela are heavily dependent on oil for their revenues. In Russia, 40 percent of the government income is from oil. When U.S. money stops pouring into Iraq, that country will also be largely dependent on the sale of oil to support its government.

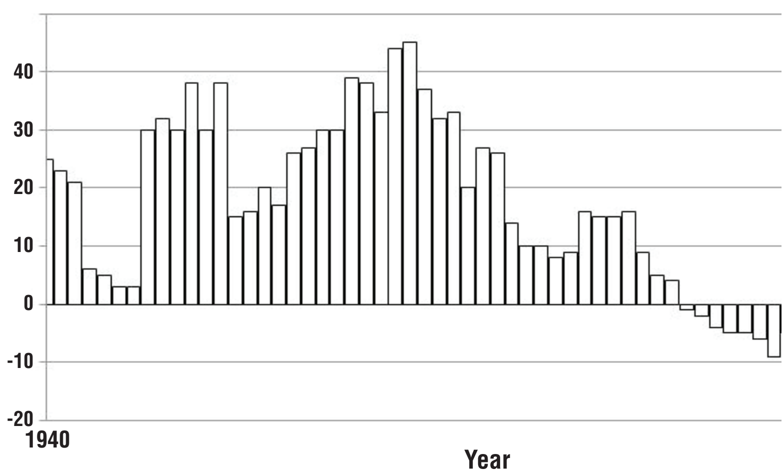
An oil price of $95 a barrel is required to finance President Chavez' social spending programs, widespread welfare, and military equipment purchases. Iran's current budget is based on $80 a barrel oil. Saudi Arabia, greatly dependent on its export of crude and upgraded oil products, needs an oil price of $55 to balance its government budget. Russia needs $70 oil.

So "addiction to oil" works both ways, and when oil ceases to flow abundantly, those addicted as producers and as users will suffer. Actually, the United States is less addicted to oil than is generally believed. It has substantial coal reserves and some hydropower, and it is still a major oil producer, third among nations. And it has fertile soil and freshwater, neither of which are abundant in Gulf countries, except to a limited extent in Iran. The desert sands of Kuwait, Qatar, the United Arab Emirates, and Saudi Arabia do not support much agriculture for their populations, which is a serious problem.

Discoveries versus Production

As shown in Figure 9-5, since 1981, more oil has been produced annually than has been found.

Figure 9-5. Net Difference between Annual World Oil Reserve Additions and Oil Consumption 1940-2000 (billions of barrels)

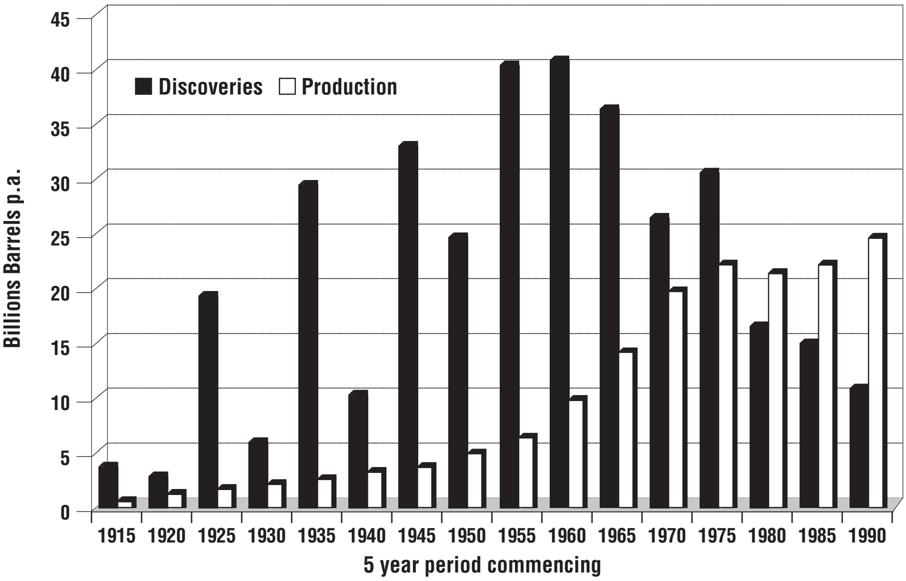


Source: Aleklett and Campbell, 2003

This trend continues and the disparity between production and discovery increases. Recent statistics show that the world consumes 31 billion barrels a year, but combined discoveries and drilling in and around already discovered fields, yields only 14 billion barrels. New discoveries, the lifeblood and the future of the oil industry, are only seven billion barrels. This means we are consuming more than four times the amount of oil we are discovering. That is not a sustainable trend.

The peak of world discovery for volume of oil was approximately 1965 (Figure 9-6). Since then, there has been a decided downtrend in discoveries, and discoveries have tended to be smaller.

Figure 9-6. World Oil Discoveries and Production (billions of barrels per year)

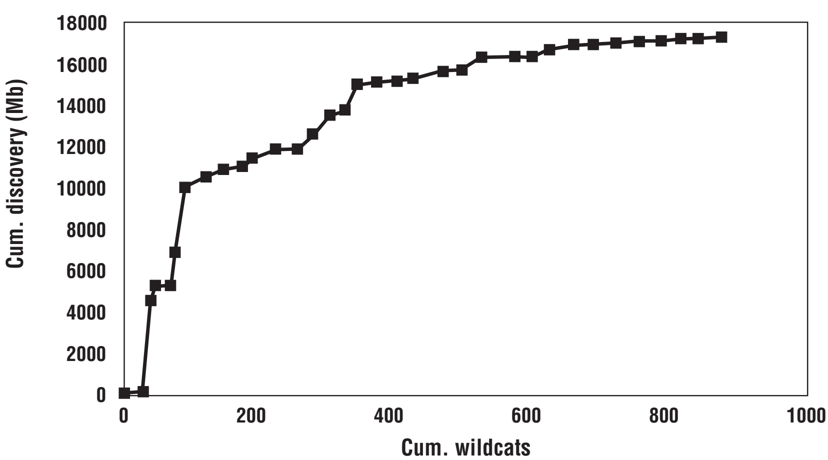


Source: United States Geological Survey, 1994 and BP Statistical Review, 1999 (Adapted from Selley, *Changing Oil*: Briefing Paper New Series No. 10 January 2000, The Royal Institute of International Affairs, London)

The reason for this is that large oil fields, because they are large, are usually discovered early in exploring a basin. As drilling proceeds, less and less oil is found per foot drilled. French geologist Jean Laherrère, putting this trend in graphic form, calls it the creaming curve. Campbell shows this in Figure 9-7.

Campbell has also studied the results of drilling in the Persian Gulf region, and finds those nations are not immune to the same problem of finding less oil per foot drilled

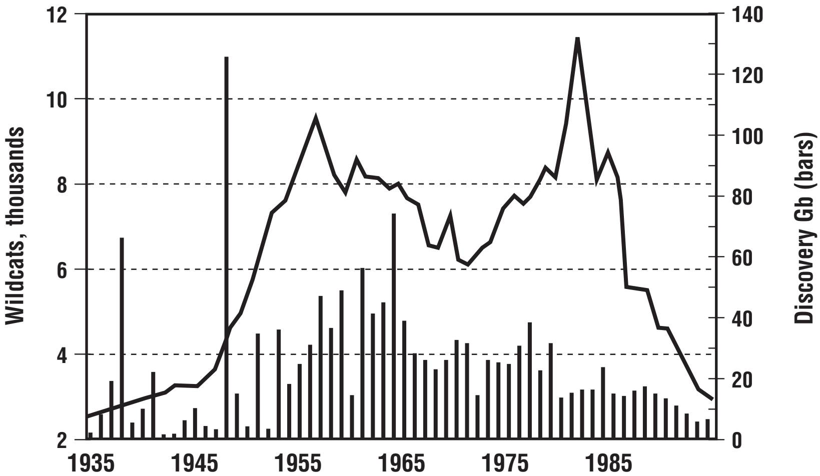
Figure 9-7. The Creaming Curve. Major Oil Company Exploration Experience 1956-1996



Source: Campbell, 1997

over time. A spurt in worldwide drilling from 1976 to 1983 (Figure 9-8) did not find a commensurate amount of oil, illustrating that large, easier to find oil accumulations had already been discovered. What remained required more drilling. Thus each barrel of oil discovered is more expensive than it was in earlier years.

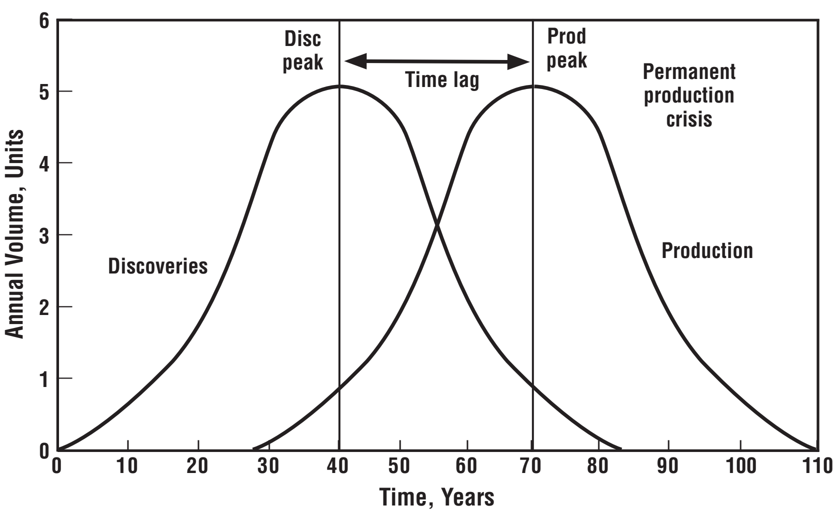
Figure 9-8. World Oil Drilling vs. Discoveries
Drilling effort not matched by discovery rate. Wildcat wells (solid line) in thousands, discoveries (bars) in billions of barrels [Gb] annually



Source: Campbell, 2005a

The classic theoretical curves of discovery and production are shown in Figure 9-9. The production curve here mirrors the discovery curve. In actual experience, both curves are less symmetrical, since discoveries depend on where exploration is conducted and how successful it is. Both discovery and production are influenced by market conditions, as

Figure 9-9. Theoretical Curves of Discoveries and Production During a Complete Life Cycle of a Finite Resource



Source: After Hubbert, 1956

well as the political environments of individual countries. However, taking the broad view, these classic curves reveal that discoveries rise to a peak and then decline. Production follows the same pattern. Both ultimately end at zero. Although in the case of production, there may be a long "tail" in its curve toward the end because oil prices may rise very rapidly, bringing marginal production on stream.

The depletion problem

Like the proverbial alligator continuing to eat up a leg, depletion of oil fields continues everywhere. When primary (flowing and pumping) and secondary recovery (water flood and gas injection) have been used, sometimes a third method of oil production is used termed Enhanced Oil Recovery (EOR). These methods include injection of steam or chemicals to improve oil flow to wells from the reservoir. Costs range from $1.50 to $30 for each additional barrel recovered. But this technology has been only moderately successful, and does not add much to the total oil being produced.

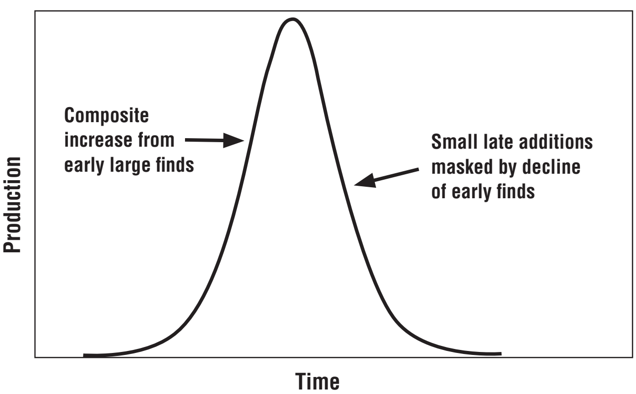
The worldwide oil depletion rate has been estimated at between four and nine percent annually. A figure of 6.7 percent seems to be the current situation. The huge investments needed just to slow this decline are not forthcoming. Many countries spend their oil income mostly on domestic needs and cannot or do not invest in oil production enhancement projects on which little immediate return is available. Mexico, for example, has underfunded its oil infrastructure to pay for social programs.

Campbell has graphed the depletion problem as it applies both to a basin and to a country (Figure 9-10).

Oil depletion protocol

This is a method of managing the depletion of a nonrenewable resource to make the effects of depletion less disruptive — gradually integrating into a new economy. It was suggested using a different name by Bartlett (1986) and later independently proposed and described in detail by Campbell (2005a). Heinberg (2006) has expanded on the topic of oil depletion protocol to book length.

Figure 9-10. Typical Oil Depletion Profile. Basin and Country



Source: Campbell, 2005

The concept is simple: "Each importing country shall reduce its imports to match the current World Depletion rate, deducting any indigenous production" (Campbell, 2005a). This concept has considerable logic and merit, but little political appeal, as is true of many needed changes. It, therefore, has been ignored by policymakers, but its time may yet come.

Daily oil well production

There is a big difference in what oil wells from different quality reservoirs can produce each day. Usually highly productive wells are "choked" down, that is, the diameter of the valve for controlling oil flow is reduced to prevent injury to the reservoir by unnecessary water invasion or high gas flow. The water and gas pressure should be used for aiding oil production. But in daily production, there remain great differences. From approximately 1400 wells, Saudi Arabia can produce nine million barrels a day, whereas in the United States, more than 500,000 wells now produce only about 5.4 million barrels a day.

The average well in the United States produces 10.1 barrels per day, and more than half of the more than 500,000 wells are "stripper" wells — wells producing less than 10 barrels a day. In the State of Pennsylvania, where the modern oil industry is credited with getting its start, the average well now produces two barrels a day, which is an average of intermittent pumping over a period of time. Table 9-6 shows daily oil production per well in selected countries, by region.

In 2010, the United States had 531,951 wells from which it produced just 73 percent of the amount of oil produced by Saudi Arabia from only 2,889 wells. The difference is due to the average quality of reservoirs in the two respec-tive countries. Allah favored Saudi Arabia in that matter also.

Table 9-6. Daily Oil Production Per Well. Selected Countries 2011. Well Production, Barrels/Day

	Barrels/Day
Western Hemisphere	
Argentina	40.0
Brazil	142.6
Canada	41.6
Colombia	69.3
Mexico	1072.4
United States	10.1
Venezuela*	163.6
Western Europe	
Denmark	1613.2
France	4.6
Italy	507.2
Norway	3077.4
United Kingdom	1088.3
Eastern Europe including former Soviet Union	
Azerbaijan	4807.7
Kazakhstan	1503.5
Russia	248.2
Middle East	
United Arab Emirates*	1557.1
Iran*	3330.4
Iraq*	756.7
Kuwait*	2341.8
Qatar	1726.6
Saudi Arabia*	5403.8
Syria	4000.0
Africa	
Algeria*	1046.7
Angola	1296.8
Libya*	1154.9
Nigeria*	933.2
Asia/Pacific	
Australia	97.6
China	49.6
India	185.6
Indonesia	107.7
Malaysia	935.3

Source: Based on data from *Oil & Gas Journal*
*OPEC Member

World peak oil

Peak oil (conventional oil only; excludes shale oil and oil sand oil) refers to the time when world oil production reaches its peak and then begins its inevitable decline, with perhaps a few brief reversals in the decline curve. In 1956, geophysicist M. King Hubbert made a remarkably accurate study that predicted U.S. oil production would peak in 1970. When he made his prediction, the United States produced more than half the world's oil. Hubbert was scoffed at. But when his prediction proved uncannily accurate, others were encouraged to broadly apply "Hubbert's production curve," as it became known, to the matter. For various reasons, that curve is not a very good fit, and others have been used.

Since oil is intertwined in our economies and lifestyles in countless ways, the date of the peak and the decline of world oil production is exceedingly important.

Over the years, there have been many studies and estimates of peak oil. The Association for the Study of Peak Oil and Gas

(ASPO) was created and many of its member geologists and engineers continue to explore approaches to understanding world peak oil production.

Study results

Despite numerous studies, the date of peak oil remains subject to wide division of opinion. Technological advances in the recovery of oil from existing fields have mitigated the overall annual world field decline of about five to six percent. The ability of industry to make discoveries offshore in ocean depths up to 10,000 feet has added new oil reserves. Offshore West Africa and Brazil are notable sites, and discoveries continue with a recent new field discovered offshore Ghana. Rising world demand resulting in higher oil prices has made the economic recovery of more oil possible.

In 1956, M. K. Hubbert predicted world oil would peak in 2000. The technology and knowledge of oil basins then was very limited compared to that of today, excusing Hubbert's erroneous prediction. Later studies tended to settle on the years 2005-2007 for world peak oil production. In 2010, the International Energy Agency stated that production of conventional crude oil peaked in 2006. Duncan and Youngquist (1999) put it at 2007. A recent study (Towler, 2011), citing higher oil prices, advanced technologies, and regions yet to be explored as prime factors, stated that world peak oil production is still years away, with the peak unlikely to occur before 2018 and possibly later. In yet another view, the U.S. Department of Defense Joint Operating Command, in a 2011 report, stated that an oil shortfall poses a serious challenge to military preparedness, and that world oil production could begin to decline by 2012.

Bearing on the matter of peak of world oil production is a study published in 2012 by Swedish physicist Kjell Aleklett, *Peeking at Peak Oil*, wherein he examines what unconventional oil sources might do for future oil production. Noting the decline of conventional world oil production at the annual rate of about four million barrels a day, he estimates that the incremental addition to world oil supplies from unconventional oil will ultimately be about eight million barrels per day. This would be just two years offset to the decline of conventional oil and does not provide for any gain in world production. He also notes that whereas oil demand is currently either flat or declining in most OECD countries, total world oil demand is increasing.

Further complications are both the high cost and time lag involved from the difficulties in bringing the additional eight million barrels a day of unconventional oil on stream, as compared with the relative rapid development of conventional oil sources. The peak of oil production from all sources may be essentially upon us (2012), as the previously cited U.S. Department of Defense study has suggested. Higher oil prices seem a certainty (Bezdek, 2012).

What seems clear is that the era of cheap oil has passed. The easy oil has been discovered and developed and the oil industry has moved into far more expensive frontier areas such as the Arctic regions and deeper ocean waters. The precise date of world peak oil production is still subject to debate, but oil remains a finite Earth resource. Opinions continue to differ, but all place the peak sometime early this century, and this seems most likely to be correct. Most people living today will see the peak arrive and witness the beginning of the historic changes that diminished oil supplies will bring to civilization we know today. The changes will be far more profound and far-reaching than most people realize. Peak oil production will be a major event in world history.

Exact peak date irrelevant

The precise date of the peak of world oil production, however, is an irrelevant academic exercise, since the true peak will be known only in retrospect, after several years of well-documented declining production. The important fact is that oil production *will inevitably peak and then decline*. Campbell, in several published studies, has emphasized the "end of hydrocarbon man" (relating not only to oil, but natural gas and coal), calling it "a turning point for mankind." The "oil interval," unlike some parts of human history, can never be repeated. It is a one-time only event, and the world must move on to a new energy paradigm and make myriad adjustments accordingly.

Basic Changes and Current World Oil Industry Trends

Probably the most important change has been the rise of the national (government-owned or NOCs) oil companies, and the corresponding decline in international oil influence by the investor-owned companies (IOCs). This change dates back to the time when the several waves of oil company nationalization took place. Since that time, the NOCs have been gaining in importance, as they are increasingly able to run their own oil industries.

Currently NOCs control about 90 percent of world oil reserves. The combined reserves of ExxonMobil, BP, Shell, ConocoPhillips, Chevron, and Total (a French company) are less than one-quarter of the reserves Saudi Arabia claims.

In countries where IOCs can still operate because they have the technology and the capital (i.e., Angola, Algeria, and Nigeria), the host nations are demanding so much of the profits that some IOCs have decided they can no longer operate there. ExxonMobil abandoned the Orinoco heavy oil deposits when Venezuela abruptly raised taxes from 1 percent to 16 percent.

It takes as long as 10 years from the time of winning bids (all proceeds going to the country of ownership regardless of whether oil is found or not) to reach any oil production. Corporate plans have to be made on the basis of the initial financial agreements. Countries may, and increasingly do, simply tear up existing contracts and insist on new ones. One country did so after a company had spent years and millions of dollars in explo-ration and finally discovered oil. The host country then canceled the original contract. When asked about this action, the country told the company that "we gave you the lease at the original agreed cost because we didn't expect you to find any oil."

In another country, before leases were issued, an IOC spent two years and millions of dollars determining which of the lease blocks being offered had the best prospects. When they told the host country they would take the leases, the NOC of the host company took the leases for itself instead. So the IOC did all the work and the NOC took all the benefit.

If IOCs are to continue finding oil after their home country has been thoroughly explored, as the onshore United States has been for example, they must explore new areas and depend on other countries for their survival as oil companies. This has also pushed drilling offshore, sometimes to depths down to 10,000 feet, making these ventures very costly. Major oil companies in the United States have moved both abroad and into the Gulf of Mexico, drilling as far as 200 miles offshore, risking hurricanes and other harsh conditions. Offshore drilling platforms are leased and the daily lease cost for one drill rig is as high as $700,000. A company has to find a lot of oil to justify such costs, and, at best, the oil is very expensive to recover.

In 2011, the largest investor-owned companies—ExxonMobil, Royal Dutch Shell, commonly known as Shell, and BP—reported higher profits but they produced less oil from fields around the world. Their decline in production was 7 percent. The results high-lighted a growing problem. New petroleum supplies are increasingly hard to find, and they cost more to find and develop. A decade ago, bringing in an oil well cost about $20 for every barrel produced. The cost now is estimated to be $50 to $60 per barrel. Cost is calculated on the basis of exploration and subsequent field development expenses amor-tized over the life of the field and oil produced.

For a time, these increased costs can be offset by price increases. Eventually oil com-panies will have to operate on a diminished production basis that cannot be offset by price increases.

Return on oil investment compared with other industries

Historic returns on the money invested in U.S. investor-owned oil companies have been in the mid-range of all industries. The greatest returns have been from tobacco and liquor companies, which do not have to lease drilling platforms, have their contracts torn up by foreign governments, or be subject to violent offshore hurricane damage with related high insurance costs. Ironically, oil companies supply a very useful commodity of daily benefit to millions, whereas tobacco and alcohol use damages health and results in huge medical costs to users and many others.

The rising cost of oil exploitation in increasingly difficult situations is illustrated by Petrobras, the Brazilian national oil company with its world class oil discoveries in the off-shore Campos and Santos basins. Petrobras ranks fifth among New York Stock Exchange (NYSE) listed world oil producers, but ranks first in capital investment, $43.5 billion for the most recent 12 months on record. But its return on investment ranks last. Worldwide, the oil industry is spending more to find each barrel of oil, and oil (and gasoline) prices trend upward accordingly.

Petroleum industry's use of technology

No other industry employs the magnitude and diversity of technology that petroleum does through its exploration, production, and refining. The scope of technology used includes satellites for positioning offshore drilling platforms and for transmitting data from remote drilling locations to regional offices to get a vision of the internal structure of the Earth. Completing ocean floor oil wells with robots laying and repairing thousands of miles of ocean floor pipelines to facilitate gathering crude oil and natural gas from wells to central locations is now possible. And there is much more. In refining, the chemistry and physics complexities involved are enormous.

Lengths to which oil industry now goes to reach oil

There have been many advances in oil exploration and production. One has been the increased distance to which multiple drilling bits can now be steered to reach an oil res-ervoir from a single drilling platform. The most recent record is 7.6 miles. This extended reach drilling (ERD) means that the "footprint" of oil production is greatly reduced, as ERD can now reach an area of as much as 4.4 square miles.

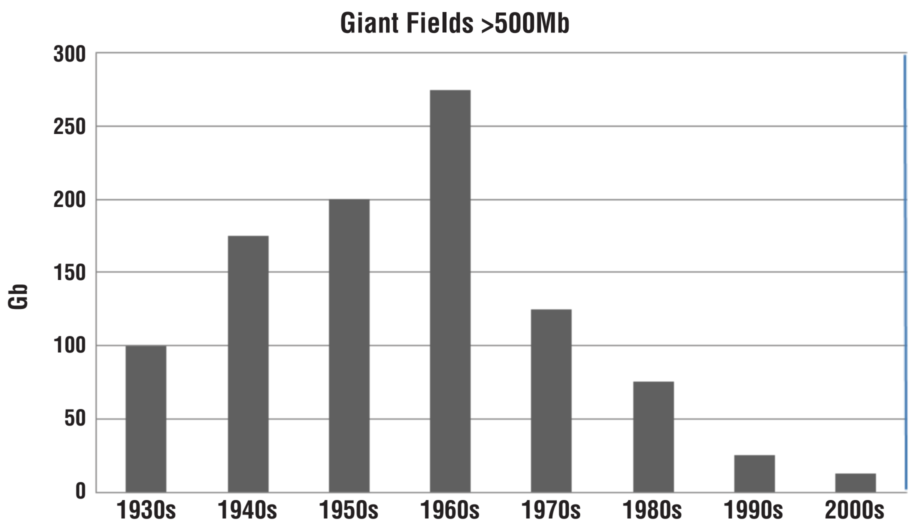
Not replacing their reserves

Because they now have fewer quality exploration opportunities, most major IOCs are not replacing their production with new discoveries. In 2008, for example, ConocoPhillips only replaced one out of every four barrels of oil they produced. The inevitable ultimate depletion of oil reserves is well recognized by IOCs and NOCs. Both are considering long-term alternatives in the energy future. BP and Chinese companies are investing in biofuels. Abu Dhabi Future Energy Company has invested in wind power. Solar energy is being explored by several companies. For this alternative, Saudi Arabia could again be a major producer.

At one time, when IOCs were dominated in production, they also set the price of oil. Now, the free market and OPEC's influence over production combine to determine the world oil price. IOCs have no control over pricing because of their diminished role in production and resource ownership. Still, Congress and other politicians hold "hearings" and "investigations" to take U.S. investor-owned to task oil companies in response to price increases. Many journalists, cartoonists, and now bloggers deprecatingly call the IOCs "Big Oil" but it is really "little oil" (*The Economist*, 2006). If congress or commentators truly wish to show concern for the American public, they need to get this right. At one time, the U.S. Congress did vote to sue OPEC over high oil prices. Nothing has been heard of it since, and it is doubtful OPEC was ever concerned.

Oil production (some call it "extraction") has exceeded the volume of oil discoveries since 1981, now by a factor of four. Around the world, the 31 billion barrels of oil con-sumed each year are not replaced with discovery, even with the combined exploration totals of the NOCs and the IOCs. Big fields, which contain most of the oil, are not being found as they were previously.

Figure 9-11. Discovery of Giant Fields Greater Than 500 Million Barrels (Billions of Barrels [Gb] Cumulative by Decades 1930s to 2000s)



Source: Campbell, 2005a

The International Energy Agency has projected that U.S. oil consumption will continue to increase and will reach 27.6 million barrels a day in 2030. However, since it is very unlikely that the peak of world conventional oil production will be later than 2010, all projections of increased consumption after that time are questionable. Some countries may outbid others for the remaining world oil supplies and, therefore, increase their oil consumption, but the total amount of oil available will be lower and total consumption will be lower.

By mid-century, world oil production may be down from its peak by at least half, perhaps more.

At an energy conference in Houston in 1999, Mike Bowlin, then Chairman and CEO of ARCO, made this observation:

> We've embarked on the Last Days of the Age of Oil. Nations of the world [that] are striv-ing to modernize will make choices different from the ones we have made. They will have to. And, even today's industrial powers will shift energy use patterns. So I believe it's time to prepare ourselves for the 'new look' of the energy industry of the twenty-first century.

We have been consuming oil at an unsustainable exponential rate. As a widely used advertisement by Chevron says, "It took us 125 years to use the first trillion barrels of oil. We'll use the next trillion in 30."

That said, how the new oil paradigm of higher oil prices, horizontal drilling, and shale "fracking" will alter the oil industry in the next several decades is unknown, but may be significant.

An oil reserves, oil industry, and geopolitical game-changer?

In the next chapter, I discuss the newly utilized technology of drilling vertically to a target shale formation and then drilling horizontally and hydraulic fracturing ("hydro-fracking" or just "fracking") the shale with chemically treated water and sand, which greatly increases the amount of gas ultimately recovered. Experience has shown that using this technology may also recover oil from shales. These strata were previously regarded only as oil source beds, not producible oil reservoirs. Combined with the rise in the price of oil, likely to remain at $80/barrel or higher, oil is now being economically recovered using this technology directly from some shales.

The volume of shale strata around the world is enormous, but there are also great unknowns. Still to be discovered in many areas is whether the shales have been buried deeply enough and long enough over geologic time to have reached the temperature (the "oil window") at which oil is formed. If the shales are not yet mature, the organic mate-rial is still kerogen, the precursor of oil, as is the case with misnamed "oil shale" strata, which have no oil.

Shale oil and oil shale — the distinction

At this point, we should make the distinction between *shale oil* and *oil shale*. It is easy to be confused. Oil from shale (shale oil) comes from shale containing oil that has not yet migrated into conventional oil reservoir rocks, and, in fact, might never have done so if reservoir rocks are not reachable by oil migration. It is true oil. *Oil shale* has no oil. It contains kerogen that is not yet heated to the temperature of the "oil window" when it could become oil.

Shales which have gone through the "oil window" differ in the amount of oil they may contain. Some have very little. Individual shales may also have "sweet spots" subject to economic exploitation. Other areas where the oil content is lower may not be economic to drill.

There are environmental impacts from the amount of water needed by each well (5-6 million gallons), and from the subsequent disposal of the recovered water containing chemi-cals used to thicken the water to enable it to carry sand farther into the formation to hold open the fractures. Obtaining enough suitable sand for fracking operations is a problem in some localities. Bowing to environmental concerns, France, Germany, South Africa, and in the U.S., New Jersey, New York, Maryland, and some other states have imposed tempo-rary or permanent bans on fracking.

But other states and many countries are using the new technology. It provides income, employment, a welcome energy source, and possibly revenue from exported oil and gas. Horizontal drilling and fracking of shales are being used worldwide to develop fossil fuel resources previously thought unavailable. China is moving fast to study its shales, which are numerous and widespread. Canada has several good prospects, some of which are already test drilled and proven.

With the large number of shale deposits in the United States and abroad, the frontiers of exploration have been greatly enlarged. Shale deposits may have large production potential not earlier recognized. Broadly interpreted, there are 600 sedimentary basins in the world (Guoyo, 2011). Evaluating all these prospects will take many years, so the amount of oil and gas that can be produced from these basins is unknown today. Exploitation of these resources may well result in two peaks rather than one oil production peak. The first is the peak (possibly already passed) of oil recovered from conventional reservoirs (usually sandstones or fractured or vulgar limestones). The second peak may come from conventional oil production with the added increment of oil from shale. A peak made independently by shale oil alone is possible, but not likely.

Key to economically recovering both oil and gas using the hydrofracking technology is the energy/profit ratio, also termed energy recovered on energy invested (EROEI). Because the technology is new, it is premature to make a study, but eventually it will be done to give an overall view of the worth of the technology. The energy/profit ratio for shale oil is likely to be less than for conventional oil now, estimated to be about 15 to 1. This ratio is declining as more costly oil is being produced in more difficult environments like deep water and Arctic regions.

Also, shales differ from one another in several respects, and some may require re-fracking to maintain production. The length of time significant shale oil production will last has not yet been established. Some shales can yield oil steadily for an extended period, but at a slow rate. Both shale oil and gas production may be extended for many years. The story of the oil industry is still unfolding. The last chapter is not yet clearly in sight. The period of the "oil interval" and gas production may be longer and geographically more widespread than we originally thought.

The potential geopolitical implications of these recent developments are great. The influence that OPEC has had on world oil prices and on international political alignments to accommodate the need for OPEC oil may diminish as other regions become important in petroleum production from shale. Extending the economic availability of oil and gas may also delay the development of alternative energy sources — delay, but not eliminate their ultimate need.

Importance of "fracking" for the United States

A number of enthusiastic statements have been made about the possibility that fracking will free the United States from dependency on imported oil. A more realistic geological and engineering assessment suggests that the production of oil from shale by fracking is likely to reduce but not eliminate the need for imported oil. Longer term, the U.S. and many other countries will still depend on the Gulf countries, where the "gift of oil from Allah" will be the last remaining source.

Oil still a finite resource

Whatever period of time oil from shale adds to the length of the "oil interval," it does not negate the fact that oil from whatever source is finite. Its inevitable decline in production to the point of essential exhaustion will cause a major transformation of economies and societies from what they are today. It almost certainly will mean a reduction in population that our petroleum-based (oil and gas) agricultural systems now support. For a time, additional oil and gas supplies may have the effect of supporting an even larger population, making the eventual but inevitable population reduction problem even more severe.

It is frequently said that we have sufficient oil left for 40 years at the current rate of production. But the current rate probably cannot be maintained. Furthermore, oil production does not proceed at a fixed rate for 40 years and then drop off to zero. Production curves rise from zero to a peak and then decline back to essentially zero. Some oil will be produced for many more years, but there will be less, and it will cost more. Oil will be used only for higher end-value uses.

The extravagant ways in which we have used oil also hold within them the seeds of oil's ultimate demise. The decline of world oil production will sort out excesses and pare down waste. A post-oil energy paradigm will emerge, but for many uses, there is no adequate satisfactory substitute for oil.

A fundamental concern is whether or not the absence of oil can be met by alternative energy sources in amounts necessary to prevent an energy supply gap somewhere between now and 2030. In 2007, a comprehensive report on this issue, "Facing the Hard Truths about Energy: A Comprehensive View of 2030 of Global Oil and Gas," was issued by the National Petroleum Council, an industry advisory group with more than 500 members. The report was requested by the U.S. Department of Energy. It is a detailed and exhaustive study, whose principal conclusion is: "There is no single, easy solution to the global challenges ahead," and that all available sources of energy must be developed and drawn upon to reach 2030 without a severe dislocation of the world economies due to insufficient energy supplies.

Colin Campbell and Jean Laherrère, in several books and many articles and lectures, have been far ahead of this issue, trying to inform the public of the looming changes in world oil supplies. A decade ago, their article in *Scientific American* (1998) was titled, "The End of Cheap Oil." The same title was on a 2004 cover article in the *National Geographic*. The late Matthew Simmons, in numerous articles, lectures, and media presentations, greatly added to efforts to inform public understanding of oil supply issues.

The oil market has been increasingly volatile as the margin between supply and demand for oil has narrowed. A slight change in either element results in wide price swings. But low prices are only temporary. Inevitably, the geological limits of the oil supply dictate that prices will go up. Other resources then will shape our future just as oil has for a century and a half.

> Humanity's way of life is on a collision course with geology — with the stark fact that the Earth holds a finite supply of oil. The flood of crude from fields around the world will ultimately top out, then dwindle.
>
> —Tim Appenzeller, "The End of Cheap Oil"
> *National Geographic*, June 2004

Historical Note: The "Oilman's Barrel"

The standard measurement for crude oil is the barrel, which contains 42 U.S. gallons at 60°F. The origin of this measurement has been widely researched and debated. The most comprehensive study of the origin of the barrel is the 122-page volume in 1958 by Robert B. Hardwicke, University of Oklahoma Press. A brief summary of some ideas on the origin of the barrel is given in a note on page 788 of Daniel Yergin's *The Prize* (1991). The exact origin of this measurement appears to be lost in history, but the more commonly accepted ideas are cited here.

When crude oil was first produced commercially in Pennsylvania, whatever containers handy were used, like those used for wine, beer, whiskey, cider, and other liquids. The need for a standard measurement soon became apparent to establish an oil trade. The "tierce" was a defined wine measurement in early use in Britain, as was the herring barrel, and a barrel for spruce beer. These were 42-gallon containers. These barrels may have become the standard oil field measurement, because they were in common use in the United States. They were very carefully made tight containers so they would also hold oil very well.

The *Oil & Gas Journal* of April 15, 1921 reported that in 1864-65 the first, standard barrel was made by Samuel Van Syckle at Miller Farm, near Titusville, Pennsylvania. It had a 42-gallon capacity, the size fixed in the year 1461 in England for the herring barrel, during the reign of Edward IV. Van Syckle specified the size of the staves to be used and made an honest 42-gallon barrel. Almost immediately he gained practically a monopoly of the business and the odd size barrels gradually disappeared.

Another possible origin stems from the fact that the lack of a standard measure caused confusion, friction, and short tempers. In 1866, a group of oil producers got together in West Virginia and issued a proclamation stating they would sell oil only by the gallon, but that an allowance of two gallons (for leakage and impurities) would be made for every 40 gallons, thus making a total of 42 gallons. From this, the standard 42-gallon barrel emerged, and ten years later, a Council of Producers formally adopted the 42-gallon barrel as the standard measure.

These are two of the more likely possibilities for the origin of the oilman's barrel. There are several others. There is also a related question of how the abbreviation "bbl" came to be used for the oil barrel, because there is no second "b" in the word barrel. Oil historian Paul Giddings, in his book *Standard Oil Co.* (1955), writes that kerosine was shipped in blue painted barrels and gasoline was shipped in red painted barrels. The term "rbl" was used to designate the red gasoline barrel and "bbl" indicated the kerosine blue barrel. The "bbl" symbol was the designation most commonly seen in refinery shipment records and ultimately became the general symbol for all oil in barrels. (NOTE: Kerosine is the petroleum industry spelling. 'Kerosene' is the more common spelling.)

Conversion equivalents

That theoretical 42-gallon barrel of crude oil is equal in energy to 5,800,000 British thermal units (Btus), 5,614 cubic feet of natural gas, or 0.22 short ton (short ton = 2000 pounds) of bituminous coal. Various crude oils differ in density, but the average barrel of crude oil weighs about 310 pounds.

Some Oil Terms and Numbers

The oil industry uses a host of technical terms and jargon, most of which do not get into the general media. For example, DST means drill stem test. Here are some the reader may encounter. Those related to natural gas are included at the end of Chapter 10.

- "boe" — barrels of oil equivalent; adding natural gas to total oil estimate, with 6,000 cubic feet of gas taken to equal one barrel of oil
- "bpd" — barrels per day
- "upstream" — exploration and production operations
- "downstream" — refining, transportation, and marketing operations
- "E & P" — exploration and production
- "mbpd" — thousand barrels per day
- "mmbpd" — million barrels per day
- "Gb" — international abbreviation for a billion barrels (gigabarrels)

Sometimes capital "M" is used either for thousand or million, so sometimes million may be written either as M or MM. It can be a bit confusing, and one has to know to a certain degree in what scale and in what context the discussion is being conducted. In general literature, the lower case "m" is widely used for million.

CHAPTER 10

Natural Gas

In common usage, "gas" means gasoline, but in the oil industry, gas means natural gas, which is mostly methane. With four hydrogen atoms attached to one carbon atom (CH_4), methane is the lightest of the hydrocarbon gases. With the largest amount of hydrogen relative to carbon, it is the cleanest burning of the hydrocarbons.

Once considered a nuisance in the oil fields and simply flared (burned off), natural gas is now in increasing demand as a feedstock for petrochemicals, for home heating and industrial use, and more recently, as a replacement for coal to produce electricity. As gas occurs in a greater variety of geological circumstances than oil does, and is more widespread in its occurrence, it now appears likely that the overall energy content of all gas reserves may be larger than that of all oil reserves. Gas may displace oil as the dominant fossil fuel in this century.

Table 10-1. Use of Natural Gas in the United States

Use	Percent
Industrial	33
Electric Power	25
Residential	21
Commercial	14
Other	1

Source: US Energy Information Administration 2010

Current use of natural gas in the United States is shown in Table 10-1.

Gas pipelines now reach all 48 adjacent states. About 60 percent of U.S. homes are heated with gas, and 70 percent of new subdivisions are being designed for natural gas heat. Much of northern Europe is heated with natural gas from the North Sea fields and Russia. Natural gas is the raw material for a large and growing worldwide petrochemical industry, which includes plastics and many other products. Natural gas is also the feedstock for the production of ammonia fertilizer, the most important fertilizer used in agriculture. The United States is the world's largest consumer of natural gas, and currently uses about 23 trillion cubic feet (Tcf) annually, equal to 26 percent of world production.

Origin of Natural Gas

Hunt (1996) writes: "All known hydrocarbon gas accumulations are biogenic in origin in that they come from the decomposition of organic matter in the earth's crust. No known non-biogenic methanic accumulations exist based on stable isotope measurement…." Occasionally, people suggest natural gas comes from somewhere deep within the Earth from virtually inexhaustible sources. Some methane could have been made inorganically but the amount is small and accumulations are of no economic value.

Although gas from the Earth is mainly methane, other associated gases exist including carbon dioxide, nitrogen, and usually small amounts of hydrogen sulfide. Some gas wells also produce helium, which is the only known source of that gas.

Methane comes from a greater variety of organic material than oil does. Deltaic sediments contain relatively large amounts of woody and other land-derived material, and are more likely to have gas than are deposits that are more marine in origin.

There are two principal processes that form natural gas. First, it may be expelled from micro-organisms during the digestion of organic matter. Methanogens are methane-producing microorganisms, which pervade the near-surfaces of the Earth's crust and are devoid of oxygen, and where temperatures do not exceed 207°F (97°C). Methanogens also live in the intestines of most mammals (humans included), and in the cuds of ruminant animals such as cows and sheep. This is called biogenic gas.

Second, methane gas is also produced by the decomposition of organic matter by heat and pressure, and accordingly is called thermogenic gas. This methane is formed similar to oil. Organic material deposited in mud and other sediment is deeply buried, heated, and compressed, causing carbon bonds to break down and form oil with some gas. Because the temperature of the Earth increases with depth, below about 15,000 to 16,000 feet, the temperature is so high that oil cannot exist and decomposes into methane. Gas is now being drilled and produced from depths of 25,000 feet and more.

Unlike oil formed by organic material, which must go through a heat "window" of at least 156°F, natural gas can form at relatively low (normal atmospheric) temperatures and pressures. The bubbles you observe in lakes are not due to fish blowing bubbles, as folklore would have it, but result from the production of natural gas from the decaying vegetation in the lake bottom. The relatively shallow Devonian black shales (black because of their organic material) of the eastern and central United States and the Cretaceous black shales of the Great Plains, some of which lie at shallow depth, contain methane gas. Farmers have drilled shallow wells (from a few dozen to a few hundred of feet deep) in their backyards and produced gas, which they piped into their farmhouses, and into other farm areas for various purposes.

Gas is often associated with oil, but a considerable amount of gas is not— thus the terms *associated* and *non-associated* gas. Gas associated with oil commonly is composed of a variety of gases including mainly methane but also ethane, propane, butane, pentane, and hexane, and is called *wet* gas. Gas not associated with oil usually does not have many other gases besides methane and is called *dry* gas. Some gas contains hydrogen sulfide, H_2S, and is called sour gas. The amount of hydrogen sulfide can be very large, to the point where one well in southwestern Alberta was classified as a sulfur mine. Many of the wells in the Caspian Sea region produce sour gas and also oil with hydrogen sulfide, which has to be taken out. The result is huge piles of sulfur for which there is no immediate use. Sulfur in oil and gas combines with water to form highly corrosive sulfuric acid, attacking any metal equipment it touches. Likewise, acid rain, which damages aquatic ecosystems, soils, and forests, is formed when sulfur dioxide (SO_2) combines with water to produce sulfuric acid (H_2SO_4).

Coalbed Methane and Gas Hydrates

Gas found by drilling a well into sediments in which various organic materials have produced gas is called conventional gas. This is where most gas comes from today. However, there are special occurrences of gas. One of these is coalbed methane gas.

Coalbed methane

The bane of underground coal mining is the toxic and explosive methane gas trapped in coal deposits. The miners' canary was taken into the mine to provide early detection of methane gas. Recently, with surging demand for natural gas in North America, particularly the United States, the search for gas supplies has expanded to coalbed methane.

Coalbed methane accounts for about 10 percent of total U.S. gas supplies. The estimated resource base is large, most of it located in the Rocky Mountain States, which now produce 80 percent of the coalbed gas. The wells for the most part are shallow and coal can be reached at less than 300 feet in many places with a truck-mounted drill rig as they do in the Powder River Basin of Wyoming. There, a well costs around $65,000 and the gas finding cost is about 16 cents per thousand cubic feet, with average well reserves of 400 million cubic feet. In other places, costs are substantially higher but it still may be economic to drill.

To release the gas in the coal, the coal has to be dewatered. As water is pumped out, gas is released from the coal as water pressure is reduced. However, pumping out the water can result in regional lowering of the water table, and the water may also be toxic, and if discharged on the surface, can contaminate both the landscape and local streams. In some areas, there is now substantial public resistance to coalbed methane development.

Nevertheless, coalbed methane development is continuing, with many thousands of wells projected to be drilled in the next decade. Canada and Australia have begun to develop their considerable coalbed methane resources, which appear to be considerable. Mexico is investigating its prospects, which, however, appear to be modest.

Gas hydrates

Gas hydrates (also termed gas clathrates) remain a tantalizing elusive source for the gas industry. Gas hydrates occur worldwide as solid material composed of water molecules forming a rigid lattice of cages of various sizes with most of the cages containing a molecule of gas, chiefly methane. They are gas-laden ice crystals. They exist in thin layers interbedded with other sediments, and are found in two principal regions: polar areas both onshore and offshore where it is cold enough for permafrost to form, and at the outer edge of continental shelves where there are cold ocean-bottom temperatures.

The total volume of these gas deposits is impressive, with estimates as large as 10,000 billion metric tons of carbon, more than twice the amount of all other known fossil fuels. These are resources, and here again, the distinction clearly needs to be made that resources are the amount of a given material in the Earth which is different from reserves, and which are the quantities of resources that economically can be produced with known technology. These gas hydrates estimates have been questioned by Laherrere as being too large. Laherrere (2000) also reports that the hydrates generally occur as dispersed grains and very thin laminae, with the thickest bed recorded so far, as being about one meter.

To date, efforts to recover significant quantities of gas from gas hydrates have been unsuccessful. The Japanese, who are very short of energy, have had and continue to have gas hydrate research projects with no significant success thus far, nevertheless Japan is continuing to explore for methane (Rach, 2004).

Opinion is divided about the prospect of recovering commercial gas from hydrates (Youngquist and Duncan, 2003). At least one major oil company has written them off for the foreseeable future. Others have more positive views and research continues. A recent report about the Canadian Mackenzie Delta, where a gas hydrate well flared gas, raised hopes that this area could see commercial methane production from hydrates in a few years. The United States conducts gas hydrate research through the United States Methane Hydrate Research and Development Act of 2000 (Public Law 106-193).

Extensive gas hydrate deposits are known to exist off the southeast United States coast, in the Gulf of Mexico, offshore Oregon, and in the Arctic coastal regions of the United States (Alaska), Canada, Russia, and elsewhere. The U.S. Geological Survey suggests that 38,000 Tcf are trapped in the Gulf of Mexico hydrates, and 590 Tcf are in the Alaska North Slope. However, for at least the next decade and probably for some time beyond, it is unlikely that gas hydrates will be a significant part of either North American or world gas supply. And they may never become commercial. Campbell (2005a) says, "… the methane occurs in disseminated granules and laminae, which are unlikely to be producible." Laherrere (2000) makes the same point. The potential volumes of energy resources being so large, however, gas hydrate research is continuing (Fisher, 2000; U.S. Geological Survey, 2001). The prize for success is huge.

Stranded Gas: LNG, GTL, and GTO

As noted earlier, gas is widely distributed; many deposits are located where there is no ready local market, nor can a pipeline be economically built to reach a market. This is called stranded gas. Of all known gas deposits, about 60 percent are classified as stranded. There are two solutions to this problem and a third is on the way.

Liquefied Natural Gas (LNG)

The technology for liquefying natural gas has been known for many years, dating back to the nineteenth century when British chemist and physicist Michael Faraday experimented with liquefying different types of gases including methane. The technology involves a liquefaction plant (called a "train") located where the gas is produced. There, gas is cooled to a liquid at -260°F, at which temperature it occupies 1/600th of its volume as a gas. Then it is put into refrigerated containers on a ship and transported to a regasification terminal where it is stored until it is ready to be gradually released into a pipeline system. There are four regasification terminals in the United States, which supply about two percent of U.S. gas demand.

LNG is expensive because the cost of the facilities at each end of transportation and the specially built ships which have to be built. One such system can cost several billion dollars. LNG tankers of the size now operating can carry from 150,000 to 200,000 cubic meters of LNG, about 4.2 billion cubic feet of gas per ship. One tanker can meet the energy needs of about 14 million U.S. households for one average day of space heating and other heat requirements. But the energy involved in cooling gas to a liquid, and required to transport it makes the net energy recovery considerably less than that from gas produced locally, processed, and then put into a pipeline.

Depending on the distance it has to be shipped, as much as 30 percent of the energy equivalent of the gas being transported can be consumed by the LNG system.

LNG in Japan, U.K. and U.S.

Currently, Japan is the world's largest LNG importer at 62.1 million tons per year. About 20 percent is used to power industry, 59 percent is used for electric power produc-tion, and 18 percent goes for residential and commercial uses. Primary energy consump-tion in Japan is now 48 percent oil, 25 percent coal, and natural gas and nuclear 12 percent each. Because of high oil prices and the emissions from coal plants, future energy expan-sion will be from natural gas and nuclear, in part to help mitigate climate change and in part to diversify away from oil. All of Japan's gas imports are in the form of LNG.

In 1964, the United Kingdom became the first LNG importer. Stranded gas in Cook Inlet, Alaska, was first transported as LNG to Japan in 1969 where Japanese housewives have been using it to cook with ever since. Today, an LNG tanker pulls into Tokyo harbor almost every day. The United States also has been importing LNG.

Table 10-2. Top Five Importers and Exporters of LNG. Metric tons/year 2010

Importers		Exporters	
Japan	57.9	Indonesia	23.4
S. Korea	22.4	Malaysia	21.9
Spain	17.1	Qatar	20.6
USA	12.8	Algeria	18.6
France	9.7	Australia	11.2

Source: The International Group of Liquefied Natural Gas Importers; Wood Mackenzie

LNG safety

The safety record of natural gas transport is excellent. There have been more than 33,000 LNG shipments in 45 years without a significant accident or cargo spill (Glenn, 2004). How-ever, safety concerns, particularly with respect to what terrorists might do to regasification installations, has created considerable local opposition to the sit-ing of regasification plants.

LNG tankers are huge. A typical tanker is longer than three football fields and contains more than 33 million gallons of LNG. However, raising the risk of terrorist attacks, articles have appeared stating that a terrorist attack on an LNG tanker " …would have the force of a small nuclear explosion." Such concerns have generated strong oppo-sition to siting LNG landing sites along any coast. Zellner and Hindo (2005) reported, "From Maine to California developers of liquefied natural gas (LNG) terminals are facing protests at every turn." "Liquefied gas projects energize opposition" read the headline with respect to four proposals to put LNG terminals along the lower Columbia River to supply Oregon and Washington now that an expanded population consumes all the power that can be guaranteed from the dams on the river.

With opponents painting horrific scenarios of terrorist attacks and raging infernos, it's easy to understand the opposition. The northeastern U.S. has "gone way past 'Nimby' (not in my back yard)" said Wallace P. Parker, Jr., president of Energy Delivery at KeySpan Energy Corporation. He went on to say, "it has gone 'BANANA' (Build Absolutely Noth-ing Anywhere Near Anything)."

How dangerous LNG would be in a terrorist attack is disputed. The Federal Energy Regulatory Commission says that, " …LNG won't explode and won't burn in its liquid state." In a spill, the product can be ignited but only after it vaporizes and combines with a mixture of air ranging from 5 percent to 15 percent. Mixtures outside that range are either too lean or too rich to burn and most of the gas, being lighter than air, quickly dissipates, so any resulting fire would be of very short duration. Very strong opposition to LNG terminals persists, even though New England, for example, during a record cold period in January 2004, got 30 percent of its natural gas from an existing LNG facility, and Boston's main power plant, which now runs entirely on LNG, kept the lights on.

Numerous onshore sites exist worldwide

Before the present concerns for LNG were thought of, a number of LNG regasification sites were built onshore. There are now 17 LNG export terminals and 40 LNG import terminals worldwide, and about 150 specially designed LNG ships in operation. LNG landing facilities exist in many countries, including Taiwan, Turkey, France, Greece, Spain, Belgium, South Korea, India, and others. China is planning to build as many as 10 LNG terminals over the next few years and is tying up long-term supply contracts with Indonesia, Russia, and the Persian Gulf nations.

Gas to liquid — GTL

A recent technology has been developed to convert natural gas to a steady-state liquid. "Steady-state" means it remains a liquid at ambient pressure and temperature. In this condition, it can be transported by ordinary oil tankers. The end product is a high-grade diesel fuel, which also can be used for a variety of other purposes including lubricant basestocks and petrochemical feedstocks. Several installations are under development for the conversion of standard gas deposits to liquid. The most significant is being constructed at the huge gas field in Qatar. However, the International Energy Agency (IEA) says that the gas-to-liquid technology is wasteful, with about 45 percent of the natural gas lost in conversion. The process consumes 10,000 cubic feet of natural gas to make one bar-rel of fuel. This is partially offset, however, by the fact that the end product is a high-grade, clean, diesel fuel, which does not need further refining.

Gas to Olefins — GTO

A third way to capture stranded gas for economic use is being developed by ExxonMobil. This is a new process for producing the basic chemicals needed to make polymers and other olefin-based chemicals. The process turns natural gas into ethylene and propylene—the high-value basic building blocks for making products ranging from food packaging and diapers to auto parts, toys, and medical supplies. The gas is first turned into methanol which can be easily transported. The methanol can be either shipped to the ultimate customer location for conversion into olefins or converted directly to olefins at the remote location. What makes GTO particularly appealing is its potential to use natural gas from remote fields that doesn't have easy access to world markets— "gas that otherwise would be difficult to sell" (The Lamp, 2004). The first on-site GTO plant, however, is several years away.

Electric Power Production from Natural Gas

There are no more significant hydroelectric sites available in the United States. Nuclear power production is out of public favor. Coal, because of its pollution potential, is also out of favor. Because of these factors, natural gas has become the choice for additional electric power generation.

Pipeline quality natural gas is 94 percent methane. Methane, as the simplest of the hydrocarbon molecules, produces the least amount of carbon dioxide when burned. This contrasts with coal, the most abundant of the fossil fuels, which has the lowest ratio of hydrogen to carbon. Coal, therefore, tends to produce more pollution and carbon dioxide, the main greenhouse gas, in the burning process. This is one reason why gas is preferred for electric power generation.

Gas is also preferred over coal because it is easily transported by pipeline to the point of use. Coal is dirty to handle and usually must be shipped by rail and put in huge storage yards adjacent to the power plant and moved again when it is put into the furnaces beneath the boilers. Unlike natural gas, which leaves almost no ash when burned, coal leaves considerable quantities of ash, creating a disposal problem. Burning coal also produces sulfur and other toxic materials such as mercury. In fact, coal-fired power plants are the largest source of mercury emissions in the United States. Although considerable progress has been made in reducing smoke stack emissions from coal burning power plants through the use of pollution control technology such as electrostatic precipitators and scrubbers, natural gas remains the premier fuel for electric power production.

There are o ther advantages f or using g as in electric p ower production. Th e combined cycle gas turbines can be built relatively quickly in small units (50-100-200 megawatts) compared with coal-fired plants, which may take a year or more to construct, and are much larger units. Also, gas turbines can be turned on quickly to meet peak power demands, whereas coal-fired plants cannot respond as fast and are used strictly in baseload electricity generation. Gas turbine sites are less damaging to the environment than coal-fired plants, and, therefore, the siting paperwork burden is less than for coal plants. Furthermore, combined cycle gas turbines are about 50 to 55 percent efficient in use of fuel, compared to coal-fired plants that are about 40 percent efficient.

Although most of the electric power generated in the United States is still generated by coal, natural gas has been gaining. It already has displaced oil to the extent that oil now only supplies two percent of the fuel used for electric power. So the arguments sometimes used to promote solar and wind development — that they will replace oil in electric power production — have limited validity in the United States. In other places, such as the islands of the Caribbean, oil for power generation is of major importance. These island nations are now investigating the feasibility of constructing a subsea pipeline from Ven-ezuelan gas sources to supply them with gas.

Gas as Aid to Oil Production

Gas associated with oil may occur as a gas cap over the oil in an oil-bearing structure, and also dissolved in the oil. Gas dissolved in the oil makes the oil more fluid and, therefore, easier to move to the well bore for recovery. Gas above the oil in a gas cap pressures the oil, moving it to the well bore and also aiding in greater oil recovery. So when oil is being produced, the ratio of gas to oil — the gas/oil ratio (usually expressed in cubic feet per barrel of oil) — is kept as low as possible, by “choking” the well with small aperture valves. These apertures are sometimes as small as 1/8th or 1/4th inch in diameter, to produce oil more slowly and retain as much gas as possible in the reservoir. If the well were run wide open, the gas dissolved in the oil would tend to come out first, reducing the pressure, leaving the oil behind. This is oil and gas reservoir engineering, a very important part of oil and gas production, managed by highly trained petroleum reservoir engineers.

If there is no pipeline to remove gas from the well site, the gas is almost always pumped back into the producing formation to aid in further oil production. This is the situation in the north Alaskan Prudhoe Bay Field. Eventually, this gas could be piped down to the 48 contiguous states. In the meantime, it is retained in the oil reservoir, except for a small amount that is used locally to support the living and working facilities of the oil camp. It gets as cold as -60°F in north Alaska, so the gas is very useful.

World Natural Gas Reserves

Because serious natural gas exploration has occurred much more recently than oil, reserve figures as we have them now, will no doubt be subject to substantial revision over the next decade or two. In the United States and Canada, about 80 percent of all wells now being drilled are for natural gas — quite a reversal from time past when oil was the prime exploration target.

Table 10-3. Ten Largest Holders of Natural Gas (Trillions of Cubic Feet 2010)

Country	Cubic Feet
Russia	1,581
Iran	1,045
Qatar	894
Saudi Arabia	283
United States	272
United Arab Emirates	213
Nigeria	186
Algeria	159
Venezuela	152
Iraq	112

Source: BP Statistical Review, 2011. Conventional gas only. Shale gas not included.

Table 10-3 presents current estimated world gas reserves of top ten countries.

In comparison with the top 10 countries, Canada, which currently makes up the difference between gas supply and demand in the United States, has reserves of 57,906 billion cubic feet. Mexico has estimated gas reserves of 13,162 billion cubic feet, which is not enough to meet its own needs. Under the North American Free Trade Agreement (NAFTA), Mexico imports gas from the United States.

Natural Gas Supply for North America

Unlike oil, which can be shipped easily in large quantities for great distances from source to use (e.g., Saudi Arabia to the United States), natural gas, except for some now being piped across the Mediterranean from North Africa to Europe, is mainly a continent-by-continent situation. This may change with increased shipments of liquefied natural gas, but at present, most gas supply must come from domestic sources.

Gas production and consumption in the United States

From 1960 to 1971, natural gas production in the U.S. grew by 83 percent. But from 1971 to 2001, it grew only nine percent. The peak of per capita gas production in the United States occurred in 1971, and on a per capita basis, production dropped by 26.2 percent from 1971 to 2001, indicating that population was growing faster than the ability of the United States to produce gas. Currently, the United States produces about 19.2 Tcf of gas per year, but uses about 23 Tcf. Gas demand is expected to grow to 30 Tcf within a decade. Can this demand be met?

To make up for the growing deficiency in domestic gas production, more and more gas has to be imported from Canada, which now amounts to about 16 percent of U.S. supply. At present, average per capita gas production in the United States is 68,790 cubic feet. For Canada, a much colder country on average, per capita consumption is 192,190 cubic feet per year. This very large per capita gas consumption makes Canada vulnerable to the time when its gas production peaks and begins to decline. This already may have occurred. In 2002, Canada drilled 18,000 gas wells, but production fell (Potential Gas Committee, 2003). There are two reasons for this. Gas wells have very high decline rates compared with oil wells. In Canada, first-year gas well depletion rates may be as high as 50 percent or more (some as high as 83 percent). The depletion rates settle down after about two years to 20 to 28 percent (Youngquist and Duncan, 2003). Also, the size of new discoveries has been falling. In 1991, average initial production per gas well drilled in the Western Canadian Sedimentary Basin (lying between the granitic Canadian Shield to the east and the folded Rocky Mountains to the west) was 775 thousand cubic feet a day. In 2001, average initial production was 375 thousand cubic feet a day. Obviously, the new reservoirs being discovered are decreasing in size which is typical of a maturing exploration region.

Mexico uses 12,020 cubic feet per capita per year, almost all of it for industrial purposes. Although the U.S. imports gas from Canada, the U.S. is a net exporter of gas to Mexico— a somewhat anomalous situation required by NAFTA.

Gas versus oil well depletion rates

Oil and gas reservoirs are managed quite differently from one another. Gas travels through pore spaces in the reservoir far easier and faster than oil. An oil well usually has a water-drive. If an oil well is run wide open, the water will tend to "channel," because the reservoir rock has different degrees of permeability. The result is that water, which can move through reservoir rock more easily than oil, will channel through the more permeable strata, bypassing the oil. The well then tends to go to water, leaving a lot of oil still in the reservoir. Oil wells are "choked" down so the oil is produced slowly, and while it moves slowly through the reservoir rock, water does not bypass it. This concept is termed the maximum efficient rate of production (MER).

In contrast, in a pure gas well, the gas rises through any water to the well bore. There is no channeling problem, and the well can be run essentially wide open. Thus, all the gas in the reservoir is produced rather quickly. As there is a time value for money invested in drilling the well, the quicker the gas is recovered, the higher the rate of return. The only major restraints may be the market for the gas and the availability of pipelines to carry the gas.

In summary, all these factors result in a much higher decline rate for gas wells than for oil wells. The average onshore gas well in the United States experiences on average, a 22 percent annual decline, much higher in early well life, but lower later. Offshore wells in the Gulf of Mexico have as high as a 50 percent annual decline rate. Gas wells, therefore, have a much shorter life than oil wells. This means many new gas wells must be drilled each year just to maintain production levels, which we are not doing. In 2003, the United States drilled 23,000 gas wells and the overall production level barely changed. It is a treadmill, and as gas drilling goes deeper, it is an increasingly expensive treadmill. In the first quarter of 2002, the top 30 U.S. gas producing companies suffered a gas production drop of three percent from the fourth quarter of 2001. These companies generate more than half of all U.S. gas production.

Size of discoveries

Larger fields tend to be found early because they are large. Simple random drilling can find them. As exploration proceeds, it takes more drilling to find gas and the amount of gas found per drilling rig declines. In the United States in 1994, the added production found by each drilling rig was 27.9 million cubic feet a day. By 2001, this figure had dropped to 13.9 million cubic feet a day.

Alaskan gas

There is a large amount of gas in the Prudhoe Bay and adjacent oil fields. Currently, this gas, which is associated with oil production, is reinjected into the reservoir to maintain reservoir pressure. Eventually, as the oil is depleted, more of this gas could be commercially produced. But this will require a pipeline using some route to the lower 48 states.

The volatile price of natural gas, which in the early years of the 21st century has ranged from $2 to $10 per thousand cubic feet, creates economic uncertainty for the viability of the project. The new Alaska pipeline will be built, but the cost is estimated to be $20 billion, and no gas is expected through the projected line until 2015 at the earliest.

More drilling

With the rapid depletion rates of gas wells, in order to get more domestic gas production, more drilling must be done, and done consistently. Emphasis should be placed on discovery of "giant" gas wells. These wells generally are deep (to 25,000 feet, and more) and very expensive.

Where are the prospects for more U.S. natural gas?

The U.S. Geological Survey has estimated where future U.S. gas supplies will be found. The study suggests that the Rocky Mountains and offshore areas of the United States offer the best prospects. Because of environmental restrictions in the Rockies, more and more U.S. gas exploration is taking place offshore. But there are drilling bans in effect on both the East and West Coasts, and in parts of the Gulf of Mexico. So areas open for gas exploration and development are limited.

Natural gas spills do not occur, and offshore natural gas developments do not create an environmental risk. Indeed, offshore drilling and production platforms are often sites of abundant organic growth, and fish and fishermen seek out these places. When these structures are abandoned, they are often sunk to provide reef habitat for plant and animal organisms.

Natural gas in Canada

Natural gas production in Canada has a long history of continuous expansion. From a peak in 2001, production has declined 4.5 percent. At this writing, the decline continues. Exploration is gradually moving northward, as well as seaward into more hostile, remote, and expensive to develop terrains.

The last frontiers for major gas finds in Canada appear to be offshore Newfoundland and Labrador, and northwest Canada in the Beaufort Sea-Mackenzie Delta Basin (BMB). Gas discoveries have already been made here in the BMB, but without a pipeline, have not been producing. The gas from the BMB may never reach the United States or even southern Canada because the energy-intensive Athabasca oil sands are projected for substantially increased development. Processing the oil sands may use all the gas from the BMB. The gas will be transported by a 1,200-kilometer pipeline at a cost of $7.7 billion (Canadian dollars). This will stimulate more drilling in the BMB, where there is apparently considerably more gas to be discovered. But wells drilled in this difficult environment are costly. Onshore wells cost about $20 to 25 million (Canadian dollars). Some gas may be found off the coast of British Columbia, but environmental objections have already been raised there. Eventually, drilling is likely to proceed.

As previously noted, Canada's main source of gas has been the Western Canadian Sedimentary Basin, lying between the largely granitic Canadian Shield to the east and the highly folded Rockies to the west (Canadian Gas Potential Committee, 2001). A modest amount of gas has been found off the east coast of Canada. Some 6 to 7 Tcf of gas have been identified in the BMB, and pipeline plans are well-advanced with completion estimated to be five to six years. However, it is estimated that by 2020, some 25 percent of western Canada's gas production may be used for Athabasca oil sand operations.

There are also oil and gas developments off Canada's east coast. The Hibernia oil field, with its associated gas, is now in production and several other fields have been discovered. One pipeline runs south and brings much needed gas to the New England area of the United States, boosting heating and industrial supplies there. However, recent mixed drilling results have precluded putting in a second pipeline. Fortunately, there is more to be explored.

Canada now exports 60 percent of its natural gas production to the United States. But there is already dissent in the Canadian Parliament against this volume of gas exports. As Canada's population grows, and gas supplies are inevitably depleted, Canada no doubt will choose to keep warm first rather than send gas to the United States. Anticipating the time when its gas supplies are limited, Canada is considering sites for LNG landing facilities.

Mexico

Mexico's gas reserves have declined from 77 Tcf in 1984 to less than 56 Tcf now. Production is insufficient to meet domestic demand, due in part to the lack of a pipeline infrastructure to distribute the gas from discoveries made during oil operations in the Tampico region. Even with that supply, Mexico would still be domestically short of gas. Under NAFTA, Mexico now imports gas from the United States at the same time the United States is importing gas from Canada. But Mexico, like Canada and the United States, is moving toward importation of LNG. One site has already been approved.

Elasticity of demand

The likelihood is that natural gas supplies in North America will be unable to meet the current and future demand for at least several years ahead. There is little elasticity in the use of natural gas for space heating of residences, offices, and service facilities (hospitals, etc.). These would have priority for limited supplies. Switching to other fuels would be difficult. Use of gas for electric power generation is an increasing trend, but there is some elasticity for this use in that other fuels can be substituted (coal, wind, solar).

Gas Now Worldwide Commodity

Natural gas in its various forms has become a worldwide commodity much like oil. As LNG, it is not as readily transported and discharged at the terminal as oil. The entire system from liquefaction to cryogenic ship transport to regasification facilities is more costly than oil's infrastructure. In stabilized permanent liquid form (GTL and GTO), however, gas is readily transported. Natural gas has gone global (Sen, 2004). One estimate is that it will overtake oil by 2025 because oil production will likely peak earlier than natural gas. With gas peaking later, it may eventually be a more important fuel than oil, but both will essentially be gone by the end of this century.

The cost of the whole process of liquefaction, transport, and regasification has been sub-stantially reduced in the past decade. Larger facilities have seen economies of scale, including larger ships and an average decrease in the cost of the ships from $250 million in the 1990s to $160 to $170 million today.

Gas — Expanding Use, Production, and Export

Natural gas is now being discovered in many areas that were ignored in oil exploration. Gas wells are simple to complete because gas does not need pumps, it flows. Processing gas to a usable quality is also simpler than the refining processes for oil.

Russia, with the world's largest known gas deposits, is an increasingly import source of gas for Europe. Because the gas fields of the British portion of the North Sea are declining, Great Britain is now a net gas importer. Norway continues to have a gas surplus for export.

In China, there is a major effort to secure long-term supplies of natural gas from both domestic and foreign sources. To enhance their position in energy supplied abroad, and gain technical expertise in shale oil and gas development, China Petrochemical Corporation in 2012 paid U.S.-based Devon Energy $2.5 billion for a one-third interest in Devon's several U.S. regional lease positions. The Chinese National Oil Corporation (CNOC) also bought interests in Chesapeake Energy's operation in south Texas Colorado, and Wyoming. Indonesia has a surplus of gas and has built liquefied natural gas facilities to export it to other countries. The Gulf of Thailand also has substantial gas deposits that are used domestically and exported as LNG.

In South America, Bolivia is fortunate to have substantial gas deposits and sells some of it by pipeline to Argentina. Peru recently discovered large gas deposits east of the Andes. A pipeline is being built from the Camisea gas fields in eastern Peru across the Andes to supply the Lima area with fuel and for export.

World Gas Reserves

Similar to oil, estimating proven natural gas reserves is not an exact science. Only rough estimates of the resource positions of various countries can be made at this time. The markets for natural gas in the form of LNG, GTL, and GTO are rapidly expanding.

Table 10-4. Percentage Share of World Gas Reserves by Country. Ten Largest Holders 2010.

Country	Percentage
Russia	23.9
Iran	15.8
Qatar	13.5
Saudi Arabia	4.3
United States	4.1
United Arab Emirates	3.2
Nigeria	2.8
Algeria	2.4
Venezuela	1.9
Iraq	1.7

Source: BP Statistical Review, 2010. Conventional gas only; does not include shale gas.

Note: Canada, largest supplier of natural gas to the United States, holds one percent of world's reserves.

Table 10-4 presents estimated natural gas reserves of the top ten holding countries expressed as a percentage. Gas exists in all oil producing countries, but the distribution of the total amount of gas in various countries is considerably different than oil. Saudi Arabia, for example, ranks first in oil reserves, but fourth in gas reserves.

Table 10-5 shows the world's top ten gas producing countries by percentage of share of world production. There are wide differences between proven reserve holdings (Table 10-3) and gas production by country. The U.S. has only four percent of world gas reserves but accounts for 19.3 percent of world production. Canada holds only one percent of world gas reserves (not enough to show in Table

10-3), but produced five percent of the world's gas supplies as of 2007.

As interest in natural gas increases, these figures will undoubtedly change considerably. However, the world's largest single gas deposit probably already has been discovered. It is located partly in Qatar and partly in Iran, in a large anticlinal structure that stretches across the lower end of the Persian Gulf between the two countries and holds an estimated 10 to 12 percent of the world's known gas reserves. The Iranian portion of this field is called the South Pars field. The Qatar portion is called the North Dome field. Some of this gas is consumed domestically by both countries, but large facilities are being developed for export of the gas in the form of LNG and GTL.

Table 10-5. Ten Top Gas Producing Countries. (Percentage Share 2010)

Country	Percentage
United States	19.3
Russia	18.4
Canada	5.0
Iran	4.3
Norway	3.3
Indonesia	2.6
Saudi Arabia	2.6
Algeria	2.5
Netherlands	2.2
United Kingdom	1.8

Source: BP Statistical Review, 2011

Note differences between reserve holdings (Table 10-3) and gas production (this table). Examples: USA 4.1 percent of reserves, production 19.3 percent. Canada (not in top 10) 0.9 percent of reserves, production 5.0 percent.

The Worldwide Future of Gas

The energy contained in world gas reserves is probably equal to, if not larger, than the energy in remaining oil reserves. Thanks to the many varied ways in which natural gas is used, worldwide demand is growing rapidly. For a time, gas is likely to become the dominant part of the world energy mix.

Gas Notes

In the United States and Canada, the price of pipeline quality natural gas (94 percent methane) may be quoted in thousands of cubic feet at a pressure of one atmosphere. You will see the letters "mcf" (for example, $5mcf) in the newspapers. The "m" is the Roman numeral for thousand and the "cf" stands for cubic feet. Gas is also sold on the basis of its energy content measured in British thermal units (Btus). (A British thermal unit is the amount of heat required to raise the temperature of one pound of water one degree Fahr-enheit at or near 39.2°F). Gas prices then are quoted at $5mmBtus, the "mm" standing for a thousand or a million. Or the gas may simply be quoted as "$5 per million British thermal units," which is one thousand cubic feet. Gas in the United States is sold to the consumer in "therms" (see your gas bill). A therm is a unit of energy equivalent to 100,000 Btus, which is the heat energy in 100 cubic feet of natural gas.

In gas well production, volumes are measured in thousands of cubic feet per day. Exceptionally good well production is stated in terms of millions of cubic feet per day. In measuring annual consumption of gas, as in a large industrial establishment, or a country such as the United States, in the estimated amount of gas in a gas field, the figure will most likely be measured in trillions. The U.S. currently uses about 23 trillion cubic feet a year.

Utilities that sell gas to the public, try to tie up long-term contracts with gas producers to assure a supply of gas at a known price. But after the recent fluctuations in the price of North American natural gas, producers are reluctant to enter into long-term price agree-ments. Therefore, utilities often buy gas on the short term. They can level out their gas costs to some extent by buying gas at times of the year when demand is low. In North America, spring and fall are lower demand seasons. In winter, and in summer, for air conditioning. The off-season gas can be stored above ground, or pumped back into certain porous stratigraphic units in the ground, including abandoned small oil fields to be recovered later when demand is high. If demand is higher than anticipated, the stored gas may be insufficient to meet demand and the utilities may have to buy gas on the "spot market," which is the immediate market. Then they may be bidding against others with the same problem so that the "spot market" prices may be several times the normal price that gas would be without the emergency. Utilities are allowed to pass on these higher costs to consumers, but are barred from making any additional profit.

Gas prices to the public are controlled by a regulatory body in each state, usually called the Public Utility Commission. Gas prices at the wellhead are determined by supply and demand.

The difference between the price of gas at the wellhead and the price of gas sold to the consumer represents the cost of cleaning the gas to pipeline quality, pipeline mainte-nance and pumping costs, and the return on the capital investments of the entire opera-tion. Those include the cost of building and maintaining the thousands of miles of pipe-lines to transport the gas to more than half the households and commercial buildings in the United States and to many industrial operations.

Abbreviations

Here is a short table of abbreviations used in the oil industry which occur every day. These are taken from a list in the Marathon Oil's Annual Report of 2000.

- mcf — thousand cubic feet
- mmcf — million cubic feet
- bcf — billion cubic feet
- Tcf — trillion cubic feet
- mcfd or mmcfd — thousand or million cubic feet a day
- bcfd — billion cubic feet a day
- boe — barrel of oil equivalent taken to be 6000 cubic feet of natural gas for easy calculation — exact figure is 5,614 cubic feet
- Btus — British thermal units — a measure of heat
- M — sometimes is used in place of mm for million

In general literature, outside the petroleum industry "m" and "M" are frequently used interchangeably, both referring to million. Thus, in reading, one must know the scale of the topic discussed.

If you find yourself confused by the symbols and numbers, take heart, for you are in good company. The lead editorial in the venerable *Wall Street Journal* (May 3, 2005) was entitled "Unnatural Gas Prices." The writer had no idea how appropriate the title was because he quoted an unnatural natural gas price when he wrote, "Gas prices have been as high as $7 per million cubic feet …." As just noted, the writer read the small "m" in "mcf" to mean million, rather than the correct one, a thousand. Wholesale gas is sold and quoted on the mercantile exchanges by the thousand cubic feet.

Shale Gas — New Frontier for Gas Discovery and Production

Much of the foregoing discussion is based on existing knowledge about natural gas occurrence and recovery methods, wherein U.S. natural gas production was facing permanent decline. But this may be changing. In the first decade of this century, technology has been developed to produce natural gas from black shales on a scale previously not thought possible. Small volumes of natural gas have been produced in the eastern United States from black shales for more than 100 years, lighting street lamps in some communities. But production methods then were relatively primitive, and used in only a few areas.

First used in the United States, new technology involves drilling a vertical well down to the black organic-rich shale and then drilling laterally, followed by injection of water, sand, and chemicals under high pressure. This fractures the shale, allowing its trapped gas to flow. This has reversed the decline of natural gas production in the U.S. Because gas-rich black shale deposits are widespread in the U.S. and Canada and many other parts of the world, this has opened a large new frontier for gas exploration and production. The technology was pioneered in the Barnett Shale of Texas. Canada also is using this new technology.

Combining shale gas wells with gas wells drilled into conventional gas reservoirs has raised the annual depletion rate to 32 percent compared with the conventional gas well depletion rate of 22 percent. The reserves found in shale gas wells are typically not as large as those found in conventional gas reservoirs. Shale gas wells cost three to four times as much to develop as do conventional gas wells. So the future of shale gas is subject to some limitations, both economic and environmental. Beyond the fracking fluid problems, minor earthquakes have been traced to the drilling and completion of shale gas wells. Also, the sheer amount of wells, roads, pads, pipelines, and other surface infrastructure that need to be developed to produce the widespread shale gas resource compound its "environmental footprint" by fragmenting natural habitats and disrupting landscapes.

The result is that many shale gas wells are not commercial unless natural gas prices are relatively high (Berman, 2009). A main advantage of shale gas is that black shales are widespread. In the United States there are several large gas "plays" in black shales of diverse ages, lying at various depths. Producing natural gas in large quantities from the world's black shales is likely to defer the world natural gas production peak well beyond its previously estimated date of around 2021. An accurate date for peak production cannot now be projected.

How this shale gas development will affect China, now the world's largest carbon dioxide emitter, and India, which both use coal almost entirely for power production or India, is now unknown. It will depend on how extensive their deposits of gas-bearing black shales are, and how intensively they pursue shale gas production. In a 2011 analysis of world shale gas, the Energy Information Agency estimated that China had 1,275 trillion cubic feet of technically recoverable shale gas compared with 862 trillion cubic feet in the U.S. For reference, the United States currently uses about 25 trillion cubic feet of gas per year.

In the U.S., ample domestic supply of natural gas has made the import of liquefied natural gas (LNG) much less attractive. As a result, LNG terminal construction has been put on hold, and existing plants are underused.

If natural gas production from black shales proceeds as hoped, gas may be the energy transition bridge to a low-carbon energy future. Already in limited use, natural gas is likely to be more widely used in transportation for gas-powered cars, buses, and trucks. The caveat, however, is that natural gas is far more difficult to transport, store, and dispense to consumers than gasoline. Building a nationwide network of natural gas service stations will take considerable time and great expense, and may not be economical in remote locations. Nevertheless, natural gas will assume an increasingly large role in our energy future for some time to come.

CHAPTER 11

Alternative Energy Sources: Nonrenewable

THIS HEADLINE WOULD HAVE BEEN untimely and of little concern two decades ago, but an awareness now exists that the enormous consumption of our fossil fuel inheritance has geological limits. When the abundant cheap energy supplies essential to our civilization are no longer available, the question is: then what? It is clear that nations have and can continue to have or obtain adequate energy resources in the future will be those best able to survive and compete. The result will be a worldwide scramble to obtain part of the remaining nonrenewable fuels. At the same time, other energy sources are being investigated. "Alternative" energy sources are the subject of numerous and growing numbers of books, articles, editorials, and of government and private funding.

The reality that we will witness the peak and irreversible decline of world oil produc-tion within the lifetime of most people living today (which may have already occurred) has encouraged numerous ideas on what the alternatives might be. Features articles about energy alternatives appear frequently. Some ideas deserve serious consideration. Others are rather far-fetched. It is important to make the distinction so investments of time and money can be made efficiently. Hopeful illusions will only confuse the public and policymakers. The one fact that has emerged is that no single future fuel can replace oil in its many uses.

The public has great faith in the ability of science and industry to solve the problem of the looming depletion of fossil fuels. The common view is that we can move to other energy sources with no great difficulty or adjustment to today's lifestyle. Policy makers and government officials promote this optimistic view. Few people in public life are likely to admit we have a problem for which there is no easy solution. In 2004, Alan Greenspan, then Chairman of the Federal Reserve Board of Governors, discussed rising oil costs. He said, "If history is any guide, oil will eventually be overtaken by less-costly alternatives well before conventional oil reserves run out." The subsequent news headline read:

"Greenspan: Alternative fuel will eventually handle demand." Although assured by a high government official that there is no future energy problem, the statement was an example of unsupported optimism by someone with no background or experience in energy resources. Factually, there are no less-costly alternatives to oil in sight. Chairman Greenspan did not clarify any alternatives. The reporter writing the article noted that the Chairman's comment was, "consistent with Greenspan's deeply held belief that market forces will eventually solve almost any kind of shortage …." This is the standard view of most economists, and has been accepted uncritically by much of the public.

Industries involved in the development of alternative energy sources are increasing in numbers as the need becomes clear. Solar, wind, and other energy projects receive government subsidies in the form of direct money grants, lower taxes, or accelerated write offs for research and development costs. It will take years of practical experience to fully evaluate what a particular alternative energy source can do for the economy and how much it will impact the environment. Meanwhile, there is great scurrying about not only among alternative energy industries, but also among car makers to determine what form the energy future will embrace, and especially the future transportation segment. The title of an article in May 22, 2006, *Business Week* asks: "Fill 'Er Up – But With What?" That is indeed, the question.

Chapters 11 and 12 on alternative energy sources, examine both positive and negative aspects of the alternatives.

Oil alternatives

When people refer to "alternative" energy sources (sometimes erroneously called "alternate" energy sources), they generally mean alternatives to the conventional supplies of oil and natural gas that we now obtain from wells. Their main concern is about oil. Because our economy's infrastructure, especially transportation, depends on liquid fossil fuel, the initial search has been to find as close a substitute as possible. This is the chief consideration of this chapter — an energy source as similar to conventional oil as may exist among the other nonrenewables.

Transition not simple

A fact that can hardly be over-emphasized is that the transition from a petroleum-based economy (especially the oil phase of petroleum) to an alternative energy-based economy, whatever the alternatives are, will not be simple and easy. There is a vast difference between drilling for oil that either flows or is pumped out of the ground, and any other energy source. The ease of handling and transporting oil and its various derivatives to near and distant places to be used in all sorts of motors, or heating, or many other uses is a characteristic of oil that is unmatched by any other energy form. Replacing approximately 84 million barrels a day of world oil consumption with a comparable high energy density alternative will be difficult, perhaps impossible.

Energy mix

In coming decades, there will be big changes from today in what is called the "energy mix," that is, the amount that various energy sources contribute to the total energy supply. Until 1880, wood was the principal fuel used in the United States. From about 1880 to about 1945, coal became the largest single energy source. Since 1945, petroleum (oil and natural gas) has been the most important energy source and now constitutes about 65 percent of U.S. energy supply. Nuclear energy has met stiff resistance in the U.S. No new plants have been started here since 1976. Solar energy, geothermal energy, wind power, and other minor energy sources are being developed very slowly in the United States. In other countries, however, nuclear energy is being more vigorously pursued, for example, in France and South Korea, and more recently in China. After the earthquake and tsunami of 2011, which damaged several units at the Fukushima Daiichi nuclear power reactor and caused mass evacuations over a wide area, Japan is having second thoughts about nuclear power.

The energy mix is continually changing, but at different rates at different times. How fast will the next shift to other sources of energy occur? Will it include new sources or re-mix present sources? The general trend has been away from fuels with a high-carbon content to ones with a lower-carbon content. The end of this trend in fossil fuels is natural gas, which has four hydrogen atoms to one carbon atom. The ultimate end is pure hydrogen.

In changing to alternatives, the question is what alternative energy sources are most easily integrated into our carbon-based infrastructure? Questions to be answered regarding alternative sources include:

- How easily can alternatives replace existing sources in terms of convenience of use?
- What is the initial cost and then the maintenance cost of the infrastructure to supply the alternatives?
- Can the alternatives be obtained in significant quantity?
- How widespread are they around the world?
- What nonrenewable resources (if any) do they require for their production?
- What is their net-energy recovery (energy expended to obtain them compared to energy produced)?
- What is the environmental impact of their production and use?
- This is the century when these questions will be answered to considerable degree.

Extensive literature

The oil crises of 1973 and 1979 brought home to the United States the fact that the nation cannot supply its own oil needs. This resulted in a flood of literature discussing alternative energy sources. With such a large volume of literature, these two chapters about nonrenewable and renewable energy sources are relatively long. This is justified, however, because the subject is extremely significant for the future in both personal and national affairs.

Facts

It is important to know the reality about the energy prospects that lie ahead. In the area of alternative energy sources, the general public has high but not well-founded hopes, and considerable misinformation. Many people hold firm opinions and prejudices for or against various energy sources. (Wind energy and nuclear power seem to evoke some of the strongest feelings, pro and con). As the Petroleum Interval begins its slow but inevitable decline, it is important in a democracy in particular, that citizens are well informed as to what can, and what probably cannot be accomplished in the realm of alternative energy sources. In the United States, the decline in oil production began in 1970. The general public seems to believe that adequate substitutes will be found when they are needed. Here we examine the possibilities.

Renewable and Nonrenewable

Energy sources can be grouped in various ways. A common approach is to divide them into those which are renewable and those which are non-renewable. All energy sources ultimately come from the Sun except nuclear energy (of which geothermal energy is an aspect), and tidal energy, the latter being a combination of the gravitational influences of the Moon and the Sun. Coal, petroleum, shale oil (from oil shale), natural gas, wood and other biomass, wind, hydropower, ocean thermal gradients, and waves are all in various ways energy forms which have their source in the Sun.

More sources?

One might ask if these lists (Tables 11-1, 12-1) of energy sources are complete, or if there is some significant energy source or sources which we do not yet see, or see only dimly? It is a fair question. Before the advent of the atomic bomb, the potential energy from the atom was only glimpsed by only a few. Before Col. Drake drilled his well, and the Industrial Revolution made use of oil, the potential for this liquid energy was almost unknown and certainly not visualized in terms of the importance of oil today. Before electricity was generated commercially, the lightning in the sky was only an interesting phenomenon.

Table 11-1. Nonrenewable Energy Sources

- Oil Sands
- Shale oil (if economically recoverable)
- Gas hydrates (huge volume if economically recoverable)
- Nuclear fission (subject to depletion of fissionable uranium isotope U-235; long term outlook may be improved if breeder reactors can be successfully operated)
- Geothermal (high temperature reservoirs needed for electric power generation subject to slow depletion, and other low temperature uses can be managed sustainably)
- Hydropower (Nonrenewable: life determined by life of reservoir if dam involved. Renewable if run of the river is used.)

But we have come a very long way in a few decades in understanding what kinds of energy sources do exist. It may seem rash to state that all the major energy sources potentially available to us are known. We do seem to have a rather reliable and complete view of the energy spectrum which extends from wood and other biomass to fusion, the energy in the Sun. It is unlikely that there is anything beyond fusion that we could understand and use, even if it existed. In this regard, Dr. Albert Bartlett (1994), nuclear physicist, writes:

> The probability is very small that technological developments will produce new sources of energy in the next century, sources not already known in 1994, that will have the potential of supplying a significant fraction of the world's energy needs for any appreciable period of time.

Making transitions

When considering alternative energy sources, the question is: now that we have known oil, how easily can we exploit other energy sources that may be more expensive, and importantly, may be less convenient than oil? Each energy source is distinctive, and although one can draw Btus, horsepower, or some measure of energy, from the source, the economic problem is the full cost to get the energy and use it in a particular application. Substituting coal, wood, or solar energy for gasoline energy in a car can be done, but it would be a complex matter to do. Oil is hard to replace as a versatile, compact, and convenient energy source. One of its big advantages is how much energy it contains per unit weight ("energy density"). Being able to conveniently carry the amount of energy in a five gallon container that can propel a car 100 miles or more is quite remarkable.

Another exceedingly important advantage of oil (and its derivatives, kerosene, diesel, and gasoline) is that it does not have to be used when it is produced. It can be stored and used later. This contrasts with electricity that must be used immediately when it is produced (as in the case of a power plant connecting to a power grid), or, if stored in batteries, requires a large volume of space compared with the energy stored in the same volume by oil. Other ways to store electricity are also problematic. It is difficult to grasp how large this difference is until one experiences the problem of storing electricity in quantity. So far, the problem has defied any satisfactory resolution.

The following discussion of alternative energy sources suggests how important they could be and which countries have them. There are variations in energy sources. For example, fuel cells are not an energy source in themselves but merely a different way of using energy materials. The long word, magnetohydrodynamics, simply refers to a tech-nology to obtain electricity from coal, oil, or gas, rather than burning these in a boiler. In simple words, magnetohydrodynamics (or MHD) is a process for the direct conversion of heat energy into electric energy by passing a hot ionized gas through a strong magnetic field. The technique is still being researched.

Heavy Oil and Oil Sands

There are various gradations of oil from those that are almost gas at room temperature to very heavy tar deposits. Some "oil" is solid enough to be dug up. Like Pitch Lake in Trinidad, where for many years the material was put in wooden barrels and shipped to Europe for paving. "Conventional oil" is oil produced by wells (flowing or pumping) that is now the major source of world oil. Heavy oil in its various forms is sometimes called "unconventional oil," because most heavy oils need special procedures to produce them instead of flowing or pumping from wells. The oil in oil sands is a step beyond heavy oil because it is thoroughly mixed with sand and cannot be separated from it without special procedures beyond those required to produce heavy oil. The product is called "syncrude."

But all these oils are heavy. They appear to be oils that have lost their lighter fractions by migration near or to the surface. Or they are organic materials that matured to the early oil stage but did not yet mature in the Earth to lighter oil, perhaps because they were not heated long enough to become fluid. The term bitumen is a general term applied to solid and semi-solid hydrocarbon materials, and is sometimes used for oil sands.

Heavy oil

According to the American Petroleum Institute standard, "heavy oil" is oil below 20^{o} gravity, which is basically a density measurement. There is a very large amount of heavy oil worldwide. It is more difficult to produce and to refine than lighter oil, but with higher oil prices, more of this oil is becoming more economical to recover. In conventional oil fields, usually less than half the oil in place is being recovered, and in general, heavier oil fractions are left behind. With higher prices, better technology, and by applying new technologies, more may be produced than is now included in "conventional proven reserves." This will help stretch out oil supplies, but the low-cost flush production of higher quality oil that the United States and other mature oil producing countries have enjoyed is gone. There is still a lot of oil available in various kinds of deposits both here and abroad, but at a price, and with a considerable time lag in development to put the needed equipment in place. The higher cost of recovering this oil will be passed on to the consumer.

In California, which passed its peak of production many years ago, heavy oil resources are the last to be developed because they are the most expensive. And lighter oils are mostly depleted. Northwest of Taft, in the southwestern San Joaquin Valley, the site of one of the very early oil fields developed in that state, there is a huge complex of steam generating stations, which pipe steam into the ground to reduce the viscosity of the oil so it can be pumped to the surface. Pumping each barrel of crude oil here requires about 320 gallons of water, in an area where water is scarce and coveted by agriculture as well (Miller, 2010). This is far less efficient and more costly than drilling a well and having the oil flow to the surface. It represents the final effort to get oil left behind by earlier flowing or pumping methods of oil production.

Another huge oil field in North America, the Alaskan Kuparak River Field, lies northwest of Prudhoe Bay. The oil reservoir is at a depth of about 7,000 feet below the surface. But above that is another potential oil field, the West Sak. It is a shallower unit (about 3,500 feet deep) that contains an estimated 20 billion barrels of oil, almost twice as large as the Prudhoe Bay Field. But the oil is thick, and the reservoir rocks are a loose, sandy forma-tion, which tends to clog up wells. This is an example of an oil deposit that is technically "recoverable." However, the cost would be high and the net energy that would be obtained would be small after the energy inputs of the production processes are subtracted.

Other heavy oil

There are very large deposits of heavy oil in the world that were never developed as oil fields. This is oil that has lost its lighter fractions, or was initially composed of organic compounds which did not mature in the Earth as conventional oil does, and never were very fluid. The two most notable of these deposits are in eastern Alberta and adjacent west-ern Saskatchewan, and in eastern V enezuela.

Heavy oil in sands can be produced by the CSS method (cyclic steam stimulation). In this process used by Imperial Oil for the Cold Lake region of eastern Alberta and also used in similar deposits in western Saskatchewan, steam is injected into the formation for a time to warm the bitumen and make it flow. Then the well is pumped. This cycle can be repeated several times. Since oil flows much better horizontally than vertically, and because shale partings are present in oil sands, this is the most effective way of producing oil *in situ*(Deffeyes, 2005). Imperial Oil later announced that they had patented a process to improve oil recovery still more by adding a solvent to the steam being injected. These oil deposits are being developed and can marginally compete with conventional sources. There are at least 25 billion barrels, and perhaps several times that much in these deposits. How much can be recovered economically is not known, but the net energy recovery will be low.

Eastern Siberia heavy oil deposit

There is a large heavy oil (really tar) deposit in eastern Siberia. Largely unknown because of its remote location and undeveloped status, the deposit is comparable in size to the Canadian Athabasca oil sands and appears to be the broad exposed edge of an ancient oil basin. Since Russia has far easier oil resources to develop, and the cost of exploiting the Siberian deposit would be prohibitive, it is unlikely to be developed in the immediate future. But the price of oil 50 years hence may see that field revisited.

Venezuelan very heavy oil

One of the world's largest deposits of heavy oil is in southeastern Venezuela, estimated to be about 1.2 trillion barrels. It spans about 54,000 square kilometers (20,800 square miles), but the main development covers about 13,600 square kilometers (5,250 square miles). The deposit lies along the east-flowing Orinoco River whose course is controlled by the northern edge of the ancient rocks of the south flank of the East Venezuela oil basin, which has received a huge charge of oil from the richly organic Cretaceous La Luna Formation (Green, 2006). Going down to the north at greater depths and correspondingly higher temperatures, the oil is a lighter oil, and is the basis for the highly productive Greater Oficina oil fields region, along with the Maracaibo Basin, one of the two mainstays of Venezuela's oil industry.

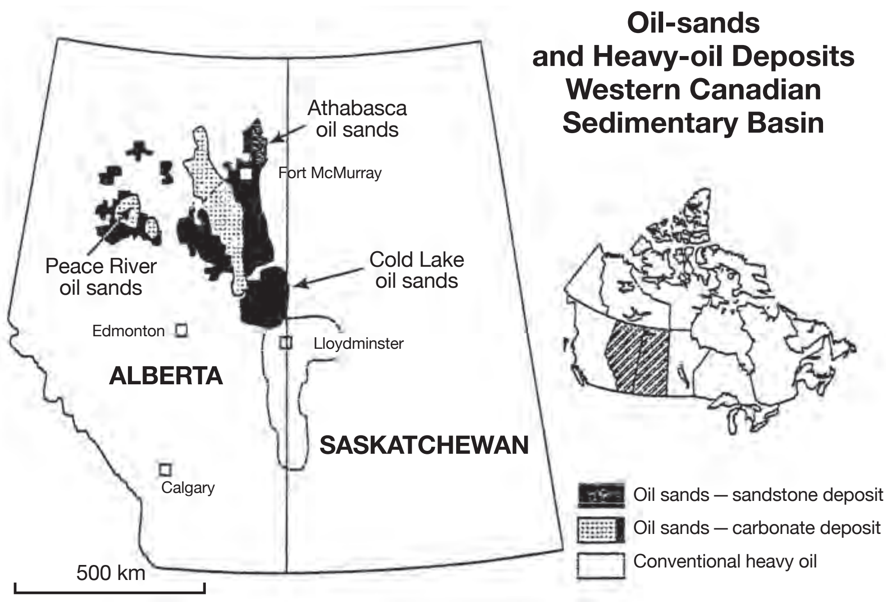
This exceedingly thick Orinoco Valley oil is found in an elongated deposit sometimes called the "*cinturon de la brea*" (belt of tar). To produce it, they drilled a pattern of five wells with the peripheral ones injecting steam to drive oil to the central producer. More recently they have been able to extract some oil by horizontal wells partly without steam (Campbell, 2005a). Production was expected to rise from 680,000 barrels a day to about one million barrels a day by 2010. However, in 2006, Venezuelan President Hugo Chavez canceled all oil development contracts with foreign companies working in the region and imposed new taxes several times higher than those in their original agreements. In January 2007, President Chavez announced he would simply nationalize all Orinoco operations (Wertheim, 2007). Given the record of nationalization in Venezuela and elsewhere, the end result will probably be a reduction in oil output as the investor-owned companies and their technical expertise depart.

Oil Sands

These deposits are ancient oil fields that have been uncovered by erosion or ones from which oil has migrated to the surface or near-surface, and has lost its lighter, more volatile elements. The largest of these deposits is in northern Alberta, the Athabasca oil sands a few miles north of Fort McMurray. The sands contain an estimated 1.7 to 2.0 trillion or more barrels of semi-solid hydrocarbons (Suncor, 1995). These deposits at Peace River, Athabasca, and Cold Lake (which do not exist at the surface) cover approximately 149,000 square kilometers (57,514 square miles), an area about the size of Michi-gan. If regarded as a single oil field, it would be the world's largest. It underlies about 23 percent of the Canadian Province of Alberta. The hub of operations is the city of Fort McMurray, once a small fur trading post, which now has a population of 70,000.

Some of the oil sands crop out along the Athabasca River and have been known to the native peoples for hundreds if not thousands of years. Because of the abundance of cheap conventional oil, the oil sands were largely ignored. An early experimental project was developed in 1948 and 1949, successfully demonstrating that the oil could be extracted. Commercial development began in 1967 when the Great Canadian Oil Sands Company (now Suncor) made a serious effort to produce the oil. But it was not until 1986 that Suncor was able to reduce production cost from $35 a barrel to about $11, making oil production competitive.

Figure 11-1. Geographic Distribution of Oil Sands and Heavy Oil Deposits in Western Canada



Source: Geological Survey of Canada

The rise in the price of oil from near $10 a barrel in the 1990s to over $147 a barrel in 2008 (in 2012, about $90), and public awareness of the reality of eventual peak world conventional oil production have increased both commercial and public interest in oil sands. Riding this wave of interest, the large cadre of those who write investment letters for a living have suddenly discovered oil sands. My mailbox has been flooded with enthusiastic offers to tell me how to invest in this "new energy source" and make my fortune. A promotional investment letter, *Outstanding Profits*, May 2006, tells me to buy a stock that is " … sitting on an oil discovery that is so huge it's bigger than the entire reserves of Iran, Iraq, and even Saudi Arabia." It goes on to state that " …this mammoth hydrocarbon deposit will soon become America's #1 oil source for the balance of the twenty-first century." The headline in another letter, *Elite Stock Report*, May, 2006, said: "Enough oil to last 100 years has been found…and it's right in our own backyard." It goes on: "It's like finding another Saudi Arabia. The MOTHER of all oil deposits. It's like a vast underground lake of oil…."

Many people had not heard of oil sands until recently. From the foregoing statements, they might conclude that oil sands are indeed a great new discovery, when, in fact they have been known to the oil industry for many years. And claiming the entire oil sand deposit is a producible reserve, when, in fact, less than half can ever be recovered, is a false promise. As to "enough oil to last 100 years" — for whom? Canada, the world? Such statements are highly misleading and encourage unfortunate public illusions. The prospects and the limitations of producing oil from oil sands need to be understood by both the public and policy makers so oil sands can be correctly viewed in the role they may play in our liquid fuel supplies.

Oil sands facts

Contrary to enthusiastic investment letters, oil sand deposits are not like an underground lake of oil. It would be nice if such were true. The deposit consists of grains of sand each of which has a thin film of water and outside this water film there is another coating of oil. There are two main methods of recovering the oil. One is by open pit strip mining in which the oil sand is loaded into the world's largest trucks. These are 400-ton capacity behemoths whose tires cost $45,000 each. The sand is trucked to a processing plant or to a conveyor system going to the plant. It takes two tons of oil sand to produce one barrel of oil. Using a hot water floatation process, the oil is stripped away from the sand. Initially, on recovery, the hydrocarbon is a black, viscous, tar-like material. In several steps, chiefly involving the addition of a light hydrocarbon solvent, the bitumen is upgraded to a straw-colored synthetic crude oil. Then it can be pumped and piped to a refinery where it is further upgraded to the various end products produced from ordinary crude oil.

However, up to 80 percent of oil sand deposits are too deeply buried to be recovered by surface strip mining, so an *in situ* process has been developed. Two wells are drilled vertically to the productive strata, and then deviated horizontally to exactly five meters vertically apart, and cased with perforated pipe. Steam is injected in one well which reduces the viscosity of the bitumen that is then pumped out using the other well. This is the SAGD (pronounced "SAG-D") process — steam assisted gravity drainage recovery method. It can recover from 60 to 80 percent of the bitumen in the formation.

How much can be produced?

The Alberta Energy and Utilities Board says that of the approximately 1.7 trillion barrels of crude bitumen estimated to be in place, only about 19 percent of it (315 billion barrels) can eventually be produced. Using today's technology, only about 174 billion barrels can be recovered given current and economic forecast conditions. So, of the vast amounts of oil in the oil sands that are enthusiastically cited by writers of investment letters and other reports, much less than half will ever be produced.

What is the ultimate daily rate of production?

The processes by which oil is recovered from oil sand do not lend themselves easily to large production rates. The weather is also a limiting factor. At times, it is 50°F below zero in winter. And because much of the land is boggy tundra, some operations, such as putting in new installations, must be done when the ground is frozen. To stop the newly mined moist sand from freezing to the bottoms of the trucks, truck beds are electrically heated. In summary, the conditions of production are vastly different and far more difficult than drilling a well in Texas or in the Persian Gulf.

Production is currently somewhat over a million barrels a day, with projections that it could reach 2.7 million barrels a day by 2015. The Canadian government projects six million barrels a day by 2030, and "some energy analysts project production as high as 11 million barrels a day by 2047. A more likely figure is four million barrels a day by 2030.

Limitations

There are two main limiting factors in oil sands production. First, it is an energy-intensive operation. Natural gas is now the chief energy source, although there is some effort to use some of the heavy elements of the oil sands themselves as fuel. It takes 1000 cubic feet of gas, using the SAGD process, to produce a barrel of bitumen. Each day, enough natural gas is consumed in the oil sands operation to heat 3.5 million Canadian homes.

The seven trillion cubic feet of gas discovered in the Mackenzie Delta may be piped to the Athabasca oil sands operation, and all of it may be used just for that purpose, with none available for other needs in Canada. To produce two million barrels [of oil] per day would require approximately two billion cubic feet of natural gas, which is roughly equivalent to the amount of natural gas needed to heat every home in Canada for a day. There has been some discussion about building a nuclear plant as an energy source. Because natural gas, like other fossil fuels, is a continually depleting resource, some other heat source will have to be found for the long term if Canada is to produce oil from sands into the next century.

A second factor limiting production is that large quantities of water are needed for both processes, and water is limited in the resource area. The Athabasca River is the main source of water. But the river has insufficient flow to support the needs of all the planned oil sands operations.

A third possible limitation on oil sand production is the diluent needed to thin out the bitumen so it will flow at ambient temperature and move by pipeline. This light diluent oil is produced by conventional oil production in Canada, which is declining. So there is some doubt that domestic sources can supply all the diluent required for the projected expansion of the oil sands operations.

Net energy recovery

Generally, the comparisons made between the recoverable volumes of oil sand oil with the reserves of Saudi Arabia simply state that Alberta has 174 billion barrels and Saudi Arabia claims 264 billion barrels. But this is a misleading comparison because the *net energy recovery* of a barrel of oil from oil sand is considerably lower than from a barrel of oil from a Saudi oil well. Besides the energy cost of the natural gas it takes to recover a barrel of oil sand oil, there are other energy costs incurred in the surface mining, stripping off the overburden, loading and hauling the oil sand, and the ultimate disposal of the leftover sand. Saudi Arabian oil incurs none of these costs.

I have discussed the issue of calculating net energy recovery with various people in the oil sand country, and even suggested that the cost of supplying and heating the Fort McMurray population should be included in the energy cost. In northern Alberta, winter is severe, arrives early, and stays a long time. Conducting mining and plant operations in sub-zero temperatures, and keeping all the equipment working is difficult. The quartz sand in these deposits is harder than steel and it inevitably gets into the machinery and causes maintenance difficulties. Including the narrower and more immediate energy costs, the open pit mining and floatation process reportedly yields an eight to one ratio of energy recovered to energy invested. The SAGD process yields a four to one energy recovery ratio.

The *Oil & Gas Journal* now includes 174 billion barrels of oil sand oil in with Canada's conventional oil reserves of about five billion barrels, making Canada the second largest holder of oil reserves in the world after Saudi Arabia. But in terms of net energy recovery, this is not a valid comparison. A reasonable estimate might be that the net energy recovered from oil sands is about 70 percent of that recovered from oil produced by conventional oil well operations. This would reduce the estimated oil to be recovered from oil sands to about 122 billion barrels, still a significant amount, and equivalent to a four-year world supply at the current rate of world demand.

Environmental effects of oil sand developments

The impacts of oil sands development in Alberta are considerable. Aside from carbon dioxide emissions discussed in Chapter 20, there are several other significant environ-mental impacts (Clarke, 2009; Nikiforuk, 2008). Waste water and large volumes of sand resulting from the extraction of oil are dumped into tailings ponds, which now cover more than 50 square kilometers (19.3 square miles).

Taking water from the Athabasca River, especially in winter when the flow is substantially reduced, has an adverse effect on the fish population. It also has a negative impact on the Peace-Athabasca Delta in Lake Athabasca, which is the largest boreal delta in the world, and one of the most important waterfowl nesting areas in North America. The areas where strip mining is conducted leaves a moonscape land surface, of which only about 17 percent has been reclaimed to date. Huge piles of discarded sand mar the landscape along with great quantities of contaminated waste water. The original pristine land-scape of bog, marsh, and boreal forest cannot be restored. The *In situ* SAGD recovery process (which will gradually replace surface mining) has considerably less impact than strip mining, but there is environmental damage from roads and drill sites.

Upgrading oil obtained by either process also causes a substantial increase in carbon dioxide emissions to the degree that the pledge Canada signed in the Kyoto Protocol to reduce carbon emissions has not been met. Instead, emissions have increased. In 2011, Canada formally withdrew from the Kyoto Protocol, drawing condemnation from environmentalists worldwide (Curry and McCarthy, 2011). Alberta, and Canada as a whole, pay a high price for the revenue and jobs gained from oil sands development (Nikiforuk, 2008). Under present royalty arrangements, the federal government actually gets more income from oil sands than the Province of Alberta does. Some thought is being given about how best to invest the money from oil sands to leave a lasting legacy for Canada after they are gone (David Hughes, personal communication).

A last refuge for the oil companies

Since most of North America is thoroughly explored and drilled, there are few new places left for major oil companies to operate. Canada has a stable government, a pleasant change from what companies experience in many other countries. There is also little or no exploration cost or risk to operating in the oil sands. We know where they are, and except for drilling a few holes to determine the depth and thickness of productive strata, there is little drilling to be done except for putting the pipes in place for the SAGD production process. The long lead times required to negotiate leases with unstable and corrupt governments, the lengthy and costly exploration operations, the billions it now costs to build and put drilling platforms offshore in as much as 10,000 feet of water where they are subject to hurricanes and the possibilities of terrorist attacks, are all avoided by operating in the Alberta oil sands. It is a last refuge for the oil companies, not only for North American companies, but also for those of other countries like Shell from the Netherlands, and Total of France. The recovery of oil from oil sands is not a geological matter but a manufacturing process. Costs are quite predictable. There is also a greater stability and security than in many other oil operations in distant lands where pipelines are blown up and workers on oil rigs are kidnapped. Oil field workers have been killed by local insurgent groups in places where oil companies operate in regions of civil war, as in Nigeria and Colombia.

There are very few oil sand deposits in the United States. Some exist in Utah and elsewhere, but these are small, and the hydrocarbon is dense and, therefore, takes even more processing than Canadian oil sand. In the past, fuel production from unconventional sources usually depended on large government subsidies. The Canadian oil sand industry is an exception. It succeeded, where others have failed. Thanks to careful engineering and the absence of exploration costs, Canadian oil sands look better and better.

As a result, several major oil companies and a number of other companies are vigorously pursuing oil sand resources. Several oil sands plants are in operation and more are planned. The largest are the Syncrude plant (a consortium of companies, including the Alberta government), and the Suncor operation (an independent company based in Calgary). Canadian Natural Resources is another major player in oil sands development. The production activity in the Alberta oil sands is currently the largest single industrial development in the world.

What can oil sands do for future world oil supply?

There are very optimistic projections as to what oil sands can do for the world's oil supply. But given current world oil consumption of 84 million barrels a day, four million barrels of oil a day from oil sands by 2030 can only meet a small fraction of world oil demand. Furthermore, by 2030, when four million barrels a day of production could be reached, Canada's conventional oil resources will be largely depleted and Canada itself will need increasing amounts of oil from the oil sands. In 2001, daily oil production from oil sands exceeded the production from conventional oil wells in Canada, and it has done so ever since. Minimum Canadian demand on the oil sand oil by 2030 could be two million barrels a day. Canada rightly will take care of its own needs first, leaving perhaps two million barrels a day to be divided among all the other consumer nations waiting in line, including the United States.

The U.S. Energy Policy Development Group has described the oil sands as "a pillar of sustained North American energy and economic security." But the total demands for just two million barrels that might be available for daily export, makes the oil sand pillar for North American energy and economic security look rather thin. The United States, with its current consumption of 19 million barrels of oil a day, will not see its oil supply problem solved by Canadian oil sand oil. At best, it will probably be mitigated to a small degree.

Oil sands are a fine long-term resource for Canada, but they are not a significant solution to the coming world oil demand and inevitable shortage. If they eventually become significant to world oil production, it would only be because conventional oil production declined so much from what it is today that a few million barrels from oil sands would be an important amount. By that time, for all practical purposes, the "oil interval" will be over.

An Albertan authority's statement on oil sands

Award-winning Canadian journalist, Andrew Nikiforuk (2008), in his excellent book, *Tar Sands: Dirty Oil and the Future of a Continent*, presents the details and environmental impacts of production of oil from tar sands. ("Oil sands" is simply a nicer term for the same thing.) This is a landmark study of a topic that has large implications for Canada's future. Nikiforuk concludes his book with an admonition based on the environmental impact of tar sands exploitation: "The unbridled destruction there should be a bold invitation for us to live within our means, exercise prudence, and abandon the oil-fueled mythology of consumption without limits."

Oil Shale

Oil shale and oil sands are very different things, but some people who write about them, especially investment letter writers, confuse the two. There is no oil in oil shale, whereas oil sands contain true crude oil. Oil shale is solid rock. Oil sands are friable.

Shale oil and oil shale

At this point, the distinction again (as in Chapter 9) should clearly be made between *shale oil* and *oil shale*. It is easy to become confused. Oil from shale (shale oil) comes from shale that contains oil which has not migrated into conventional oil reservoir rocks. It is true oil. Oil shale on the other hand contains kerogen, organic material which has not yet been heated to the temperature of the "oil window" that would enable it to become oil. Some sedimentary basins drilled by oil companies find shale that has kerogen — not yet oil — and these are commonly referred to as "immature" basins.

"Oil shale" — a promotional name

The term "oil shale" is a promotional name, for, as Savage (1967) noted, the term "oil" is a magic word, which can raise large sums of money, whereas the true name "organic marlstone" won't raise a dime. The story is told of an oil shale promoter who went to an eastern banker and asked for a loan to develop a "low-grade hydrocarbon deposit in marl." The banker immediately turned him down. A week later, the promoter visited the banker again and announced he now wanted money to launch an oil shale development. He got the loan. Same rock deposit as the week before, but with a different name. The project was a failure and the loan went into default. But the lure of "oil" shale continues.

So, except for the fact that oil shale neither contains oil nor is it truly shale, the term is very good. It can raise money for oil shale ventures. So far, none has succeeded on a significant commercial scale.

No oil, not shale

Oil shale is neither sand nor shale, but what geologists call marlstone — a mixture of clay and calcium carbonate. This and other facts about the history of the Colorado oil shale ventures is discussed in a fascinating volume by Harry Savage (1967), titled *The Rock That Burns*.

Oil shale exists in a number of countries, notably Brazil, Scotland, and Estonia. China has some deposits. A modest oil shale production operation existed in Scotland for a number of years. In Estonia, oil shale is simply shoveled into furnaces beneath boilers of power plants and burned without processing. This results in a huge amount of ash to be disposed of, but the operation seems to be economic enough to be useful.

Oil shale has a long history. It was first exploited in France in 1837, but the mines (Autun mines) were closed in 1957. Elsewhere, oil shale was exploited in Scotland (1850-1963), Australia (1865-1952 and 1998-2004), Brazil (1881-1900, 1941-1957, and 1972-present), Estonia (1921-present), Sweden (1921-1965), Switzerland (1921-1935), China (1929-present), and South Africa (1935-1960) (Laherrere, 2005). A number of attempts have been made to produce it in the United States, and Laherrere has made an excellent chronological record of these efforts. All projects have been on a small scale.

"The rock that burns"

Oil shale burns, giving credence to the lore of the Native Americans of the West, which relates that lightning strikes cause "mountains to burn." Another story is told of a prospector who built a cabin in one of the valleys in western oil shale country and built a fireplace out of the blocks of oil shale found in the vicinity. He invited neighbors over for a housewarming. It was a cold fall afternoon, so he built a large fire in the fireplace, whereupon the fireplace caught fire and ultimately burned down the entire cabin. It was a housewarming considerably beyond expectations.

U.S. Oil Shale Deposits

The United States has the largest oil shale deposits in the world, chiefly located in Wyoming, Colorado, and Utah. The richest are in the Piceance Basin of western Colorado and the Uinta Basin of eastern Utah. These are organic-rich rocks that were deposited in ancient lake basins beginning about 50 million years ago and continuing for several million years.

Impressive numbers

Enthusiastic reports about the potential of oil shale abound. The U.S. Geological Survey, in a pamphlet distributed some years ago for general public information, states:

> The oil shale deposits of the United States can be considered collectively as an enormous low-grade source of oil, hydrocarbon gas, or solid fuel. Deposits with an estimated yield of 10 gallons or more oil per ton of rock contain more than 2 trillion barrels; their possible extensions may contain an additional 3 trillion barrels; and, speculatively, other unappraised deposits may contain several times as much oil.

Duncan (1981) projected:

> At present, only the highest grade and more accessible oil shales are of commercial interest. Such potential resources are more than double the proven reserves of petroleum in the country. However, using demonstrated methods of extraction, recovery of about 80 billion barrels of oil from accessible high-grade deposits of the Green River Formation is possible at costs competitive with petroleum of comparable quality.

A Utah State report on the Piceance and Uinta Basin deposits states that they are estimated to contain 562 billion barrels of recoverable oil (Utah Natural Resources Division of Energy, no date, approx. 1990). An ad in *Forbes*, March l, 1968, placed by the investment magazine *Indicator Digest*, urging subscription to their publication, described oil shale as "An incredible mountain of oil, so VAST it spreads over 16,000 square miles … so *plentiful* it can supply this country's needs for 200 years."

Even the venerable *Oil & Gas Journal*, in an editorial (April 7, 2008) promoting unconventional oil, stated: "And the U.S. has more than 2 trillion bbl of shale oil in place …." ignoring the fact that there is no actual oil in oil shale, and subscribing to the illusion that, even if a production method could be devised, converting all the kerogen in oil shale to oil would be impossible. Oil shale oil remains a source of great expectations, which may never be realized. The Stuart oil shale deposit in Australia was recently developed, but it is not currently operating and may never again.

Recovering Oil from Oil Shale

The term "recoverable oil" seems to be used rather loosely with regard to oil shale, and can be somewhat misleading in the sense that it may be ignoring environmental costs and basic economics. In general, "recoverable" implies profitably recovering the oil under today's economic conditions and known technology. If the oil was "recoverable" as far back as some of these statements were made, the question is why wasn't it done then?

Various recovery projects

For more than 90 years, numerous attempts have been made to develop a shale oil industry in the U.S. Shortly after World War II, the U.S. Bureau of Mines built an oil shale demonstration plant just north of Rifle, Colorado. It was closed. Other projects include Occidental Petroleum's project near De Beque, Colorado, which involved tunneling into the shale, excavating a room, and then blasting down shale from the ceiling. The room was then sealed off, and the fragmented shale set afire. The oil released from the shale by the fire was to be drained out through a trough previously cut in the floor. The project proved unsuccessful and was abandoned.

Figure 11-2. Shale Oil – the Elusive Energy

Sidney Harris: ScienceCartoonistPlus.com. By permission

Equity Oil and the U.S. Department of Energy did a joint project in which 1,000° F steam was injected into the shale through numerous wells under pressure of 1,500 pounds per square inch. Water, oil and gas were to be recovered from the injected zone through production wells. This was unsuccessful. Unocal (now part of Chevron) has been working on oil shale technology since the 1920s. One small experimental plant was built many years ago in upper Parachute Creek Canyon, in western Colorado, then abandoned.

Oil shale comes in various degrees of richness. Some deposits can produce up to 100 gallons of oil per ton like the famous Mahogany Ledge of the Piceance Basin. A good average grade that could be economical is about 30 gallons per ton. The differences in grades can be substantial in vertical distances in the strata of only a few feet, which is one of the problems in economically recovering the oil. A consistently good grade thickness of shale is required for efficient mining.

The main thing that the kerogen in oil shale needs to become oil is heat. To speed up Nature's process, the conventional approach has been to first mine the rock (blasted out to begin with), and then load it on trucks to be hauled to a plant where it is ground into fine particles and heated to a temperature of about 900° F. This produces a tarry mass to which hydrogen must be added to make it flow readily. Currently, the chief source of hydrogen is natural gas, which unfortunately brings us back to petroleum, which we are trying to replace. Also, oil shale, when heated, tends to pop like popcorn, so the resulting volume, even after the organic material is removed, is larger than the volume of rock initially mined. This creates a huge waste disposal problem. The waste material has to be hauled somewhere. The ideal situation would be to have a mountain of oil shale near a large canyon, where the oil shale could be brought down the mountain largely by gravity, run through the processing plant, and the waste material dumped into the adjacent canyon. Because there are various toxic elements associated with the oil shale waste, the pile of oil shale waste would have to be stabilized and sealed off from groundwater or surface water to avoid contamination.

How much net energy?

Developing oil shale deposits by other than *in situ* methods, involves huge materials handling and disposal problems. Also, when the energy costs of mining, transporting, refining (including the addition of hydrogen), and waste disposal are all added up, the net amount of energy recovered from oil shale is relatively small. It does not begin to compare with the net energy reward now obtained through conventional oil well drilling and production operations. Some studies suggest that the final figure for the net energy in oil recovered from oil shale is negative. At best, it is not large, and surface mining for oil shale may disturb up to five times as much land as that caused by coal mining for the same net amount of energy. It also would be far more destructive to the landscape than oil wells producing the same net amount of energy.

Water supply support

Another problem with the Utah and Colorado oil shale deposits is that the processing and the auxiliary support facilities need large amounts of water. The richest oil shale deposits are located in the headwaters of the Colorado River. This river now barely reaches the Gulf of Lower California. Present demand for water already exceeds what the river can meet. Water supply would be a serious problem for any large development of oil shale because it would take at least two barrels of water to produce one barrel of oil. The states downstream from the oil shale deposits have already protested the withdrawal of Colorado River water for shale oil production. The development would immediately pit Colorado and Utah shale oil projects against California, Nevada, and especially Arizona.

These factors and the difficult technological problems of how to efficiently mine and process the shale (organic marlstone) and dispose of the waste have combined to delay oil shale development of these deposits. So far, very little oil, except on a pilot plant scale, has been produced. The major oil companies have tried to develop a viable, economic, commercial operation, but none has been successful thus far.

An attempt to economically recover an oil-like substance from oil shale reached a rather astounding climax and conclusion in the 1980s and early '90s. With the oil crises of 1973 and 1979 fresh in mind, both Exxon and Unocal launched huge projects in the area of Parachute Creek just north of the Colorado River.

In 1980, Exxon began construction of the Colony II project designed to produce 47,000 barrels of oil a day, and announced that production of 15 million barrels a day of synthetic fuels by 2010 would not be "beyond achievement" (*Business Week*, 1980). To support this project, it was even suggested to divert part of the Missouri River, some 700 miles away.

To get the project started, Exxon announced it would spend $5 billion on various preliminary projects, and build a town for 25,000 workers. To house this small city of employees, Exxon built a model community across the Colorado River on a broad gently sloping upland called Battlement Mesa. It had everything including a recreation center. But about the time that the Battlement Mesa community was completed, Exxon concluded that the oil shale project was uneconomic. On May 2, 1982, dubbed "Black Sunday" in the town of Parachute, Exxon announced it was abandoning the project (Gulliford, 1989; Symonds, 1990). The Battlement Mesa housing was never fully occupied. Ultimately, Exxon sold it to a real estate development company.

Backed by a government production subsidy, Unocal persisted and built a large plant just north of the town of Parachute (previously called Grand Valley). Construction was completed in August of 1983, at a cost of $654 million. In its 1987 annual report, Unocal said: "The ultimate goal is to achieve steady production at design capacity – about 10,000 barrels a day." Peak production of 7,000 barrels a day was achieved in October 1989.

During its experimental phase, the plant operated with the aid of a $400 million federal subsidy. By 1991, Unocal had used $114 million of this subsidy, and received $42.23 a barrel for the oil produced at Parachute Creek, with the U.S. government paying $23.46 of that amount. Unocal's production costs were about $57 a barrel.

On June 1, 1991, this $654 million plant was permanently closed, and the project was abandoned. Parts of the plant have been sold or moved to other Unocal operations. Much of the plant, remains, however, as a monument to the failed efforts to develop a viable shale oil operation.

When oil was $5 a barrel, $10 was the magic figure at which shale oil would be competitive, according to the industry. When oil reached $30 a barrel, the economically successful price for shale oil was reported to be $40. Oil shale development has been "just around the corner" for over fifty years, and may continue to be in that position for some time to come, perhaps indefinitely.

Shale oil can, at most, supply only a small portion of current world oil demand. And shale oil, by its composition, is better adapted for use as a raw material for petrochemical plants than for the production of gasoline. As a petrochemical feedstock, shale oil may play a modest role in the future economy.

Oil from oil shale cannot possibly make the United States energy self-sufficient in terms of liquid fuel. The extravagant statements that are sometimes being made, claiming that shale oil can make the U.S. oil independent, are usually made by promoters or those who have not fully analyzed the difficulties of recovery.

Nevertheless, in numerous articles and in some books on future energy supplies, oil shale oil is frequently cited as one of the probable major oil sources. Even ExxonMobil, in their shareholder information magazine *The Lamp* (Spring, 2006), in a worldwide assessment of energy resources, included shale oil as part of an optimistic future for fossil fuel energy, stating, "Conservative estimates of heavy oil and shale oil push the total resource well over four trillion barrels." Note: It is a resource, not a reserve.

Now Shell Oil Company is once again (2012) attempting to produce oil from oil shale in commercial amounts. It built an experimental operation in the Piceance Basin of Colorado in which a series of holes are drilled in a block of oil shale, and electrodes are inserted to heat the rock. To prevent groundwater from migrating through the rock and cooling it, a perimeter of frozen ground was created around this block of shale. Shell says it will take several years to heat the shale to the point that the kerogen is converted to oil. Then it is to be produced from wells drilled into the shale. However, shale is not very permeable.

This *in situ* operation eliminates several problems of conventional shale oil production. The handling of great volumes of rock material is eliminated. There are no mining, transportation or grinding costs. There is no waste disposal or stabilization problem, and the demand for water is modest. Shell is famous for having good engineers, and they claim they could generate a positive energy recovery ratio of 3.7/1. Since rocks are good insulators, it will take a very large amount of electricity to heat the rock and convert the kerogen to oil. How many electric power plants will it take to provide the power for a significant production of oil by this process? And what are the fuel requirements for the power plants? Even if the Shell project proves successful, it is difficult to see how it can make a significant contribution to world oil supplies, given the years it takes to heat a block of oil shale, and the power plant requirements and other infrastructure that are required.

Skeptics including Randy Udall and Steve Andrews (2005) doubt the success of this project. These long-time observers of oil shale resources make some interesting observations about the Shell project:

> The plan is audacious. Shell proposes to heat a 1000-foot-thick section of shale to 700 degrees, then keep it hot for three years… Imagine a 100 acre production plot. Inside that area, the company would drill as many as 1,000 wells. Next, long electric heaters would be inserted in preparation for a multi-year bake. It is a high stakes gamble, but if it works, a 6-mile by 6-mile area could, over the coming century, produce 20 billion barrels [of oil], roughly equal to remaining reserves in the lower 48 states.
>
> Although Shell's methods avoid the need to mine shale, it requires a mind-boggling amount of electricity. To produce 100,000 barrels per day, the company would need to construct the largest power plant in Colorado history. Costing about $3 billion, it would consume 5 million tons of coal each year, producing 10 million tons of greenhouse gases. (The Company's annual electric bill would be about $500 million….) A million barrels a day [1/20th of U.S. current daily consumption] would require 10 new power plants and five new coal mines…. Using coal-fired electricity to wring oil out of rocks is like feeding steak to the dog and eating his Alpo. [Laherrere has estimated that at the current cost of electricity in the region, the cost in electricity of each barrel of oil produced could be as high as $800.]
>
> Udall and Andrews (2005) conclude: "All hype aside, oil shale is the poorest of the fossil fuels…. A meager amount of energy, tightly bound up in an enormous volume of rock, oil shale seems destined to remain an elusive bonanza, the petroleum equivalent of fool's gold."

But the lure of the theoretically huge amount of oil that might be extracted from oil shale continues. In 1985, the federal government abolished the Synthetic Liquid Fuels Program, after 40 years and $8 billion. Unocal's shale operations continued using special test funds, but these, too, were halted in 1993. But with high oil prices and resulting public pressure, the federal government implemented the Oil Shale Development Act of 2005. Under this plan, small acreages of oil shale land are leased to companies for experimental plant sites. If companies wish to develop operations on a commercial scale, they have the option of leasing several thousand additional acres around the pilot plant. Several companies have bid and been awarded leases.

For more than 60 years, I have looked at oil shale prospects and developments and have written about them (Youngquist, 1998a). In the past two decades, I have examined a number of oil shale project proposals sent to me for review. After delineating the problems and prospects, I have wished them all well and told them to call me when they are in commercial production. So far, my phone has remained silent, but I would be very pleased to hear it ring. We need all the help we can get to mitigate our looming oil supply problem. Significant economic shale oil production is likely to be several decades ahead at best, and it may never be a significant oil source in terms of world oil demand. Looking at all the past efforts, and the uncertain future, has given rise to the comment: "Shale oil — fuel of the future — and always will be." This is also my view.

A variety of attempts – not much so far

In 2008, Raytheon (inventor of the microwave oven) launched a project to recover oil by underground heating of the shale with microwaves beamed from transmitters lowered into the shale. The process, like Shell's, would use large amounts of electricity but also involves multiple steps of heat conversion with some energy lost during each stage, a method more complex than Shell's approach. But unlike Shell's project with electrodes, microwaves can generate heat faster than convection heat (Shell's process) and reduce the heating time to a month or two, rather than years. As both the Shell project and the Raytheon project have yet to be completed, results are not now known. ExxonMobil has also resumed interest in oil shale.

Oil shale continues to be cited as a major future source of oil. Like gold in the ocean, the figures are impressive. But like ocean gold, the economic recovery of shale oil in significant volume is unlikely (Youngquist, 1998a).

The saga continues

The inevitable decline in oil production lends further impetus to find a solution to producing this elusive energy source.

Terry O'Conner, Vice President for External and Regulatory Affairs at Shell Oil Company's Exploration and Production of Unconventional Oil Division in Denver says that no one knows what the impact of commercial shale oil development would be because it has never happened. Bill Ritter, former Governor of Colorado, has stated that extensive leasing of shale oil lands (much under the jurisdiction of the U.S. Department of the Interior, Bureau of Land Management) should wait " …until we know the water needs, the water resource impacts, and the energy needs to produce oil from oil shale."

A study by the Rand Corporation for the U.S. Department of Energy found that producing just 100,000 barrels of oil per day (bpd) using the currently most advanced *in situ* process would require 1.2 billion watts of dedicated electricity for heating. This would require a power plant equal in size to the largest coal-fired plant now operating in Colorado. It would cost $3 billion to build and would burn five million tons of coal annually, producing 10 million tons of greenhouse gases.

Putting all this in perspective, even the most enthusiastic forecast of 500,000 bpd oil from oil shale production, when viewed against the current U.S. oil use of approximately 20 million barrels a day, or the world use of 84 million barrels a day, shale oil would be only the proverbial "drop in the bucket." The ad placed in *Forbes* magazine in 1968 claiming oil shale investment would be a "ground floor" opportunity, was an understatement, for now, 40 years later, we are still trying to get into oil shale at the basement level. Getting out of the basement, however, might be difficult if the observation of Australian engineer, Brian Fleay, is correct: "Shale oil is like a mirage; the closer you try to get to it, the more it fades away into the distance."

There is clearly an industry division of opinion on the outlook for early shale oil production. A BP (British Petroleum) official said: "I discount oil shale in my own or even my children's lifetimes." After an extensive study, the U.S. Office of Petroleum and Oil Shale Reserves concluded that even an aggressive production shale oil target for 2020 would be only two million barrels a day (Leggett, 2005).

In a 2005 report, Rand Corporation examined prospects for U.S. shale oil production, predicting production of one million barrels a day is probably more than 20 years in the future, and three million barrels a day is 30 years in the future.

In June, 2008, White House spokesman for then President Bush argued that there are "800 billion barrels of oil in western U.S. oil shale, ready to be developed." How this could be accomplished was not stated. Unrealistic political and media statements may make the public feel better in suggesting a solution to the problem of future oil supply, but they mislead the public into a false sense of security, which may delay realistically facing the oil problem.

A national treasure

Enthusiasts for shale oil production have called these rocks a national treasure. But even if they never become a significant commercial source of oil, they can still be called a national treasure. The reason is that the very fine-grained deposits have preserved in great and delicate detail a wonderful record of life during the Eocene Epoch in this region. Pollen grains, as well as large plant remains (palm leaves), reveal the vegetation at that time, and myriad insects are preserved so well that the compound eyes of even very tiny specimens can be seen by microscope. Many vertebrate fossils have been found, most famous of which are exquisitely preserved fossil fish, which grace museums the world over. These fish are the reason for Fossil Butte National Monument near Kemmerer, Wyoming. Oil shales are a natural library of geological history second to none, but their oil production potential remains elusive.

Oil shale/oil sands — again, the distinction

These are sometimes confused by writers. For the sake of clarity, the differences are worth repeating and very obvious when oil sand and oil shale are seen together. Oil shale contains no oil as such, but has an intermediate form of hydrocarbon between plants and oil, called kerogen. Oil shale usually contains some carbonates, so it is technically a marl. It is a hard, dense rock, which on fresh exposure is black but weathers to a tan or grey color. Oil sands, on the other hand, are black, do not weather to another color, and contain true oil, but it is very heavy (thick). It occurs in sand which is not solid rock, as is the case of oil shale, but is friable and can be mined with a power shovel.

Coal

Coal is a form of biomass handed down to us from the geological past. It has been referred to as buried sunshine and, like oil, in a sense it is. Coal currently provides 26 percent of the world's primary energy requirements, and until it was displaced by oil, it was the major fuel of the industrial world. It may become so again, because in terms of total energy content, the world's coal far exceeds the energy in the world's oil and gas.

World coal reserves in percentage by region

Estimated proved world coal reserves by region as a percentage of total resource show North America has 28.0 percent with the United States having nearly all (27.1 percent). Central and South America have very limited coal reserves at 2.2 percent. Within that region, Brazil has the most followed by Colombia. Europe and Eurasia have 31.6 percent with Russia holding more than half. In the Middle East and Africa, reserves are 5.6 percent with South Africa having nearly all. The oil-rich countries of the Persian Gulf have almost no coal (less than 0.05 percent). The Asia Pacific region has 32.7 percent of proven reserves. China holds the most, India is second, and Australia is third. (Source: *BP Statistical Review of World Energy 2007*.) The tonnages of economically recoverable coal in the five countries with the most coal are shown in Table 11-2.

Table 11-2. Estimated World Coal Reserves 2010

Country	Billion Tons
United States	237.3
Russian Federation	157.0
China	114.5
Australia	76.4
India	60.6
Rest of the World	215.1

Source: BP Statistical Review of World Energy, 2011

In terms of percentages, these figures equate to United States 27.6, Russian Federation 18.2, China 13.3, Australia 8.9, and India 7.0 percent.

In China, coal is now the principal fuel, with concurrent severe air pollution problems. China has to expand its coal production to meet its growing industrial energy needs. Coal will be their principal source of energy for at least several decades and their air pollution problem is likely to become even worse than at present.

Coal provides the fuel to produce 40 percent of the world's electricity. Being the most abundant fossil fuel and cheaper than oil, its role for electric power production is certain to increase. In poor countries, the use of coal for electric power generation is projected to double by 2030. In China, 1,000 megawatts a week are added to the electric power supply by means of coal-fired plants.

It is clear that coal, largely because of its widespread occurrence, abundance, and relatively low cost will continue to be a major source of energy for some time to come.

World Coal Outlook

Coal has long been regarded as our "black ace in the hole" with the view that world coal reserves are huge and can supply our coal needs for a century or two with no decline in availability. Recently, two studies have cast some doubts on this assumption. *The Future of Coal* (2007) by the Institute for Energy of the European Commission Joint Research Center, and *Coal: Resources and Future Production* (2007) by the Energy Watch Group composed of independent scientists and experts from around the world, have provided an overview of world coal reserves and resources, from which the following observations have been extracted:

Coal was the main energy source not only in Europe but also worldwide until the 1960s. The convenience, relative cleanliness, and price competition of oil then began to erode coal demand. Nuclear power and natural gas also began competing with coal. Now the situation is somewhat reversed as cleaner coal-burning technology, higher prices of oil and natural gas, concerns about the safe disposal of nuclear wastes, and concerns about longer term supplies and greatly increased prices of uranium to fuel nuclear plants have put coal into a more competitive position.

The U.S. alone holds 30 percent of all reserves and is the second largest producer. China is by far the largest producer but has only half the reserves of the U.S. Therefore, the future of world coal production and peak will be the combined production curve of these two countries. Global coal production will peak around 2025 at 30 percent above present production in the most optimistic view.

The main use of coal now, in approximate percentages, is electricity and heat generation 58 percent; metallurgy (iron and steel making and general mineral metal smelting) 16 percent; cement and other industries 14 percent; and residential, agricultural, etc. 12 percent.

U.S. coal production in terms of *energy* (as opposed to *mass* or *volume*) peaked in 2002. It is unclear whether this trend can be reversed. Also, productivity per miner has declined since 2000. About 60 percent of U.S. reserves are located in the states of Illinois, Wyoming, and Montana. Montana and Illinois show no signs of expanding production, which has remained at low levels for two decades, and may decline even further.

Conversion of coal resources to coal reserves on any significant scale is not anticipated. Therefore it is unlikely that recoverable reserves eventually turn out to be higher than reported. Although coal reserve data are not very reliable, the World Energy Council (WEC) collects data from member countries. Estimates of global reserves, based presumably on increasingly improved data, have been lowered continuously from 1980 to 2005, by a total of 50 percent.

Coal consumption takes place primarily in countries of origin. Only 15 percent of world coal production is exported.

China is depleting its coal resources the most rapidly, at an annual 1.9 percent rate. It will reach its maximum production within the next 5-15 years. The high growth of coal production in recent years must decrease over the near term. An indication of imminent problems in future coal production is that the U.S. has recently changed from being a net exporting country to being a net importing country for steam coal. Both China and the United States, previously coal exporters, are becoming net coal importers for all coal grades except lignite.

Australia is likely to become the ultimate global coal supplier. It has sufficient coal for current domestic demand, and substantial quantities for export.

Worldwide, the quality of the coal being mined is declining. This is why the amount of *energy* of U.S. mined coal has been decreasing while the *volume* of coal has been increasing at the same time.

French geologist Laherrere (2007) projected China's peak coal production rate would occur about 2020, and world coal production will peak in approximately 2050.

China's coal reserves essentially will be exhausted by 2100. China relies on coal for two-thirds of its energy supplies, and currently burns more of it than the United States, Europe, and Japan combined. Most of it is burned in older plants almost totally lacking emission controls. Even the newest Chinese electric power plants and industrial facilities using coal are relatively inefficient, and their pollution controls are below western standards. China is now putting about one new coal-fired plant a week into operation and has already displaced the United States as the world's largest emitter of carbon dioxide. It is likely to maintain that position for the next several decades, and along with India, has not been a signatory of the Kyoto Protocol.

Projections to at least 2030 show that China and India will continue using coal as a major source of energy. Currently, the two nations account for 45 percent of world coal consumption. Worldwide coal demand is forecast to soar by 73 percent from 2005-2030, with China and India representing four-fifths of the increase. These International Energy Agency projections make the outlook for a decrease or even stabilization of world carbon emissions not encouraging. The five major areas projected to lead in using coal by 2025 (millions of tons/year) are China 3,242, United States 1,505, Europe 853, India 736, Russia 288, and other 1,602.

The world's reserves of hard coal (bituminous and sub-bituminous) and low-grade coal (lignite) are about the same, but their consumption trends are different. Demand for hard coal is rising, while the use of lignite for fuel is essentially flat. Lignite has a high water content, making it more costly to ship per unit of energy than for hard coal. The result is that the world will run out of higher quality coal much sooner than it will run out of lower quality coal.

This parallels the situation in oil. High-quality oil is easier to produce and easier to process into higher-value end products so it is exploited before lower-quality oil (e.g., oil sands, heavy oil) is produced. The sum of both situations is that the quality of both oil and coal being produced (the two current major world sources of energy) is declining, and they are more costly to produce in terms of energy units recovered.

These facts have profound implication for the future, in an energy-intensive industrialized world. Energy, its cost and availability, largely determine physical living standards, which are almost certain to decline in the coming decades. At the same time, our continually growing population will exacerbate the energy problem.

Coal — large U.S. energy source

It has been estimated that 90 percent of the total energy in coal, oil, and natural gas deposits in the United States, is in the form of coal. These coal deposits are already known; there is no expensive exploration work involved as there is for deeply hidden oil reservoirs.

Coal, however, has some substantial problems, starting with the fact that underground coal mines are dangerous. Each year miners are killed, and many others have their health permanently impaired. In the United States, most western coal, and considerable eastern coal, now is mined by open-pit methods. Underground mines are becoming less common. In mountainous areas such as the Appalachians, surface or strip mining and mountaintop removal mining of coal can have severe impacts on scenery, hydrology, water quality, local air quality, flora, and fauna. On the other hand, in the Powder River Basin of Wyoming and Montana, impacts from surface coal mining tend to be much less severe and reclamation generally more successful. Germany also mines a lot of its coal (which, in general, is rather poor quality) by the open-pit method. But in many other parts of the world, coal is still mined underground and safety precautions are frequently inadequate, China being a prime example. The result is that worldwide, coal mining remains a hazardous occupation that claims lives every year.

Environmental negatives include air pollution, mercury emissions, and acid rain when coal is used for power production. Research on these problems and very large expenditures of money on pollution control technologies at coal-fired power plants has reduced emissions considerably, but not entirely.

Temporary decline in use of coal

Historically, coal has generated slightly more than 50 percent of U.S. electricity. Recently, due to competition from natural gas, coal has accounted for only about 48 percent of U.S. electricity production. Natural gas is now the fuel for 25 percent of U.S. electricity output. Thanks to the recent abundance of gas from shale fracking technology, gas is now in much greater supply and much cheaper than before. As a result, an increasing number of power plants are switching to gas and more will use it in the future. Recognizing this trend, U.S. coal companies have begun to reduce their coal output. However, coal use is likely to rise in the future as natural gas supplies are depleted. This may not occur for several decades, a positive circumstance with regard to reducing greenhouse gas emissions. China also seems to be turning to natural gas for the generation of electricity, and has extensive shale deposits with natural gas production potential.

Coal to oil

It is also possible to convert coal to oil. Hitler did it during World War II. For many years, South Africa has had a coal-to-oil conversion process in operation that supplies about 40 percent of the country's oil needs. These coal-to-oil plants were built when South Africa, because of its apartheid policies, was partially isolated economically and feared a total cut-off of oil supplies. The coal is converted to oil by employing the Sasol Process. It cannot compete with conventional oil, so the government paid a subsidy for the synthetic fuel which amounted to $960 million from 1985-1994. The future of this synthetic fuel industry after apartheid and the resumption of conventional oil imports is a matter of some debate. Since South Africa has no oil, some people want to preserve the synthetic fuel industry as an insurance policy against a future when oil supplies may be scarce.

The largest coal deposits in the United States are located in Montana and Wyoming. A coal-to-oil pilot plant is planned to be built by the federal government in the vicinity of Medicine Bow, Wyoming. A similar plant is being built by the U.S. Air Force in Montana. The governor of Montana recently said that his state has enough coal that, if converted to oil, would more than equal the reported oil reserves of Saudi Arabia. It is doubtful such could be accomplished, and the environmental impacts would be significant. If coal were to be used in the United States as a substantial substitute for oil by liquefying it, the cost of putting in place the physical plants that would be needed to supply the United States with oil as we use it now would be enormous. The mining operations required to supply the coal would be huge and probably unacceptable to environmental interests.

Coal can be a partial substitute for oil but cannot completely replace oil as we use it today. However, coal regains its importance as a fuel in whatever form it takes.

Additional constraints to coal-to-liquid fuel production

Beyond the fact that coal resources are not as plentiful as previously estimated, the coal-to-liquid process would involve the largest mining endeavor the world has ever seen if it were to substantially replace oil. In the United States, it would require strip mining many square miles a year to provide the needed coal. A report in the June 25, 2007, Association for the Study of Peak Oil — USA newsletter puts coal-to-liquid prospects in perspective:

> Late this year, China will complete construction on the world's largest coal-to-liquids plant using direct gasification technology. It will require 3.5 tons of coal to produce about 7 barrels of oil. The plant will be able to process 3.45 million tons of coal into 8 million barrels of oil annually (22,000 barrels/day).

From the perspective of China's current daily oil demand of more than nine million barrels, this plant, the world's largest producing, 22,000 barrels of oil daily output is a very small drop in the bucket. What then, can be said of the impact such a plant would have on the 19 million barrels of oil consumed daily in the U.S.? Nonetheless, the U.S. government has embarked on a program to build a number of these plants.

It would take 45 plants the size of China's to produce a million barrels of oil a day, or 220 plants to produce 4.84 million barrels a day using 759 million tons of coal a year to satisfy about one-quarter of U.S. daily oil consumption. Adding an additional demand of 759 million tons of coal a year onto present and projected coal demand to provide 4.84 million barrels of oil a day requires at least a 65 percent increase in coal production. This increase probably cannot be met. Increasing the production of coal-to-liquid to produce 10 million barrels of oil a day would mean a 130 percent increase in coal production to produce what is still only about half of current daily U.S. oil demand, and the demand is growing.

The coal-to-liquid process also requires lots of water. In the already thirsty West, this is a serious limitation. The process of converting coal to oil is only 50 percent efficient. Nevertheless, it is being promoted as a future transport fuel. Grant (2007) emphasized the inefficiency of coal-to-liquid:

> Coal is an unsatisfactory and potentially very dangerous stopgap. It can be converted to synthetic gasoline, but half its energy is lost in the process. That is a stiff penalty as fossil fuels all decline.

Scientific American (2007) examined the U.S. government's recent push to promote coal-to-liquid as a partial answer to the problem of oil supply. Their conclusions were:

> …liquid coal comes with substantial environmental and economic negatives. On the environmental side, the polluting properties of coal — starting with mining and lasting long after burning — and the large amounts of energy required to liquefy it, mean that liquid coal produces more than twice the global warming emissions as regular gasoline and almost double those of ordinary diesel…. One ton of coal produced only two barrels of fuel [gross return, not counting the energy input to produce it]. In addition to the carbon dioxide emitted while using the fuel, the production process creates almost a ton of carbon dioxide for every barrel of liquid fuel....Which is to say, one ton of coal in, more than two tons of carbon dioxide out…. Liquid coal is also a bad economic choice. Lawmakers from coal states are proposing that U.S. taxpayers guarantee minimum

> prices for the new fuel, and guarantee big purchases by the government for the next 25 years.... The country would be spending billions in loans, tax incentives and price guarantees to lock in a technology that produces more greenhouse gases than gasoline does.... Instead of spending billions to subsidize a massively polluting industry, we should be investing in efficiency and renewable energy technologies that can help us constrain global warming today.

Water supply — limiting factor on coal-liquefaction

Most of the future supply of low-sulfur U.S. coal, generally mined by low-cost open-pit surface mining operations, is in the arid West, already suffering from water supply problems. To produce just 50,000 barrels of oil a day, a coal-liquefaction plant consumes 12,000 acre-feet of water a year (Pringle, 1982). The government/industry proposal to set up a number of such plants in the West directly impacts the water supply needs of the region for direct human consumption and indirect human needs through livestock and other agricultural requirements.

Coal to oil to coal — in less than 100 years

For energy measured in terms of barrels of oil equivalent (boe), world oil energy domination over coal only happened in 1963. Given current trends of increased coal produc-tion (especially in China and India), the reverse crossover point of coal becoming once again the dominant world energy source appears likely to occur no later than 2050. Some estimates put it as early as 2013. This means that oil will have reigned as the top energy source for less than 100 years. Yet another example of how the "oil interval" will be only a passing moment in human history. But coal is also a finite fossil fuel whose use will end within a century.

Europe is going back to coal, with new coal-fired plants now scheduled for Italy, Germany, and the United Kingdom. "Europe's power station owners emphasize that they are making the new coal plants as clean as possible. But critics say that 'clean coal' is a pipe dream...." (Rosenthal, 2008).

Coal still vital to U.S. economy in 2030

In spite of its environmental drawbacks and the decline in quality of coal being mined, the Energy Information Agency (US DOE) projects coal will still be a major source of fuel for electric power generation in 2030. Other sources of electricity (wind, solar, etc.) are still regarded to be very minor sources, in total, supplying less than half the fuel energy that coal will provide. Gas, however, will replace coal to some extent for a limited time.

Fossil Fuels — A Brief Flash

The fuels just mentioned are fossil fuels, the accumulation of myriad animal and plant remains during a period of more than 500 million years. It is sobering to realize that the most useful fossil fuels, coal and petroleum, which took geologic ages for nature to produce, will be consumed in a brief flash of Earth history, probably lasting less than 500 years. Even in terms of human history this will be a very short and unique time.

Oil has provided the individual freedom of movement unheard of in the past. To do this 200 years from now, will require great technological advances, which may or may not happen for the fuel sources will be much different than oil, which is in such wide use today.

Fossil Fuels and Food

The availability of fossil fuels for such a short time is of special concern in relation to how they affect agricultural productivity. David Pimentel and associates have made some interesting quantitative observations in this regard:

> Energy use, particularly fossil energy, has played an important role in increasing food production in the world. In the United States, for example, crop yields have increased about 3.5 times during the last 60 years…. The fossil energy inputs to achieve this food increase have grown 4-fold or to an input of about 1000 liters [6 barrels] of oil equivalents per hectare [per year]…. In China, a similar technological change led to a 2-fold increase in food production the last 30 years, while fossil energy use increased nearly 100-fold or to an input of about 500 liters of oil equivalents per hectare [per year]…. Energy and population growth are also interrelated. The major increases in human population growth rates during the last 300 to 400 years have coincided with the discovery and use of stored fossil energy resources such as coal, oil, and gas. Since about 1700, rapid population growth has closely paralleled the increased use of fossil fuel for agriculture and improvement in health.

With the great importance of fossil fuels to the production of food, the gradual depletion of these resources and their ultimate disappearance poses some severe future problems. Can renewable resources really replace oil, gas, and coal? In the interim, as we try to make the transition to alternative energies, and these nonrenewable resources continue to decline, the countries which have them will have an ever-larger role in the world economy. Conversely, those countries that do not have them, or have the ability to import them, will be increasingly at a disadvantage.

The dependence on fossil fuels by today's developed countries is illustrated by the fact that using fossil fuels in food production allows most Americans to work only 20 minutes a day to provide their daily diet. As a substitute for agricultural labor, a gallon of gasoline equates to about three weeks' work by one human being. Pfeiffer (2006) writes:

> The impact of fossil fuel depletion will be felt in higher food prices and, if nothing is done to completely revamp our food system, sooner or later in food shortages and massive starvation. The public needs to be informed. Our civilization is about to undergo a radical change unparalleled in history.

Since food supplies are delivered by trucks, to both near and remote food outlets, the importance of our transportation infrastructure cannot be over emphasized together with the need to fuel this transport system. Currently, biofuels seem to be the leading contenders for this role. As growing and harvesting biofuels takes energy, and most biofuels (soybeans, corn) compete for acreage and water with food, problems are likely to arise in balancing this equation. In 1993, almost all fresh produce moved by truck. By 1998, food in the U.S. traveled an average 1,528 miles to reach the U.S. dinner plate (Pfeiffer, 2006). The miles would be even greater (depending on individual diets) if imports of foreign produce were included (e.g., Chile, grapes; Australia, oranges; Ecuador, bananas; Mexico, fruits;

and many U.S. out-of-season vegetables such as lettuce and tomatoes).

The same situation exists in Europe. "A Swedish study of the food miles involved in a typical breakfast (apple, bread, butter, cheese, coffee, cream, orange juice, sugar) found that mileage estimated for the entire meal was equivalent to the circumference of the earth" (Pfeiffer, 2006). The current globalization of our food supplies has been made possible by the worldwide increase in fossil fuel consumption.

Adding up all these facts, the question of replacing fossil fuels with alternatives becomes of importance to breakfast, lunch, and dinner.

Food production is obviously the most fundamental activity a society can engage in, and its maintenance for the growing world population will be an increasing problem as our fossil fuel supplies are depleted. In a thoughtful analysis of this situation, Richard Manning (2004), "The Oil We Eat," points out:

> Ever since we ran out of arable land, food is oil. Every single calorie we eat is backed by at least a calorie of oil, more like ten…The pre-colonial famines of Europe raised the question: 'What would happen when the planet's supply of arable land ran out?' We have a clear answer. In about 1960 expansion hit its limits and the supply of unfarmed, arable lands came to an end. There was nothing left to plow. What happened was that grain yields tripled. The accepted term for this strange turn of events is the green revolution, though it would be more properly labeled the amber revolution, because it applied exclusively to grains — wheat, rice, and corn. Plant breeders tinkered with the architecture of these three grains so that they could be hyper charged with irrigation water and chemical fertilizers, especially nitrogen…. This innovation meshed nicely with the increased 'efficiency' of the industrialized factory-farm system [powered with fossil fuel]…. The way in which the green revolution raised that grain [production] contributed hugely to the population boom, and it is the weight of the population that leaves humanity in its present untenable position…. All together the food-processing industry in the United States uses about ten calories of fossil-fuel energy for every calorie of food it produces.

This is another variation of the concept that we now exist on "ghost acres" — the ability to produce more food from an acre than would otherwise be possible without using oil and natural gas. The coming end of the petroleum interval presents serious problems and the need to downsize population to a future, less bountiful agricultural paradigm.

Predictions

The question arises as to how long the combination of alternative fossil fuels can carry the growing world population into the future. The facts suggest that the point in time when such fuels cannot sustain us as we now use them probably lies well within this century. However, various sources frequently present quite different and optimistic views, most of them by those not in the frontline trenches of providing energy supplies. Clive Crook writes in *The Atlantic*:

> With present technologies, proven and probable reserves of oil will be sufficient for decades. Even if prices somewhat lower than those already seen this year were sustained, an array of existing but not yet widely applied technologies

> would make it economically feasible to extract oil from tar sands or shale, or to convert coal to liquid fuel. There will be enough fuel from those sources to meet the world's needs as far into the future as one cares to look — even if no brandnew energy-producing technologies emerge anytime soon.

Mr. Crook is a journalist and senior editor of *The Atlantic*. I would feel more reassured about his prediction if he were a graduate in petroleum geology, petroleum, chemical engineering, or physics.

Fossil fuel reserves

In terms of millions of barrels of oil equivalent (a common measure of energy equivalents), world natural gas reserves appear to be larger than oil reserves, and coal reserves contain more than three times the energy equivalent of either conventional oil (excluding oil sands and what might be obtained from oil shale) or natural gas (Ross and Sloan, 2007).

The Atom: Fission and Fusion

Although both fission and fusion are nuclear energy processes, the fuel sources for each are quite different. For fission, the source is uranium, or possibly thorium. Canada, South Africa, Namibia, Niger, and Australia have large uranium deposits. Lesser amounts exist in the United States, Brazil, Sweden, and France. Russia does not publish its uranium resource statistics, but is known to have some deposits that could be quite substantial given the large and varied geological terrains of Russia. Currently, one of the largest uranium producing area in the world is in northern Saskatchewan, Canada.

Uranium has three natural isotopes, with U-238 being the largest by volume at 99.3 percent of the total average mined content. U-235 is second with 0.7 percent, and U-234 has only 0.005 percent. Only U-235 is readily fissionable in fission reactors. U-238 is not fissionable, but can be converted into plutonium, which is fissionable by a neutron bombardment from U-235 fission. Breeder reactors use U-235 to produce fissionable plutonium from the abundant U-238 uranium isotope. Thus, more fissionable material is produced than is used in the breeder reactor. Because of numerous difficulties, there are currently no breeder reactors in operation.

The low concentration of fissionable U-235 in uranium is not useful in an atomic reactor, so the quantity must be enriched to the vicinity of 10 percent. For use as an atomic weapon, the enrichment has to be in the vicinity of 40 percent U-235. So the degree to which the enrichment of U-235 is carried out may be an indication of a country's intention as to how its uranium will be used — to produce power or military weapons.

Nuclear power supplies about 20 percent of U.S. electricity. Seven states and the city of Chicago get more than half their electricity from the atom, as does the province of Ontario, Canada.

Except for France, Western Europe has serious reservations about nuclear power. As far back as 1980, Sweden voted to gradually phase out all nuclear plants. What they will do after that no one seems to know. It is likely that Sweden will have to reconsider that decision, for nuclear energy still provides 50 percent of Sweden's electricity.

In contrast, energy-short France has vigorously pursued nuclear power and now generates more than three-fourths of its electricity from the atom. Many nations outside Western Europe are pursuing nuclear power, including Brazil and Japan, and others that lack large coal or petroleum supplies. There are presently 441 nuclear reactors in operation producing 16 percent of the world's electricity.

Huge energy per weight

Uranium has a special attraction to energy-short countries because the amount of energy which can be shipped in the form of uranium is very large per unit weight compared with coal or oil. Weight for weight, uranium has more recoverable energy than any other source by far. The energy in one kilogram (2.2 pounds) of U-235 is the energy equivalent of three million tons coal. Shipping energy in the form of uranium is very efficient.

Table 11-3. Percent of Electric Power from Nuclear Plants in Selected Countries 2011

Country	Percent
Lithuania	80
France	78
Slovakia	57
Belgium	55
Sweden	50
Ukraine	46
South Korea	40
Switzerland	40
Bulgaria	38
Czech Republic	31
Finland	27
Japan	25
United Kingdom	24
United States	20
Russia	17
Canada	13
Mexico	5
India	3
China	2

Source: Energy Information Agency, US Department of Energy

Nuclear energy = electricity

Nuclear energy is transformed into electricity. Therefore, it can only be substituted for whatever fuel is being used to generate electric power. Where oil or natural gas is used for electric power generation, nuclear energy can replace them. Unless electric vehicles are invented that are efficient and used in quantity, uranium (used in power plants to produce electricity) will not be a major substitute for gasoline or jet fuel. It is hard to visualize atomic powered or battery-run airplanes. The best fuel alternative for aircraft would seem to be hydrogen. But hydrogen's extreme flammability means that alternatives need to be viewed with some misgivings. Uranium can produce electricity, which through the electrolysis of water, can make hydrogen for fuel.

However, each change in energy form involves a loss of energy and efficiency. Air transport beyond the age of oil presents a huge technological challenge.

Trains can use electric power. And as diesel fuel becomes more expensive, the electri-fication of the world's railroads is likely to be the trend. Russia now makes extensive use of electricity for that purpose. A lot of the Trans-Siberian Railroad has been electrified, saving diesel fuel for uses that electricity cannot replace, and for sale abroad to obtain for-eign exchange. In the United States some once-electrified railroads, like the Milwaukee Road in the west, changed over to diesel engines. As oil supplies become more costly, electric trains may make a comeback. Subways everywhere are electrically powered. Electric trains already are widely used in Europe.

Safety

The Three Mile Island nuclear power plant accident in the United States, Chernobyl disaster in Russia, and Fukushima disaster in Japan have given nuclear power a black eye in the view of many. The accident at Three Mile Island in Pennsylvania in 1979 produced no casualties, but still sparked domestic antipathy toward nuclear power. Ristinen and Kraushaar (2005) wrote: "A nuclear power reactor cannot explode in the way that a nuclear weapon does…. However, serious accidents can occur with nuclear reactors." The authors detail what such accidents might be, but note several studies by the Nuclear Regulatory Commission on the probability of accidents that stated, " … with 100 operating reactors, the chance of an accident killing 100 people was said to be about the same as the probability of 100 people being killed by the impact of a meteor."

Whatever the odds are of a fatal accident in the U.S., the public remains divided on the future of the atom as a source of power.

Waste disposal problem

A big problem with nuclear power is waste disposal. Waste from currently operating U.S. nuclear power plants is stored on site at the generating plants. This can only be a temporary solution and poses the hazard of potential local contamination. Ultimately, wastes must be stored where they are away from population centers and where they can be monitored for decades. One site has been established at Yucca Mountain in western Nevada. Although several billion dollars was invested in the project from fees charged to current nuclear plants, in 2009, the Obama Administration abandoned the project, leaving nuclear waste stored in sites adjacent to nuclear reactors. The problem of permanent waste disposal is still unresolved.

Breeder reactor

Nuclear energy might be considered almost renewable, or at least extremely long-lived. Breeder reactors convert non-fissile uranium, which is more than 99 percent of the uranium mined, to fissile plutonium 239, the stuff of powerful atomic bombs. But there are numerous problems with breeder reactors, and for the moment, countries are not pursuing this option.

I asked about the breeder reactor during a recent phone conversation with Professor Albert Bartlett (Harvard Ph.D. in nuclear physics). He replied, "If the breeder problems could have been solved, this reactor would have been used long ago." Britain shut down its breeder reactor experiment in 2009, and Russia shut down the world's last breeder reactor in 2010.

Uranium supplies

With the breeder reactor not in commercial use, supplies of uranium for existing conventional reactors are in increasing demand, and a uranium boom reminiscent of post-World War II is developing (Barta, 2005). The 441 nuclear reactors in the world including 104 in the United States, need about 180 million pounds of uranium fuel annually. In recent years, only about 100 million pounds have been mined (Lofholm, 2005). Like other Earth resources, uranium is finite, and many of the richer deposits have been mined. However, uranium is a widely distributed element and large low-grade deposits exist. As energy costs rise, lower-grade deposits can become economic.

Uranium occurs in seawater and can be extracted from seawater at a cost of about \$1000/pound. This is high compared with uranium's current cost of less than \$100/pound, but it would only add about 0.03 cents per kilowatt hour to the cost of the generated electricity. Very small amounts of uranium occur widely in various sedimentary rocks, especially organic rich black shales, which are widespread across the interior United States and elsewhere around the world. Economically rich occurrences are relatively rare. The United States mined most of its known high-grade ores, and only more marginally economic deposits remain. But in 2005, more than 8,500 mining claims were filed in Utah and Colorado (Lofholm, 2005) as the demand and price for uranium rose.

Concerns about greenhouse gases and global warming, and rising demand for more energy from growing populations, mean that nuclear power is expanding in many countries. Because greenhouse gases are not emitted in the process of generating electricity at nuclear power plants, even some of the more ardent environmental groups are beginning to think more kindly of nuclear power. While there are carbon dioxide emissions associated with various phases of the nuclear power lifecycle, from mining uranium to plant decommissioning, even with these, overall CO_2 emissions are substantially lower for atomic power than fossil fuels.

Thorium

Given that known and projected discoveries of uranium are only adequate for 40 years or less of world demand, increasing attention is being directed toward thorium, which is also fissionable. Thorium is four times as abundant as uranium. India has the world's largest deposits, and very little uranium, and as a result, it has been the most active in thorium research. Canada, Norway, and Russia are also considering the use of thorium as a fuel source for power plants.

Thorium has some advantages over uranium. It produces far less transuranic waste, the toxic material containing plutonium and other substances that can be radioactive for hundreds of thousands of years. Also, waste material that would come from thorium reactors is very difficult to make into weapons-grade materials. But thorium has not been economically competitive with uranium. To be so, it must be reprocessed, something which the United States and other countries do not do with uranium, since reprocessing creates weapons-grade plutonium. But, given the greater abundance of thorium and its advantages in regard to waste products and weapons production, interest and research in thorium for electric power production continues.

Fusion

Fusion is the nuclear reaction that fuels our Sun and all the other stars. It is for all practical purposes inexhaustible. As such, it is considered in the next chapter as a renewable power source.

Continued Use of Present Energy Sources

At present, it appears that the discussion and evaluation of energy supplies must continue based on currently known and widely utilized energy sources.

Petroleum to retain dominance for years

Petroleum (oil and gas) will continue to be in demand for many years to come. OPEC need have little fear that its product will go out of style. Petroleum used for transportation, particularly the personal automobile, and its very important use as a petrochemical raw material base will continue for decades.

World trend toward nuclear

In 1960, the atom generated less than one percent of the world's electricity. Today it provides more than 17 percent. The London-based Uranium Institute projects that in the next decade, the world's nuclear electric generating capacity will rise from 261,000 megawatts to 347,000 megawatts. The International Atomic Energy Agency predicts that nuclear energy will provide at least 20 percent of the world's electricity within the next several years. Many countries including Thailand, Turkey, Argentina, Brazil, Bulgaria, Japan, France, and Belgium now use nuclear energy and are developing more of it. The U.S. Nuclear Regulatory Commission issued the first nuclear license since 1978, allowing Southern Company in 2011 to start building in the state of Georgia.

China's decision

In 1995, Yao Quiming, General Manager of the Quinshan Nuclear Power Company, said that China had decided to "energetically develop nuclear power," changing its national power priorities from hydropower and coal. This was to help alleviate electricity shortages in coastal China. With the world's largest population, and the world's fastest growing economy, China's decision adds to the long-term international trend toward nuclear energy.

Outside of the United States, nearly 600 nuclear plants in 41 countries are now in various stages of development or in operation. Even after the Chernobyl nuclear plant accident, Russia continued construction on 15 atomic power reactors. Japan has 49 nuclear plants and until the Fukushima disaster in 2011, obtained 30 percent of its electricity from them. Before the Fukushima disaster, it had planned to construct about 40 more and generate 42 percent of its electricity from the atom by 2010. Now all their existing plants have been idled, and the Japanese are undecided about the future of nuclear power in their country. South Korea has 11 nuclear power plants in operation with 19 more under construction or authorized. Taiwan operates six plants and is looking for sites for several more. Indonesia plans to build 12 plants. Will there be enough uranium to fuel all these new plants?

The two big, now-available power sources

As oil and gas supplies diminish, there are only two sources of energy potentially large enough to take up the slack on relatively short notice. These are coal and the atom (fission). However, due to increasing concerns about the greenhouse gas effect and global warming caused by burning fossil fuels like coal (which now produces 37 percent of the world's electricity), nuclear is becoming a more attractive option. But there are problems. In the United States, nuclear power has such a poor reputation that returning to that source of power will face a lot of opposition.

Nuclear energy and Japan

Japan currently imports 90 percent of its total energy supplies. It is critically dependent on an oceanic highway of tankers consisting of about one oil tanker every 100 miles along the sea route from the Persian Gulf to the Japanese islands. This is a continuous procession that must go on every day, year after year. Eventually, of course, it will stop.

The 2011 earthquake and tsunami that destroyed four nuclear plants in northeastern Japan and contaminated a large area with uncontrolled nuclear emissions, has caused the Japanese to question further development of nuclear power. In the meantime, Japan's industry and its people are suffering from reduced electric power availability. There are no obvious easy options. Japan is in a difficult and precarious energy supply situation and may be the first country to illustrate what happens to an industrial nation that has no significant domestic energy base.

Uranium supply — future limiting factor

Unless breeder reactors are more successful in the future than they have been in the past, the supply of fissionable uranium is likely to be a limiting factor in the future growth of this energy source. Already the price of uranium on the world market has risen twentyfold from $7 (U.S.) per pound of uranium oxide to $136 as of 2009. The result is that the cost of electricity from uranium is no longer competitive with coal or natural gas. Also, significantly higher prices have not resulted in increased uranium production as might be expected from the generally promoted economic concept that higher prices for a commodity stimulant increases supplies.

U.S., the world's largest producer of nuclear energy, contributing 20 percent of its electric power, consumes 60 million pounds of uranium per year but produces only two million. Worldwide, the shortfall for existing reactors is about 100 million pounds per year. With more than 50 additional nuclear plants planned worldwide, including some in the U.S., the supply of uranium reserves in the ground will last substantially less than the 40 years projected. Taking everything into consideration, the expanded long-term anticipated future for uranium in world energy supply appears to be unfounded, unless reprocessing of existing uranium supplies can be successfully accomplished on a significant scale. So far this seems unlikely.

World uranium reserves

In a comprehensive study of world uranium reserves, the German-based Energy Watch Group issued a 2006 paper in which they questioned the long-term availability of uranium to fuel nuclear reactors. The study also adds perspective on near-term maintenance of current nuclear power capacity based on the estimated useful life of the operating reactors and their age. Their conclusions:

> Any forecast of the development of nuclear power in the next 25 years has to concentrate on two aspects, the supply of uranium and the addition of new reactor capacity. At least within this time horizon, neither nuclear breeding reactors nor thorium reactors will play a significant role because of the long lead times for their development and market penetration.
>
> This analysis of data on uranium resources leads to the assessment that discovered reserves are not sufficient to guarantee the uranium supply for more than thirty years.
>
> Nuclear power plants have a long lifecycle … an average of 40 years seems to be a reasonable assumption. About 45 percent of all reactors worldwide are older than 25 years; 90 percent are now operating for more than 15 years. When these reactors reach the end of their lifetime by 2030, they must be substituted

> by new ones before net capacity can be increased. At present, only 3-4 new reactors per year are completed … . However, just to maintain the present reactor capacity will require the completion of 15-20 new reactors per year.
>
> This assessment results in the conclusion that in the short term, until about 2015, the long lead times of new and the decommissioning of aging reactors are the barrier for fast extension [of nuclear power], and after about 2020, severe supply shortages become likely, which, again, will limit the extension of nuclear energy.

Stretching nuclear fuel by recycling

Reprocessing (recycling) spent nuclear fuel has been revived. However, a careful examination of the problems raises serious questions about various hazards associated with this process. One recent study concludes the hazards outweigh the advantages.

Nuclear fuel — U.S. more dependent on imports than oil

Demands for "energy independence" are frequently heard from politicians and others who may endorse nuclear power as one of the means to such an end. In the 2008 U.S. presidential campaign, Senator John McCain urged immediate construction of 40 nuclear plants (to add to the 104 now in the U.S.) and suggested 100 more nuclear plants for the longer term as a road to energy independence. In citing nuclear plants, which produce electricity, to aid in the solution of the oil problem, the senator ignored the fact that only about two percent of electricity is currently generated using oil as fuel.

Also, the facts do not support the view that going to nuclear energy would significantly enhance "energy independence" for the United States. Eighty-five percent of U.S. uranium supplies must be imported, compared with about 50 percent of our oil. Increasing uranium as a fuel source would only increase our foreign fuel supply dependence. And that dependence is not likely to decrease, as prospects for large new discoveries of uranium seem unlikely in the already thoroughly explored United States. I worked for a year on this very problem, retained by an oil company seeking to diversify its energy base away from oil. The company eventually abandoned the project, because prospecting for uranium in the United States did not appear to be a significantly worthwhile investment.

Geothermal Energy

Geothermal energy is heat from the Earth, apparently generated for the most part by radioactivity by the decay of radioactive elements in rocks. This natural heat occurs everywhere in the Earth, but is concentrated enough only in certain places and close enough to the Earth's surface to be commercially tapped. These areas tend to occur chiefly along the junctions of what we now know to be plate margins, as defined by the theory of plate tectonics. There are, however, certain so-called hot spots, such as the Island of Hawaii and Yellowstone National Park, which do not seem to be related to plate junctions. In general, most geothermal areas tend to be related to regions of active volcanoes.

Generally, volcanoes and petroleum do not coexist geologically very well. Areas that have volcanoes have little or no oil, but do have considerable geothermal potential. These areas include the northern California Coast Range, the Cascade Mountains of Oregon and perhaps the southern part of Washington State. Mount St. Helens in 1980 provided a spectacular example of geothermal energy in action. Also included are the Coast Range of British Columbia, the Aleutian Range of Alaska, the Imperial Valley (a rift area) of California and northern Mexico, Central America, Hawaii, Iceland, Indonesia, New Zealand, the Philippines, Japan, Italy, and eastern Africa. One estimate is that there is enough geothermal power in the East African Rift Zone including Ethiopia, if properly harnessed, to light all of Africa.

Types of geothermal energy occurrences

Geothermal energy exists in several geological circumstances. There is a general heat flow from the Earth, and also a geothermal gradient which simply means that the Earth gets warmer with depth, generally about 1° F for each 60 to 100 feet. Geothermal energy exists in a few places in the form of dry steam. More often it occurs as hot water, in some instances so hot that when it is brought to the surface and the pressure reduced, it flashes into steam. This is called wet steam. It can drive turbines connected to electric generators, just as the dry steam form of geothermal energy does. The Geysers geothermal electric generating plants in California are dry steam operations. Lower temperature waters are more common and more widely distributed, appearing as hot springs. Another way in which geothermal energy occurs is in the form of hot, dry rocks. There appears to be an appreciable amount of heat energy stored in the Earth in this form, but its recovery has been difficult and so far is not commercially viable.

Geothermal energy used early

Geothermal energy was certainly the first Earth-derived energy source to be exploited, well before oil, coal, or even wood. Native peoples around the world have enjoyed relatively non-polluting geothermal energy in the form of hot springs. Native Americans were known to pitch their camps on warm ground in geothermal areas. The Maoris of New Zealand cooked their food in very hot springs of the North Island.

Two ways to use geothermal energy

This energy can be used directly in heating or in electric power generation in steam-powered plants much like conventional electric generating plants. Around the world, geothermal electric generating capacity now exceeds 10,000 megawatts. About 15,000 mega-watts is being put to direct uses like space heating. To put this in perspective, a single nuclear or coal-fired plant produces about 900-1400 megawatts. Only hotter waters (gen-erally above 360° F) can efficiently produce electric power. A technology called a binary system can use water of somewhat lower temperature, but the efficiency is also lower. By far the most common use of geothermal energy is in the form of the lower temperature waters in space heating, or in various hot water facilities. Low temperature geothermal use is expanding.

Other uses of thermal waters include heating buildings for raising pigs and chickens, growing mushrooms in sheds, and heating greenhouses to produce a variety of crops in many places in the world. Iceland has an extensive greenhouse agriculture based on geothermal waters, and reportedly has even grown bananas there. Crop drying is another use of geothermal energy, as, for example, in an onion processing facility in western Nevada. Geothermal waters have created world-famous scenic geological features. The geysers of New Zealand and Yellowstone National Park and the large travertine terrace (limestone) deposits from hot waters attract multitudes of visitors each year.

Direct use in space heating is a relatively efficient use of geothermal energy, and it is almost entirely non-polluting. At present, 60 percent of the buildings in Iceland are heated in this manner, essentially pollution free. The capital, Reykjavik ("smoking bay" in Icelandic due to the many hot springs in the region), with a population of 160,000, is heated by a geothermal district heating system.

"Geothermal living"

Klamath Falls, Oregon, has long been known as a "city in hot water" because of its use of geothermal water for heating. In Klamath Falls, it is possible to enjoy a cradle-to-grave geothermal life. One can be born in a geothermally heated hospital, be geothermally heated in schools from grade schools through college at Oregon Institute of Technology, get married in a geothermally heated church, and live in a geothermally heated house built from wood dried by using geothermal energy. One can relax with the product of a local brewery that uses geothermal energy to produce beer. You can buy a car in a geothermally heated automobile agency and park it on your geothermally heated driveway. You can drive the car on geothermally heated pavement, and take the car to a carwash using geothermal water. You can get medical attention in a geothermally heated doctor's office, and wash your clothes in a geothermally heated laundromat. If you are of good character, you can enjoy the facilities of the local geothermally heated YMCA; if not, you may be taken to a geothermally heated Klamath Falls jail. Winter snow and ice are melted by geothermally heated sidewalks. For later life, there is a geothermally heated nursing home available, and finally, one may be buried by a geothermally heated mortuary.

Many other places also employ geothermal water for space heating. The ground-to-air heat pump makes use of the constant temperature of the heat flow of the Earth and is seeing increasing widespread use.

Electric power generation

Geothermal energy was first used to produce electricity in 1905 when a light bulb was lighted in Italy from a geothermal field 70 miles north of Rome at Larderello. The field is still in operation. Italy has now developed enough geothermal electric power to generate the equivalent of what it takes to run all the electric trains in Italy, and almost all Italian railroads are electrified. This is a huge savings to Italy, which has very little oil and would otherwise have to import large amounts of diesel fuel to run its railroads.

The world's largest geothermal electric generating plant is located at The Geysers, about 70 miles north of San Francisco. Electricity was first produced there in 1960. More than 2,200 megawatts was eventually being generated, the equivalent of two large dams, and enough to supply the electric power needs of about one and one-half million people. However, the field was apparently over-drilled, and production eventually fell to about 1100 megawatts. The town of Mammoth, California, gets electric power from a local 40-megawatt geothermal plant. And there are several geothermal electric plants in the Imperial Valley of Southern California feeding power to the greater Los Angeles area.

In a number of other nations, geothermal energy is being converted to electric power. New Zealand gets 10 percent of its electricity from generating plants using geothermal as the power source. The Philippines uses geothermally generated electricity and plans a large development of this energy source. With almost no oil, geothermal power is proving a great boon to that volcanic island country. At Cerro Prieto near the United States border, Mexico generates 150 megawatts from geothermal wells, half of which is used in northern Mexico. The other half is sent to the San Diego, California, area. The large geothermal potential of sites in the Great Rift Valley of Africa is beginning to be developed.

Locally important, site specific

Geothermal energy tends to be site specific. That is, unless it is hot enough to be used to generate electricity which can be transported to distant areas by power lines, it must be used fairly close to where it exists in nature. It cannot be shipped across oceans like coal, oil, natural gas, or uranium. Thus, locally, geothermal energy can be and is important, but as a solution to the world's energy needs, it can have only minor impact. Still, there is considerable geothermal energy to be developed. But it is likely to provide only about five percent of the world's future energy supply.

Central America has very large geothermal energy potential. Some of this has already been developed in Nicaragua, El Salvador, and Costa Rica. Chile and southern Peru in the high Andean volcanic areas hold good prospects for geothermal development. Chile has some capacity already installed. The Kamchatka Peninsula of far eastern Russia has large geothermal resources, which so far have been developed only slightly. Neighboring Japan uses geothermal waters for both space heating and electric power production. There are also very large prospects for geothermal developments in Indonesia, where Chevron's Geothermal Division operates.

In total, some 80 countries are now either exploring or developing and using geothermal energy for electric power generation. This is bound to grow as demand for energy increases, and oil supplies become more costly and scarce. An international organization, the Geothermal Resources Council, based in Davis, California, holds annual meetings promoting worldwide geothermal development.

Renewable?

As a technical matter, we have classified some geothermal energy as a nonrenewable resource. When geothermal energy is used for electric power generation, it is nonrenewable because eventually the reservoirs of steam and/or hot water will be depleted to the point where they are no longer capable of sustaining electric power generation. The time to depletion is variously estimated to range from 40 to 100 years in most geothermal electric power fields. However, after being shut down over a period of many hundreds or perhaps thousands of years, the field will recover and could be used again, because the heat will still be there. It is only the hydro system that gathers the heat from fractured hot rocks and brings it to the well bore that becomes exhausted.

For this reason, geothermal energy used for electric power generation in a practical sense does not appear to be a renewable resource. There is, however, technology being tested which may modify this conclusion. In some geothermal fields, waste water is being injected back into the reservoir to see if the reservoir level and pressure can be maintained without reducing the temperature. At The Geysers field in northern California, a 65-kilometer pipeline was recently completed bringing waste water north from Santa Rosa for injection into the geothermal field. An earlier project brought water from a lake that resulted in a recovery of 68 megawatts of power and slowed the area's pressure decline. If this technology continues to be successful, it can materially extend the life of geothermal electric generating fields. With proper management, it could make geothermal electric power a sustainable energy resource.

Worldwide geothermal electric power

Currently the installed capacity of geothermal-powered electric generating plants totals more than 10,000 megawatts. This is the equivalent of about seven to nine conventional coal-fired plants. Leading countries, in declining order, are the United States (2,685 MW); Philippines (1,970 MW); Indonesia (992 MW); Mexico (953 MW); Italy (810 MW); Japan (535 MW); New Zealand (472 MW); and Iceland (421 MW).

Renewable for space heating?

When used for space heating, hot water usage can be controlled to be kept in balance with the natural recharge of the hydro system which brings the heat from the permeable hot rocks to the well bore. In this case, geothermal energy is a renewable resource. Thus, depending on its end use, geothermal energy can be thought of either as renewable or non-renewable. Even when used for space heating, the geothermal reservoir can become depleted if it is over-used. This seems to be the case in several of the district heating systems in southern Idaho, and at Klamath Falls, Oregon, where studies of this problem are under way. However, using geothermal water for space heating is its most efficient use and it should be pursued. The efficiency stems from the fact that there is no change from one energy form to another. When geothermal water is used to generate electric power, heat energy is changed to mechanical energy and then to electrical energy. Any change in energy form results in an energy loss (second law of thermodynamics). The lower-temperature waters that can be used for space heating are far more abundant and widespread than the high-temperature waters required for efficient electric power generation. Even where there is no especially warm water to use, the general heat flow of the Earth can be tapped by using groundwater heat pumps, which are efficient in most temperate areas, and better in some places than standard air-to-air heat pumps.

Use of Earth's natural heat flow

It is feasible, particularly in a hilly setting, to build a split level house with part of it below ground level. In colder countries, in particular, the natural heat flow of the Earth will add to the warmth of the house in the winter. Because it is a steady temperature, it also can have a cooling effect in the summer. Such an arrangement is a natural air conditioner. Some houses are built almost entirely underground. Whereas this requires more power for lighting, there is a net reduction in power use because both heating and cooling take far more energy than lighting does. It is also land efficient in cases where people grow gardens on the roofs of such dwellings. By using the natural heat flow of the Earth in this fashion, geothermal energy is renewable, and is also considered in Chapter 12.

A modest help

Locally, geothermal energy can be and is now in places very important, but in terms of the energy needs of the world as a whole, it is likely to contribute only a small amount. It has the advantage, particularly when used for space heating, of having a very low environmental impact. In electric power generation, it has far less environmental impact, or a smaller "footprint," than do dams, or coal-fired plants. This consists mostly of habitat loss and fragmentation at the site of the development itself (assuming the site consists of natural habitat), rather than the much more widespread effects of dams and coal-fired power plants.

Geothermal widely used

Geothermal energy is widely used. It creates easier and more pleasant living conditions for many people, and locally and even to a small country, it can be exceedingly important, Iceland being a prime example. Even though the use of geothermal energy for electric power production only may be a small part of the world energy supply, the total contribution of geothermal energy is of considerable local economic importance, and replaces other polluting fuels such as wood and coal.

Nonrenewable Alternative Energy Summary

There are several alternative nonrenewable energy sources. However, none is so versatile as oil. Each has advantages and limitations. Replacing petroleum will require a mix of other energy sources because no single alternative exists. And it will require a substantial reorganization of our economic structure. It will also mean a considerable change in personal lifestyles from those that exist today in the industrialized countries. The transition is inevitable. It is better to begin to prepare for it now. Petroleum is a finite resource which is sure to be mostly gone in less than 100 years. Coal may last longer, but eventually it too will be depleted. Professor David Rutledge at the California Institute of Technology projects that 90 percent of all economically recoverable fossil fuels will be exhausted by 2070, meaning that they will be diminishing far earlier, leading to continuing higher prices. Ultimately, renewable energy sources must provide for humankind. These are considered in the next chapter.

By the end of this century, oil, gas, and coal will be insignificant in the world energy mix. The term "alternative energy" may no longer be used. The energy mix will probably include more diverse sources than today and will be supplied regionally and locally rather than globally like fossil fuels are today. These will be our regular energy sources and no longer thought of as alternatives to fossil fuels.

CHAPTER 12

Alternative Energy Resources: Renewable

We have been living on a great nonrenewable resource inheritance. By means of the technologies and machines developed for us by the Industrial Revolution, together with cheap nonrenewable energy from fossil fuels which we use to extract more fossil fuels, we have been depleting this inheritance at an increasing rate. Perversely, the increasing demand for resources is a different result of the Industrial Revolution's technologies that have greatly improved our standard of living, especially sanitation, resulting in the survival of ever more people. It is an unsustainable treadmill moving faster and faster as population burgeons against finite nonrenewable resources and limited renewable resources.

It is an interesting fact that every form of life except humans subsists entirely on renewable Earth resources. Humans are the only organisms that have exploited nonrenewable resources as the basis for a huge expansion of their population. Depending on renewable resources alone sets natural limits, basically food and freshwater supplies, for a population size that can be supported. As we inevitably move to dependence on renewable resources, matching the size of our population to renewables that can adequately provide for us is the epic problem of this century.

As we consider a future in which civilization has to exist on renewable resources, basically the daily increment of available energy and food, the story of reindeer on St. Matthew Island (in the Bering Sea off the coast of Alaska) is pertinent.

Over centuries, the lichen that grew on the island was not grazed and it flourished into a lush four-inch thick carpet. In 1944, 29 reindeer were introduced to St. Matthew to act as part of the food supply for the 19 men who were stationed there to operate the loran (long range aid to navigation) Coast Guard station. But the men were removed before they had a chance to shoot the reindeer. With the inheritance of the huge supply of lichens analogous to our own fossil fuel supply, and with no natural predators or competitors, the reindeer population increased rapidly from the original group of 19 to a herd of 6,000 animals. But two years later, nearly all the herd had died of starvation and no breeding population was left. By the 1980s, the herd had completely died off. It was a classic example of overshoot and die-off. The minute daily growth of the lichen was insufficient to keep any of the reindeer alive.

The petroleum (oil and gas) we have been exploiting brought us abundant cheap energy, which allowed for a great expansion of food-producing acreage along with much better sanitation and other health advances. Human numbers, with a greatly expanded food supply and a decline in disease along with other health improvements, have expanded exponentially to their present size of 7 billion people.

Can the renewable energy base support today's population? If not, what happens when the projected population increases to more than 9 billion by 2050, as the nonrenewable energy base decreases? This is the critical question we examine as we consider various prospects for renewable energy supplies. Can they really fill the gap left by the continuing depletion of oil and natural gas as we use them today? Mathis Wackernagel and others, cited in a succeeding chapter, believe we have already exceeded the sustainable carrying capacity of the Earth.

Although the use of other nonrenewables (oil sands, coal, and natural gas) as alternatives to conventional oil may help tide us over in the short term, the long-term energy future must lie with truly renewable energy sources. As this is recognized, there is a great flailing about promoting a variety of possible solutions. As Roberts (2004) writes:

> Yet if it is obvious that the current energy economy is on its way out, no clear consensus has taken shape on what happens next, what the 'next' energy economy will look like.... Newspapers and magazines and political speeches are filled with descriptions of brave new energy technologies — hydrogen fuel cells and wind farms and solar-energy buildings and tidal generation and fantastic processes that turn grass into diesel and manure into gasoline. But are any of these truly viable? How much will they cost? Can they be brought to bear in time?

With depleting oil, natural gas, and coal, we are living in, as Hartmann (1998) titled his book, *The Last Hours of Ancient Sunlight*. Now what? In looking at renewable energy resources, we are searching for the "what." This is one of the realities of the twenty-first century.

Table 12-1. Renewable Energy Sources

- Biomass (including alcohol and gas derivatives)
- Fusion (a technology not yet perfected)
- Geothermal (lower temperatures than needed for electric power generation)
- Hydropower (run of the river – not dams)
- OETC (ocean thermal energy conversion)
- Solar
- Wind
- Tides
- Currents
- Waves

Rising gasoline and diesel price problems, and the underlying crude oil supply problem are, but the tip of an iceberg we are slowly approaching in an inevitable collision that will ultimately sink the luxurious hydrocarbon *Titanic* on which we have been so pleasantly traveling till now. Then we will have to take to the renewable energy resource lifeboats for survival. The two questions are: "What sorts of lifeboats can be launched to take care of the *Titanic's* many passengers, now 7 billion and growing and will the lifeboats have the capacity to take all the passengers from our sinking hydrocarbon ship?" We are approaching the time when we will have to live on current resource income instead of the nonrenewable energy inheritance the Earth very briefly provided. Table 12-1 presents the renewable energy spectrum.

The oil companies that supply much of our energy needs today recognize their survival time on finite petroleum is limited, and are examining what resources can support them in the future. They are recasting themselves as "energy companies." Some are establishing significant alternative energy divisions. In a three-page advertisement in the December 7, 2005, *Wall Street Journal*, BP, whose logo "beyond petroleum" is a registered trademark, writes:

> It's time for an alternative. That is why BP is introducing alternative energy — a new business that aims to lead the way toward lower carbon electricity. By dramatically expanding our solar, wind, hydrogen, and natural gas power activities, we aim to reduce global carbon dioxide emissions by at least 24 million tonnes a year by 2015.

Shell Oil Company's CEO, Jeroen van der Veer, was interviewed in corporate offices in The Hague, Netherlands, concerning that company's views on possible alternatives. He said:

> Every form of alternative energy is a pot on the fire. But I call it a small pot on the fire. Having a pot on the fire you can smell it and sniff it. Some pots boil very well, and some pots you take off the fire, which we have done as well.
> In 20 or 30 years, alternative energies will start to play a key role. My wish, my ambition for this company, is that if we can make at least one alternative energy a major business, then I think we have done well.

This view seems realistic. Alternatives will play a small but increasing role in our energy spectrum. However, even 20 to 30 years from now, their importance in the total energy supply is likely to be modest. Scaling them up to replace any large amount of oil and gas will be difficult and costly. The Energy Information Administration (EIA) of the U.S. Department of Energy has put out an estimate of the relative importance of various world energy sources in 2025, as shown in Table 12-2.

Despite the enthusiasm and hopes for alternative renewable energy sources, it is likely that the energy mix by 2030 will be very much like it is now, with oil, coal, and natural gas predominant. While there are changes on the horizon, we have a long way to go before other energy sources replace our dependency on fossil fuels. Most alternatives are not economically competitive at this time, nor do they have the scale or the potential to be able to significantly offset the use of fossil fuels in the next several decades.

Table 12-2. Projected World Primary Energy Sources In 2025 (Percentage of total)

Energy Sources	Percentage
Oil	39
Natural gas	25
Coal	23
Renewables (including Hydropower)	8
Nuclear	5
TOTAL	100

Source: US Department of Energy, Energy Information Agency, International Energy Outlook, 2004

Eventually, even ExxonMobil, if it is to survive as an energy company, will have to embrace renewable energy sources. It has already committed staffing to evaluate prospects, and in 2009, committed $600 million toward producing oil from algae. Technology that brings the price of alternatives down, combined with the inevitable price increase in nonrenewable energy sources, will eventually make some renewable energy supplies competitive, gradually replacing fossil fuels to a degree. The "degree" to which this can be accomplished will determine future lifestyles and the nature of our economies.

Alternatives are optimistically promoted in economic and political venues as a solution to the oncoming energy problems, which must show a positive bias toward solving pressing public problems. Governments, educational institutions, the media, and even businesses are "future directed" institutions. None could simply say there is no solution, and none will venture to say most solutions will be as difficult or limited as they might know or believe them to be. The future is always an optimistic place.

On September 15, 2004, Federal Reserve Board Chairman Alan Greenspan, noting the current high oil price (then $55 per barrel) stated: "If history is any guide, oil will eventually be overtaken by less-costly alternatives well before conventional oil reserves run out." This was an optimistic, reassuring statement to the public. However, Mr. Greenspan did not say what those less-costly alternatives are. The "less-costly alternatives" that could make a significant contribution to the world energy resources are nowhere in sight. Furthermore, there are no comprehensive substitutes for oil in its myriad end uses. But Mr. Greenspan, like others in Washington who like to bring good news, suggests alternatives will appear in time to make the post-hydrocarbon transition possible without interrupting the hydrocarbon energy lifestyle people now enjoy. If Mr. Greenspan's optimism had some basis in fact, we should be much further along in the transition to renewables than we are.

Two Fundamentals of Renewables

Net-energy recovery

We have discussed this concept as essential in evaluating any energy source. It is especially important when renewables are considered, because most renewables have a much lower energy/profit ratio than nonrenewables do, especially when total energy input costs are included, such as manufacture and maintenance of equipment to capture the energy output.

Renewables must build renewables

As we begin to develop renewables, we have the luxury of using fossil fuels for the production of wind turbines, solar energy devices, and ethanol. But in the future, when fossil fuels are no longer abundant, the equipment to capture renewable energy supplies will have to produce enough energy to replace the renewable energy equipment which inevitably deteriorates with time and use. Renewable energy capturing equipment will have to renew itself. Transitioning to renewables presents formidable problems, and will not be accomplished easily despite optimistic views to the contrary. "What happens when oil becomes much more costly and scarce?" "We will just use renewables." I have heard this many times, expressed as an expected simple transition of little concern because the scientists and engineers will just do it. Realistic prospects for this transition follow.

Biomass

This is the first fuel used by humans, and it continues to be used in great quantities in many places in the world, increasingly to the detriment of the environment. Biomass includes vegetation in all its various forms such as grass, shrubs, trees, and grains. It is the product of sunlight, air, soil, and water. Biomass in a secondary form as manure is sometimes used as a fuel. Biomass is the base for all animal life.

Wood

Only a little more than a hundred years ago (about 1880), wood was the chief fuel used in the United States. It is still the principal fuel in many parts of the world. But the exploitation of wood and other biomass is removing vegetation in many areas beyond the replacement rate, causing large and fatal landslides, devastating floods (as in Bangladesh, 1988), and widespread erosion and loss of valuable topsoil (Pimentel and Krummel, 1987). In Haiti, which was once nearly all forested, only two percent of the land is now, because the demand for charcoal, an important fuel for cooking and household use, far exceeds the reforestation rate. Topsoil is being rapidly lost too. As one flies into the Haitian capital of Port-au-Prince, the brown ring of muddy water fringing its shore reveals the disaster of over-reliance on wood. Even the stumps of trees and shrubs are dug up for fuel. In 2004, heavy rainstorms hit the Island of Hispaniola (of which Haiti occupies the western third) and massive landslides on the barren hillsides were responsible for the loss of more than a thousand lives. With the additional loss of soil, Haiti's problems have compounded.

In the countryside around Bogota, Colombia, the highlands of Peru, and throughout much of India, Pakistan, Bangladesh, Nepal, and other parts of Asia including China, in Central America (Guatemala, Mexico, Honduras), and especially in Africa there is a serious firewood supply problem. Depleting forests and brushy groundcover has harmed the soil, both by erosion and from the loss of biomass important to soil health. It is doubtful that the use of wood for fuel can be significantly expanded. In many regions, the forests need to grow back to prevent further erosion and floods, which are already severe. Loss of trees and vegetation is a particular problem in the foothills of the Himalayas where forests once regulated the gradual run-off of water. That has been changed by deforestation and now great floods occur in the lowlands to the south, especially in the densely populated lowlands of Bangladesh. In both India and Bangladesh, deforestation has also resulted in eroded soil filling reservoirs far faster than was projected for dam sites.

Wood is still a useful local fuel for cooking and heating. Some utility companies use wood in small amounts for power generation. However, the woodlands of the world are so important to the health of the environment for preventing erosion, as a sink for carbon dioxide, and in countless other ways that they cannot be used as a sustainable fuel supply in any significant amount.

Other biomass such as animal dung is used for fuel in parts of India and Africa. In some rural parts of China, human and animal excrement is accumulated in containers and the resulting methane is used for cooking. Garbage dumps in the United States and elsewhere have been covered with tarps to collect the methane being produced, which then is piped into small gas turbine generators. Garbage can also be used directly as fuel for boilers in conventional power plants. Wood waste from lumber operations and stalks from sugar are also used for boiler fuel. But the amount of energy produced from all these sources is very modest. More recent efforts to produce significant energy supplies are using what are popularly called biofuels.

Liquid Biofuels

Although all biomass burned is a biofuel, the term recently has come to refer to various liquid products that can be used in transport vehicles. Biodiesel and bioethanol are prime examples. Because biomass can be converted to liquid fuels and used in today's conventional internal combustion engines, it makes the transition from conventional oil seem a simple matter. Biomass as biofuel has become a major topic in the alternative energy discussion.

Advantages of mobility base of demand for liquid fuels

The intense demand for liquid fuels reflects the fact that personal mobility is one of the greatest aids for improving standards of living. Enhanced mobility gives greater access to a variety of services and increases choices about where individuals live and work. Ownership of a vehicle is often a matter of prestige, and almost always the first significant use of disposable income is to acquire a motor vehicle.

Actually, biofuels were the first fuels to be tried in automotive transport. Henry Ford's first automobile (of sorts), the Quadricycle, was powered by ethanol, and his Model T was designed to run on ethanol, gasoline, or a combination of the two.

Ethanol

In recent decades, ethanol has become the most discussed alternative fuel in the United States as well as in several other countries. Ethanol is an alcohol commonly made from corn, but it can also be made from other vegetative materials. Ethanol is frequently and enthusiastically embraced as a positive, non-polluting, renewable alternative to gasoline. However, there is considerable controversy over the use of ethanol as a fuel, particularly in a 10 percent blend with gasoline commonly called gasohol. Another blend of ethanol and gasoline is E85, 85 percent ethanol.

As a means for improving air quality, the U.S. Environmental Protection Agency (EPA) has required certain areas at particular times of the year to sell this oxygenated (ethanol mixture) fuel to motorists. The corn-producing states such as Iowa and Nebraska are strong advocates for ethanol as a fuel for the nation, as are political candidates running for office in those areas. Presidential candidates enthusiastically embrace ethanol when they campaign in corn states. As a result of the strong ethanol interests, Congress passed a law in 2005 mandating widespread use of gasoline-ethanol blends which increased its use to 12 billion gallons a year by 2012.

Tax subsidies

But what made it economically possible to put ethanol in gasoline was the federal government's 45-cent-a-gallon tax credit. After more than 30 years and $20 billion, in January, 2012, Congress refused to renew the federal subsidy for ethanol, letting it expire. It will be interesting to see how this will affect the industry. However, state subsidies remain available for ethanol. These subsidies are paid from general tax revenues and mean that gasoline/ethanol blends are more expensive than they appear to be at the pump. Dr. T. Stauffer, a research associate at Harvard, said, "The bottom line is that using alcohol to stretch gasoline is like using filet mignon to stretch hamburger."

"Renewable power and fuels will be more expensive than the dirtier sort for the 'foreseeable future.' This leaves the clean-energy business largely dependent on government handouts." (*The Economist*, 2007). Without subsidies, most alternative power sources would not survive at present. As oil becomes more expensive, oil's competitive advantage with alternative fuels will fade. However, for electric power, the world's supplies of coal and natural gas will be less costly and more dependable than other electric power fuels for decades to come.

Ethanol — the energy recovery

Beyond its higher cost, there is another basic problem making ethanol from corn (the grain source most widely favored for ethanol production in the United States). If the energy costs of plowing, planting, fertilizing, and harvesting the corn together with moving corn to the processing plant, and the energy involved in processing the corn to alcohol are all added in, the net-energy result may be negative. That is, less energy is being recov-ered than it took to produce the ethanol. Argument over this has raged, with Pimentel and Patzek (2005, 2006) saying it takes more energy to make ethanol than you get out of it, and the Department of Agriculture arguing the other side, saying there is a net-energy recovery (Shapouri et al., 2002).

Although ethanol is commonly thought of as a farm product, it is largely a product of the energy inputs noted, and the oil-based pesticides and fertilizers used to enhance the growing. This fact is conveniently ignored by politicians and others who endorse ethanol as an alternative to gasoline at the same time they berate the oil industry that provides the basis for modern agriculture, including corn production.

The argument that ethanol from corn is a net-energy loss looks increasingly persuasive. The U.S. Department of Energy (USDOE) has examined the facts of net-energy recovery and two of its panel studies reported a negative return. "These reports were reviewed by 26 expert U.S. scientists independent of the USDOE: the findings indicate that the conversion of corn into ethanol energy was negative and these findings were unanimously approved" (Pimentel and Patzek, 2005). These authors conclude that producing ethanol from corn requires 29 percent more fossil energy than the energy produced from the ethanol.

Consumer Reports (October, 2006) weighed in on the ethanol issue with a cover article, "The Ethanol Myth," pointing out that because of the lower-energy content of ethanol (27 percent less than gasoline), ethanol may not save as much energy as claimed, and that it greatly reduces the mileage range of cars. In one test case, it reduced car mileage from 450 miles to 300 miles per tank of fuel.

Pimentel and Patzek (2005) estimate that if the entire U.S. corn crop were used to make ethanol, " … it would replace only 6 percent of fossil fuel used in the U.S. And because the country has lost over a third of its agricultural topsoil, no large increase in the corn crop is possible."

Pimentel and Patzek (2005) further write:

> Moreover, the environmental impacts of corn ethanol are enormous. They include severe soil erosion, heavy use of nitrogen fertilizer and pesticides, and a significant contribution to global warming. In addition each gallon of ethanol requires 1700 gallons of water (mostly to grow corn) and produces 6 to 12 gallons of noxious organic effluent.
>
> Using food crops such as corn to produce ethanol also raises major ethical concerns. More than 3.7 billion humans in the world are currently undernourished, so the need for grains and other foods is critical. Growing crops to provide fuel

> squanders resources; better options to reduce our dependence on oil are available. Energy conservation and development of renewable energy sources, such as solar cells and solar-based methanol synthesis, should be given priority.

In terms of gasoline, Smil (2010) estimates that if the entire U.S. corn crop was converted to that use, it would produce an equivalent of less than 15 percent of current U.S. annual consumption.

Ethanol follies are numerous. For example, Robert Wisner at Iowa State University calculates that the demand for Iowa's corn from operating ethanol plants, those under construction, and those planned as of 2006, would be 2.7 billion bushels. A good year's corn harvest for Iowa is 2.2 billion bushels. Iowa has been one of the states that can export corn to meet foreign hunger. What happens in Iowa affects many people overseas, as well as the price of numerous foodstuffs on supermarket shelves in the United States.

Egypt is highly dependent on corn shipments from the U.S. for its food supply. China also is becoming increasingly dependent on imported grain. In a number of articles, Lester Brown of the Earth Policy Institute raised the ethical question of "food versus fuel." Pimentel and Patzek (2005) also have an extensive discussion of the "food versus fuel issue" with numerous statistics bearing on the matter.

Wald (2007), from an extensive study of ethanol, concludes:

> … relying on ethanol from corn is an unsustainable strategy: agriculture will never be able to supply nearly enough crop, converting it does not combat global warming, and socially it can be seen as taking food off people's plates. Backers defend corn ethanol as a bridge technology to cellulose ethanol, but for the moment it is a bridge to nowhere.

The energy in a barrel of ethanol (42 gallons) equals only 28 gallons of gasoline, which contains 119,000 Btus (British thermal units) per gallon compared with 76,000 for ethanol. If you fill your tank with E85, you will have to refill 33 percent sooner than if you use gasoline. Even if a gallon of ethanol blended gasoline was cheaper at the pump, drivers would have to buy more gallons to travel the same distance. (This is well documented in "The Ethanol Myth," in *Consumer Reports*, 2006). Car engines must be specially built to use E85, because ethanol destroys the seals in conventional engines. "Although the Bush Administration is giving strong and enthusiastic support to 'flexible-fuel vehicles' that can run on a blend of 85 percent ethanol with gasoline, this support is indirectly causing more gasoline consumption rather than less" (*Consumer Reports*, 2006).

Brazil has developed ethanol production from sugar cane on a fairly large scale making it a significant source of domestic vehicle fuel. Also, the production of ethanol from sugar cane is more efficient than from corn. Ethanol service stations are common in Brazil. However, David Victor, Director of the Program on Energy and Sustainable Development at Stanford University, notes that although Brazil is energy self-sufficient, meaning that the country produces the same amount of energy it uses, " … ethanol only accounts for one-tenth of the country's energy supply." Brazil recently substantially expanded its oil production, which is the major factor in its energy self-sufficiency. Victor also observes: "Scale really matters here. The U.S. market is so large, at 10 times the size of Brazil's, that modeling U.S. production after Brazilian production is not feasible. Furthermore, doing it at scale with current technologies would be economically difficult and environmentally damaging."

Ethanol from cellulose

Ethanol from wood biomass requires 57 percent more fossil energy than the energy in the ethanol it produces.

Although Congress still promotes the illusion of significant production of cellulosic ethanol, expectations consistently exceed reality. In 2007, Congress passed a law mandating that oil companies blend cellulosic-derived fuel into gasoline, and provided a $1.01 tax credit subsidy for each gallon produced. By 2010, the mandate was set for 100 million gallons, 500 million by 2012, and continuing to rise to 10.5 billion gallons a year by 2020. An energy bill was passed requiring oil companies to buy "waiver credits" for failing to buy a product that didn't exist, at a cost of $10 million in 2010. Facing the reality, the EPA quietly reduced the mandate to 6.6 million gallons by 2011, announcing the 500 million gallon 2112 goal was unattainable. In 2011, the National Academy of Science noted that "currently, no commercially viable biorefineries exist for converting cellulosic biomass to fuel."

To summarize: Congress subsidized a product that didn't exist, mandated its purchase, and punished oil companies for not buying a product that did not exist. In the meantime, Cello-Energy in Alabama declared bankruptcy. But the government-endorsed subsidized hope remains that cellulosic-based fuel will someday be a significant reality. In September 2011, the Department of Energy loaned $134 million to Abengoa Bioenergy to build a cellulosic-based fuel plant in Kansas, ignoring the important environmental reality that healthy soils require that cellulose residues be returned to the ground to decompose, form humus, and provide tilth.

Biofuels — how sustainable?

The net-energy loss for the production of ethanol from any biomass brings up the issue of how sustainable, and indeed, how rational it is to obtain ethanol fuel from crops or organic waste from any source. And there are environmental negatives to ethanol production. The annual loss of topsoil from the cultivation of corn is substantial. This is a serious consideration not only for growing corn, but for the cropping and burning of all biomass (Pimentel and Krummel, 1987). If processing switchgrass or other cellulose plant materials to produce ethanol could be done economically, it would involve breaking the normal cycle of plant growth, death, and decay that ultimately regenerates the humus in the soil. Humus is the single-most valuable material in soil, keeping it loose, holding moisture, and hosting myriad useful microorganisms making the soil useful for plant growth.

In an article, "Robbing the Soil of Its Future," John Tanton (2003) addresses this problem and records an exchange of correspondence he had with Nobel Laureate Norman Borlaug, father of the "Green Revolution," and with Cornell University agricultural scientist David Pimentel on this matter. Tanton, a dedicated gardener, wrote, "I have hauled hundreds if not thousands of bags of grass clippings and leaves into my garden, thereby markedly improving the tilth, erosion resistance, and water-retaining ability of the soil. Of course, what I have also been doing is hauling in carbon to act as an energy source of the myriad organisms necessary to soil health. But now we are seeing proposals for hauling off not just the corn grain to the alcohol fermentation plant, but also the cobs, husks, and stalks to serve as fuel for the power plants."

Borlaug replied to Tanton, "The idea … of trying to reduce our consumption of fossil fuel by removing all of the crop residue does not make sense in the long run." Pimentel added, "It would be a disaster to remove crop residues from our agricultural land. The average soil erosion on cropland in the U.S. is about 20 tons per hectare [2.47 acres] per year, which is about 10 times the soil sustainability rate. If crop residues were removed, erosion rates would increase more than ten-fold …. Few people appreciate that it takes 500 years to replace 1 inch of soil under agriculture conditions and that we need a minimum of 6 inches to grow a crop. I personally rank soil erosion, after population growth, as the most serious environmental problem worldwide …. Soil erosion rates are intensifying in most developing countries because of wood fuel shortages and the people are forced to burn crop residues — a disaster!"

Questioning the sustainability of using cellulose from corn stalks and other cellulose sources as a feed stock for ethanol, an individual identified only as "Eric" wrote on the Internet on January 20, 2007: "As a practicing farmer, I can wonder about a couple of things myself. First, what about the good farming practice of plowing the left over materials back into the soil? Have the 'city-bred' bean counters forgotten/did not know this? Soil thus becomes an energy resource in this scenario. The question then becomes are we depleting this resource the same as we are depleting our reserves? Is ethanol really a renewable resource?"

Two University of Minnesota scientists, Tilman and Hill (2007) noted that "Lost in the euphoria [for biofuels] is that three fundamental needs — food, energy, and a sustainable environment — come into direct conflict." Studies at Montana State University and Iowa State University further substantiate the view that production of biofuels is unsustainable, and there is no "waste biomass." Removal of corn stover (leaves and stalks) and other cellulose materials for production of fuel would ultimately destroy the soil, as no humus would be added.

A further negative environmental impact of ethanol production in the United States is that farmers are taking land now in the Conservation Reserve Program and using it to grow more corn to supply the ethanol plant demand. The soils in the Conservation Reserve Program are marginal lands, where any cultivation will increase soil erosion and reduce wildlife habitat. Using more marginal lands means using more fertilizer, more irrigation, and more pesticides. About 37 million acres of private land are enrolled in the Program. Since its inception in 1985, the voluntary program has protected 2 million acres of wetlands, and planted 1.7 million acres of grass and trees along waterways. Soil erosion has been reduced by 450 million tons per year and improved wetland habitation has increased the duck population by several million. Much of these environmental advantages will be lost for the sake of ethanol. Farmers now are paid $2 billion a year not to cultivate these lands. Will the additional corn from these lands be worth $2 billion a year, not counting environmental costs? Ethanol is not as inexpensive as it is claimed to be. It demonstrates the principle in nature that you cannot do just one thing. Everything is connected to everything else.

Based on the foregoing assessments by agricultural experts, the enthusiasm for biofuels, including switchgrass as a possible significant fuel source, may be called into question as a sustainable future source of energy. It may ultimately prove to be a partial short-term solution with a disastrous long-term environmental impact. In a comprehensive study of the potential for biofuel production on a significant scale, Giampietro et al. (1997) concluded: "Large-scale biofuel production is not an alternative to the current use of oil and is not even an advisable option to convert a significant fraction of it."

The net-energy return from various crops and agricultural practices is vital to our future. A comprehensive study of both the energy inputs to agriculture (extensive tables), and what energy may be derived from agricultural sources is presented in an outstanding work by Pimentel and Pimentel (2008) *Food, Energy, and Society*. It also examines issues of the environment, biodiversity, water resources, soil and soil erosion, human demands for food, population growth, and the intricate interrelationships of these topics. This book offers an excellent overview and provides extensive references for each chapter.

Food versus fuel

Arable lands are now almost entirely engaged in food production. How could additional land be made available for crops to produce alcohol to make any significant replacement of oil as we use it today? In considering the limited amount of arable land, the competition between using crops for fuel rather than food was addressed in detail by Lester Brown (1980). He concluded that any large-scale attempt to use crop-derived alcohol for vehicle fuel would have a very negative effect on the ability of nations to feed their populations, and is not feasible. He also raised the ethical issue of whether the affluent car-owning minority in the world should be allowed to use grain for automotive fuel that would drive up world grain prices, noting that, "for the several hundred million who are already spending most of their meager income on food, continually rising food prices will further narrow the thin margin of survival. It is either food or fuel, and the use of crops for liquid fuel would simply starve the already world's poor for the benefit of those who enjoy the automotive age."

In addition, it is estimated that about 3600 gallons of water are required to produce a bushel of corn, and some corn is produced by irrigation which involves pumps using energy. In many areas, aquifers are being over-pumped. This is the case of the Ogallala Aquifer, which underlies parts of eight Midwestern to Western states and is a substantial source of water to irrigate corn.

Figure 12-1. Food vs. Fuel

Courtesy of Ed Gamble: *The Florida Times-Union*

Further illustrating the water demands for biofuel production is a study by Service (2009) reporting what it takes, in liters of water, to produce a megawatt hour of power by different sources. Corn ethanol uses 2,270,000 to 8,670,000 liters of water. Soybean biodiesel requires 13,900,000 to 27,900,000 liters. This compares with the water use per megawatt hour production from both petroleum production and refining combined of 90-190 liters. Using a different scale of measurement, other studies show that producing a gallon of corn ethanol requires up to 2,100 gallons of water. In Iowa, it takes 1,000 gallons of water to grow enough corn to produce one gallon of ethanol. In the Corn Belt from the Dakotas, Nebraska, and Kansas, eastward to Indiana and Ohio, such water demands will strain existing resources, especially in the plains states where much of the water used is groundwater from depleting aquifers. Water demand is a major limitation in the use of biofuels.

Food prices and ethanol

Beyond the cost of ethanol measure in terms of the energy used in production, the public pays for ethanol by a variety of subsidies estimated by the Congressional Research Service to amount to $9 billion annually. The cost of ethanol to the public is also reflected in the form of the higher cost of corn for cattle, hog, and chicken feed, passed on as increases in price for these items at the supermarket. It takes three pounds of corn to produce one pound of chicken or seven pounds of corn for one pound of beef. Also, corn syrup is used in many products on supermarket shelves, including canned fruits, most sodas, and even catsup.

Under the title "Food Versus Fuel," the problem reached the pages of *Business Week* (Carey and Carter, 2007):

> If all the scores of ethanol factories under construction or planned go into operation, fuel will gobble up no less than half the corn crop in 2008. Corn is caught in a tug-of-war between ethanol plants and food…. Bioenergy threatens to eclipse food, live-stock feed, and all other uses….

Record prices of corn, soybeans, rice, and other grains caused by conversion of significant portions of these crops to make fuel, have caused food riots in such distant places as Rome and Jakarta. Rice riots in Senegal and street demonstrations in Italy over the price of pasta are other reflections of the collision of the demands for food versus fuel. China and Russia have imposed price controls on grains. Pakistan as troops guarding wheat supplies.

Much of the blame for these events can be assigned to the U.S. energy bill requiring an increase in ethanol production, which makes no economic sense, antagonizes other people, and threatens political stability. To fill up the tank of one SUV with ethanol requires enough grain to feed one person for a year.

Petroleum, plastics, and corn

The U.S. uses about 200,000 barrels of oil a day to make plastics for various products, including car parts, rugs, clothes, flowers, curtains, toothbrushes, bottles, and myriad other uses. Now a headline reads: "Companies create plant-based liquid that replaces oil in plastic" (Mansfield, 2007). DuPont announced the development of a product, " … the most significant invention since nylon" (first produced in 1935). This sounds like good news, but reading further one finds that the product is made from corn, and "… experts say product contributes to rise in global food prices…making it harder for developing countries to feed their populations." Humans already appropriate almost all of our agricultural-based products in one way or another, so it becomes a zero-sum game. When someone takes something, someone loses something.

Air quality

Regarding the claim that ethanol reduces air pollution, which is the reason the EPA has required the use of ethanol in gasoline; the evidence seems not to bear this out. Dr. Larry G. Anderson, University of Colorado chemistry professor, reported at an annual meeting of the American Chemical Society that burning ethanol spewed several pollutants into the air including formaldehyde and nitrogen oxides, which help spawn the brown clouds that loom over Denver in the winter. Other studies show that air quality impacts of ethanol are no better than neutral and may be a negative. Anderson said:

> Although ethanol has been advertized as reducing air pollution when mixed with gasoline or burned as the only fuel, there is no reduction when the entire production system is considered. Ethanol does release less carbon monoxide and sulfur oxides than gasoline and diesel fuels. However, nitrogen oxides, and alcohol — all serious air pollutants — are associated with the burning of ethanol as fuel mixture with or without gasoline.

Mark Jacobson, Stanford University civil and environmental engineering professor, concludes that ethanol " …is not green in terms of air pollution. If you want to use ethanol, fine, but don't do it based on health grounds. It's no better than gasoline, apparently slightly worse."

Ethanol's future

Today, public and political infatuation with ethanol seems to be fading as the realities of its costs and limitations gain wider understanding. An additional issue receiving attention is the impact ethanol production has on world water supplies. The March 1, 2008, issue of *The Economist*, reported "A backlash against federally financed biofuels is growing around the country, and water could be the 'Achilles heel' of ethanol according to a report issued by the Institute for Agriculture and Trade Policy…. A typical ethanol factory producing 50 million gallons of biofuel a year, needs about 500 gallons of water a minute." *The Economist* (2008) concludes that: "Perhaps ethanol just isn't as bio friendly as it looks."

Ethanol/methanol

Methanol (CH_3OH) and ethanol (C_2H_5OH) can both be made from biomass. Methanol is commonly made today from natural gas and from coal. It has also been made from wood and wood waste. As a political matter, the U.S. Bureau of Mines was instructed by Congress to construct a wood waste conversion to methanol plant in Oregon. The Bureau did a credible job of plant development, and proved that a liquid fuel could be made from wood waste. But it was uneconomic and the concept was abandoned. There is not enough wood waste available to provide a significant amount of methanol, even if the process was energy efficient. Almost all waste from the production of lumber is now used within the lumber mill as boiler fuel, or used for other wood products such as particle board. Forest waste in most locations has been too scattered or too expensive to transport to be an effective resource. Notably, the United States is now an importer of timber and timber products.

Both methanol and ethanol have a lower-energy content (Btu) than gasoline. Methanol has the lowest at 56,800 Btu/gallon, less than half that of gasoline.

As motor fuel

A recent test of methanol, made from coal, wood, or natural gas, was undertaken by United Parcel Service with its large fleet of delivery vans. The experiment was in southern California. A blend of methanol and unleaded gasoline was used in 50 vans. The results were higher fuel costs, poor vehicle performance, more maintenance, frequent break-downs, and lower mileage.

The impossibility of using methanol as a replacement for oil in the United States is summarized by Pimentel: "If methanol from biomass (33 quads) were used as a substitute for oil in the United States, from 250 to 430 million hectares of land would be needed to supply the raw material. This land area is greater than the 162 million hectares of U.S. cropland now in production" (Pimentel, 1995). (One hectare equals 2.47 acres.)

Other biofuels being promoted include biodiesel, a blend of diesel and soybean oil. The same limitations of ethanol also apply to biodiesel — the environmental impact and doubtful sustainability of long-term production, and the energy input costs. If it is energy positive, which is questionable, it is only marginally so. Tad W. Patzek, a chemical engineer formerly at the University of California, Berkeley, and now with the Department of Petroleum and Geosystems Engineering at the University of Texas, Austin, calculates that producing soy diesel results in a 27 percent loss of energy. "Even if you assume that the soy bean waste has energy value as feedstock for cattle, the process still results in an energy loss of 2 percent."

Biodiesel also has limitations beyond either gasoline or ethanol. The Minnesota Legislature passed a law in 2005 requiring diesel sold in that state to contain two percent biodiesel. This worked fine in the summer, but given the nature of the Minnesota winters, it turned out that even two percent biodiesel in the fuel would congeal and plug the fuel line in cold weather. This aroused the ire of the truck drivers, and the law was temporarily suspended. "It's not like they weren't warned" said C. Fords Runge, a University of Minnesota economist who prepared a biodiesel study in 2001 on behalf of a Minnesota trucker trade group (Meyers, 2005). Others had cautioned that there would be problems. "I'd stop short of saying, 'Ha, I told you so," said Russell Sheaffer, Vice President of Cummins NPower, a regional distributor of Cummins [diesel] engines (Meyers, 2005). B100 (100 percent biodiesel) is not recommended for use in temperatures below 40° F. Decreasing temperatures below 40° F require that increasing amounts of petroleum-derived diesel be blended into the fuel because petroleum-derived diesel does not have such temperature limitations.

Biodiesel from soybeans currently enjoys a dollar-a-gallon federal subsidy, bringing the cost of pure biodiesel down from $2.65/gallon to $1.65, which is about the cost of producing diesel from crude oil. The subsidy caused biodiesel production to double in the U.S. from 30 million gallons in 2004 to 60 million gallons in 2005, and more plants are being built. Vaclav Smil, a professor at the University of Manitoba and author of *Energy at the Crossroads*, says: "Of course biodiesel is physically doable, but it doesn't make any sense."

Garbage power

Some cities are running out of places to put their garbage. New York has a severe problem, and at one time, a barge loaded with garbage was put out to sea to find someplace that would take it. No takers, and the barge become famous (or infamous) as the roaming seafaring garbage barge. Some communities have enclosed their growing garbage dumps and captured the methane produced by the decaying material. The methane in turn powers a gas turbine, turning a generator, but this source of power is very minor.

Switchgrass to the rescue?

In his 2007 State of the Union address, President George W. Bush made specific reference to switchgrass as a source of liquid fuel and his view of its great potential. Aside from the question of whether or not it would be economically possible to harvest switchgrass from millions of acres either by machinery or by hand, Pimentel points out that to use all the proposed acreage for switchgrass production would involve displacing 96 million cattle, seven million sheep, and four million horses now grazing on 57 million acres of U.S. grassland and rangeland. Like other biofuels, it is unlikely that switchgrass can do much for U.S. transport fuel supply, optimistic statements to the contrary. Studies by The Land Institute of Salina, Kansas, indicate that after the first few croppings of switchgrass are removed, the loss of humus to the soil results in a marked reduction in productivity.

Biomass not a major substitute for liquid fuel from petroleum

Finally, in the case of all biomass, the total volumes of raw materials needed to produce enough liquid fuel to make a substantial impact in substituting for oil are really not there. Counting the energy costs of planting, plowing, fertilizing, harvesting, and processing, the net-energy gain would be very small. Even if one assumes that 25 percent of our current crude oil needs could be supplied by this source, the figures remain unrealistic. One reason is that much of the United States has a growing season followed by a season when plant growth is more or less dormant. Integrating this seasonal schedule with the year around demand for vehicle fuel would be a problem. Realistically, biomass simply cannot supply even a modest proportion of the current oil consumption in the United States.

Biofuels in the post-petroleum economy

It may be that in carefully managed small-scale operations in a post-petroleum era, biofuels could be produced economically in some local situations. In self-contained economic units with no crop support from petroleum-based fertilizers or oil-running machinery, the true worth of biofuels will be known. Biofuels are economically marginal liquid fuel sources and their environmental sustainability is doubtful. Oil will be sorely missed, as efforts to replace it strike out in all directions. In today's energy-intensive world, there are no apparent comprehensive substitutes.

Professor Pimentel's quantitative analysis of this situation is illuminating:

> Assuming zero energy input for the fermentation and distillation processes of ethanol production and charging only for the fossil energy expenditure to culture the corn (essential to have corn/alcohol produce net energy), the amount of cropland required to fuel just one U.S. automobile is enormous. Making these assumptions, more than 6 hectares of corn land would be necessary to fuel one automobile for one year. In contrast, one person is fed using only 0.6 hectares of cropland. This emphasizes the tremendous waste of agricultural resources when ethanol is produced from grains.

All this does not stop politicians from widely endorsing biofuels. Subsidies are but temporary Band-Aids on a very large problem. The continued expansion of energy demand due to population growth is generally missing from this public discussion, but it must be central to solving problems of energy supplies for the future.

Biomass as Energy Source: Summary

The use of wood as an energy source goes back to primitive times. It is still a worldwide source of energy used primarily for cooking and space heating. Other biomass sources of energy including corn, sugar cane, and crop residues have been converted to liquid fuels such as methanol and ethanol. In some cases, the conversion can be an energy positive (that is, have a net-positive energy return on energy invested) but only marginally so. In the case of using current crops for conversion to alcohol, the energy balance in some appears to be negative — more energy goes in than comes out, especially when the energy costs of plowing, planting, fertilizing, harvesting, and transportation are included, which they should be. Other studies show a positive net-energy recovery, but in all cases, the energy/profit ratio is low, far lower than that derived from the recovery of petroleum from conventional sources today. That is the reality of biofuels.

Engineered trees and algal ponds

Among various concepts for future liquid fuel sources, some scientists are engineering trees that will be higher in sugar than ordinary trees, and thus be able to produce more alcohol. Shell, Chevron, and ExxonMobil are looking at algal ponds as a possible source of liquid fuel. This idea has been around for several decades, and extensive studies in the 1970s indicate that algae ponds are unlikely to be economically viable. Replacing any significant amount of the 20 million barrels a day of oil the U.S. uses with oil from any single or combination of biomass sources seems unlikely.

At present, about 11 percent of the world's energy is obtained from biomass, mainly wood. As the projected increase in world population is in developing countries where much of the biomass is burned, the amount of biomass that is likely to be consumed in the future may be even more. The damage to soils from the removal of biomass is already a disaster in many regions. Biomass left to natural processes generates humus. Loss of humus greatly reduces soil fertility. The logic of our situation is that, if anything, the amount of biomass used for energy in the future should decrease rather than increase. But with growing population, this is not likely to happen — another example in which population growth is adversely affecting the long-term environmental sustainability of a region.

Cannot farm our way out of liquid fuel problem

The basic limitation on the role that biomass could play as a source for liquid fuels is explained by Grant (2007): "It might take roughly 350 million hectares — equal to one-quarter of the world's arable land — to replace something like 5 percent of the present world fossil [fuel] energy production." Estimates are that it would now take more than twice the land area of the Earth to annually grow enough biomass to replace the energy content of current fossil fuel use.

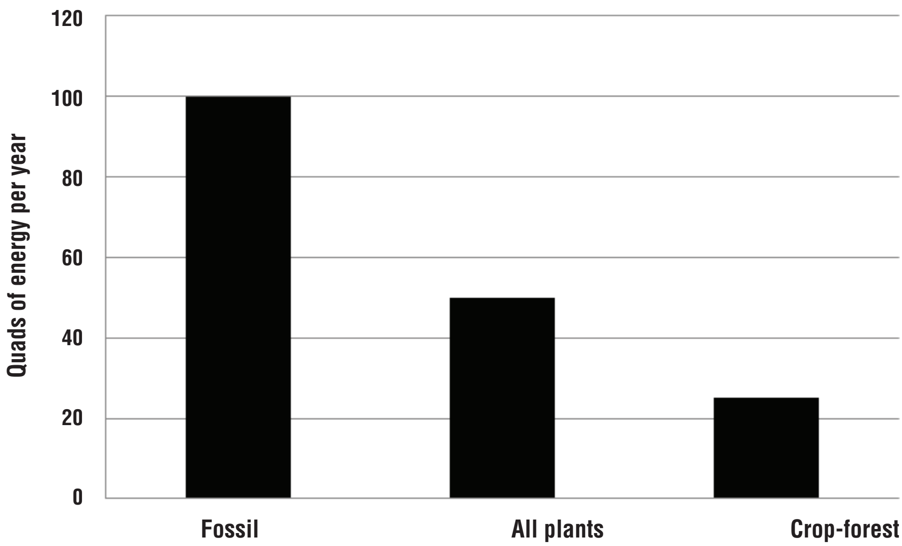
The conclusion that we cannot "farm ourselves out of the energy problem" is also supported by calculations on the website <ecoworld.com> (2006). These studies conclude that growing biofuels on 100 percent of the world's croplands would replace only 20 percent of the energy obtained each year from crude oil production. Given the energy inputs needed to produce the estimated biofuel output, it may be that even the estimate of 20 percent is too high.

Mow the United States annually?

Further emphasizing the huge contribution fossil fuels make to our economy today, and the futility of trying to replace a major part of this by biofuels, even if their production were sustainable, is the fact that in the United States fossil fuels now provide three times as much energy as the annual increment of energy produced each year by all the vegetation including forests, fields, and crops (Pimentel, letter March 21, 2008).

In other words, if we mowed the entire United States once a year to harvest the annual vegetation growth, we would still, by an impossible 100 percent totally efficient energy conversion process, be able to replace only one-third of the energy we now obtain from fossil fuels.

Figure 12-2. Amount of Solar Energy Captured Annually by All Plants in the United States, and That Just by Crops and Forest Products, Compared with Amount of Fossil Energy Used Annually in the United States



Source: Pimentel and Pimentel, 2008

Donald Anthrop (2007), Professor Emeritus of Environmental Studies at San Jose State University, has analyzed the prospects of energy from ethanol in particular and biofuels in general, as currently promoted by ethanol and biofuel enthusiasts:

> As the gasoline data show, biofuels simply cannot provide either the liquid fuels or the total energy required by the U.S. economy. Indeed, even if it were possible to collect all the above ground residue from the 200 million acres of corn, soybeans, wheat, oats, and rice in the U.S., the entire energy content of that residue is only about 7.4 quads, or about 7.4 percent of U.S. primary energy consumption. … Note that 7.4 quads is the total gross energy content of the residues. The net energy available after collection, processing, and replenishment of nutrients removed with the residue would be considerably less.

Anthrop notes what is often overlooked by promoters of alternative energy sources, namely the *net energy recovered*, or once again, the energy return on energy invested (EROEI).

Anthrop concludes: "It is time for politicians to stop pretending that biomass can make any significant contribution to U.S. energy supplies or reduction in carbon emissions." In a later study, Anthrop (2009) again examines the role biofuels might play in future energy supplies and concludes that there are exaggerated hopes for renewable energy from all the various biomass sources. He writes: "Government policy-makers would like us to believe there are vast quantities of crops, crop residues, and unused wood waste that can be easily converted into energy. The facts are quite different."

Biofuels: India and China

In spite of the trade-off of fuel for food, both China and India propose to increase crops for biofuel production. China plans to increase biofuel production fourfold, to four billion gallons of ethanol annually, 9 percent of its projected gasoline demand by 2020. India also plans biofuel increases. Both countries expect sugar cane and corn to be the basis for biofuel production. Corn is now one of the grain staples in these countries and diverting substantial amounts to biofuel production will raise the price of many foodstuffs. Also, corn and sugarcane both require large amounts of water for growth. As a result, less water will be available for growing food. China and India are now critically short of water, but the determination to become motorized is strong, and liquid fuels are a key element to achieving that goal.

Biofuels — a critical comprehensive view

In a *Wall Street Journal* article by the chairman of the Switzerland-based Nestlé company, a major food processor and retailer, Peter Brabeck-Letmathe (2008) made these comments concerning the diversion of food grains to fuel and the water requirements for biofuel production:

> This world's agriculture and water crisis is only going to get worse.... Food prices are rising in large part because agriculture suppliers can barely keep up with today's demand. So what is the world doing? Reorienting land away from food production toward plants cultivated for energy needs.
>
> This could be the single most destructive set of policy mistakes made in a generation. From time immemorial, mankind has struggled to produce enough food. Wars have been fought over arable land. Whole populations have been forced to migrate and untold millions have died because of circumstances...that have deprived them of what the German language describes as *Lebensmittel* or a 'means for survival.' This problem hasn't disappeared: our world today needs to feed some six billion people. According to some projections, that number will rise to nine billion by 2050.
>
> If there is one certainty, it is this: The production of biofuels has stimulated a massive and destructive reorientation of the world agricultural markets. The U.S. Department of Energy calculates that every 10,000 liters of water produces a little as five liters of ethanol, or one or two liters of biodiesel. Biofuels are economical nonsense, ecologically useless, and ethically indefensible. This year the U.S. will use around 130 million tons of corn for biofuels. This corn will not be available as human food, nor as fodder to animals. Is this the right strategy for a product that won't satisfy even a small percentage of our energy needs?"

(Brabeck-Letmathe, 2008). The increasing political inclination to pour food (and the water required to produce the food) into fuel tanks has harmed the entire Earth's food supply chain, driving up prices which many of the world's poor cannot meet.

The rush to biofuels has run into opposition as food-to-fuel programs have raised the price of food for rich and poor alike. It is the poor who suffer the most because food costs take a disproportional share of their incomes. A group within the United Nations has called for a five-year moratorium on the production of biofuels, warning that millions in poor countries already are living on the edge, and have been pushed deeper into poverty and even starvation because rising food prices put daily sustenance at risk.

Current agriculture and fossil fuels

Suzuki (2007) observes that it takes from six to 10 units of fossil fuel for every unit of energy collected from plants using current agricultural practices. "In other words, the enormous productivity of modern farming results from converting fossil fuels to food with a net loss in the conversion. This cannot continue, since the resources that support this style of agriculture are non-renewable and in increasingly short supply."

"Almost unlimited supply"

In the preceding chapter we examined the potential for future fuel supply from alternative nonrenewables including coal and natural gas. In this chapter, we have examined biofuels. An article in *The Economist* (April 22, 2006), discussing future fuel supply, makes the statement: "Man-made fuels, such as ethanol derived from plants, or diesel conjured from coal and gas, hold out the promise of secure and almost unlimited supply." As coal and natural gas are nonrenewable resources, they cannot be drawn upon for "unlimited supply." The production of ethanol and other biofuels has limitations of land available to produce them, and their long-term sustainability to produce significant amounts of fuel is questionable, given the continued loss of topsoil and degradation of soil fertility they cause. But the anonymous writer in *The Economist* seems unaware of these basic limitations. The dichotomy between most economists and reality seems to have no end. However, this century is likely to change that. Natural limits and environmental factors will clearly emerge thanks to the demands of continuing population growth. But the term "almost unlimited" continues to be heard from economists who have the view that technology and price will solve all commodity supply problems, a relic of past thinking.

Alternatives in agriculture's future?

Stanton (2007) observes that:

> Whether it be ploughing the fields, edging and ditching, clearing out ponds, or raising livestock, few modern agricultural procedures are less than 40 times as efficient, in terms of time taken to produce food, as they were when work was done by humans, with or without farm animals. The same applies to working the oceans, where huge factory ships, trawlers and bulk carriers have replaced wind-powered fishing boats and tea clippers.

The 40 to 1 ratio cited by Stanton of what can be produced with oil compared with human with/without animal labor is probably a conservative estimate. Stanton adds:

> A giant combine harvester with its tractor and trailers may be 100 times as effective as the peasants with their sickles and threshing floors in recovering the grain from large acreages of cereals …. The significance of this '40 factor' cannot be exaggerated. How long do we have before fossil fuels are so scarce that

> global food production begins its shrinkage to a very small fraction of what we can currently produce?

As late as 1920, the world's population was less than two billion. Beginning in the 1920s, oil began to be deployed in various important uses including fueling motorized farm equipment. It was also a source of pesticides. These uses steadily expanded, greatly increasing total quantities of surplus food produced in a few countries to feed distressed populations elsewhere. This situation continues in some countries still unable to feed themselves from domestic food production, and who are now permanently dependent on international food assistance. At the same time, this has enabled their populations to grow without the basic historic limitation of food supply. Currently, 27 countries depend on international food assistance, including Bangladesh, Egypt, Ethiopia, Haiti, and Senegal. Some population growth may be attributed to improved sanitation, improved water supplies, and advances in medicine. But these also have been aided by cheap energy from oil. Not coincidentally, world population has more than tripled since about 1920, and continues to rise.

Oil to food

Since agriculture is the basis for human existence, one of the most important questions to be answered this century is whether or not the close relationship between oil production and the size of world population can be eliminated? Albert Bartlett points out that modern farming is just a means by which oil is converted to food. Can the present population or the even greater projected future population be adequately and sustainably fed without oil? Can sustainable alternative energy sources be developed to efficiently power mechanized agriculture as oil does? Can other resources fill the role of supplying the petrochemical input now provided by oil? If not, then as oil supplies inevitably decline this century, the reality of population reduction by natural causes (higher mortality rates brought on by starvation, disease, suicide, and so forth) or by rational intent will be upon us. The use of fertilizer to expand crop production has apparently run its course as have most of the great production increases in agriculture from the "green revolution."

Sustainable agriculture/forestry

The U.S. Forest Service is part of the Department of Agriculture because the two are simply variations of the same thing – the production of vegetation and its energy derived from the Sun by photosynthesis. In considering the use of all biomass to at least partially substitute for depleting nonrenewable fossil fuels, forest practices are under the same scrutiny as agriculture. Soil scientist Peter Salonius of the Canadian Forest Service has carefully reviewed issues of sustainability in crop agriculture and forest practices. In two studies (2007,2008), he draws on 44 years of research and concludes that the planting and harvesting of crop monocultures, and large-scale removal of nutrient-rich forest biomass (harvesting slash) destroy a vital diversity of organisms and processes essential to long-term soil fertility. He points out that this is clearly unsustainable on any significant scale.

He concludes that planting and harvesting the biomass products of crop monocultures, and the large-scale removal of nutrient-rich forest biomass (harvesting slash), destroy a vital diversity of organisms and processes essential to long-term soil fertility. He regards all extractive agriculture from ancient times to the present as unsustainable.

The importance of soils and the agricultural base that must support a future population is a relationship Salonius (2008) also considers:

> Obviously, as we move toward a solar-energy dependent natural economy, we will no longer be able to run the massive ecological deficits that temporary fossil fuel availability has allowed.
> Just as obviously, the 'solar-energy dependent economy' will not support the human numbers that have been able to exponentially increase as a result of agricultural mining of soil nutrient stores for the last 10,000 years, and because of the more recent availability of non-renewable fossil energy subsidies.

Population and renewables — beyond petroleum

The importance of petroleum in modern agriculture is described in Chapter 13. In a future of renewable energy sources after the petroleum interval, the impact of the depletion of petroleum resources on current and projected populations will be clear.

Campbell (2005a) says:

> …oil furthermore contributed greatly to ever-more intensive agriculture. It is difficult to avoid the conclusion that the population will also peak after oil does so, although the mechanism by which the subsequent decline will be achieved does not bear thinking about. Some forecasts that ignore the oil factor, project that population may continue to expand throughout this century. That seems most unlikely.

How much can renewables replace oil and natural gas as we depend on them to enhance food production for a rising number of mouths? This is a part of the future that must be considered, as population numbers are a critical part of the equation. Big changes in economies and lifestyles can be expected. Many do not understand how complicated and far-reaching the transition to a renewable natural resource base is likely to be. The transition may be gradual, but ultimately it will be profound. The most basic question is whether the projected world population of more than nine billion by 2050 can be adequately fed. Even now, with a considerably smaller population and abundant and relatively inexpensive petroleum products, there are millions of starving people in the world.

Oil and natural gas are commonly thought of as fuels. Renewable replacements such as hydrogen, biofuels, and the electricity producing sources like solar, wind, tidal, and geothermal are viewed as oil and natural gas substitutes. But, the reality is that 40 percent of oil and natural gas are used in other products. Agriculture is an important end use. In addition to petroleum-fueled mechanized farming equipment, petrochemical products like fertilizers, herbicides, pesticides, fungicides, and crop preservatives may not be available from renewable energy sources.

Waning enthusiasm for biofuels

In 2009, the biofuels industry faced several hard realities, including the fact that costs of production were greater than anticipated, and biofuel production had boosted retail food costs substantially in the U.S. and elsewhere. The limitations of biofuels being able to significantly replace oil were beginning to be realized. Investors became much more reluctant to support biofuel ventures than they had been during the earlier wave of enthusiasm (Davis and Gold, 2009). In the most recent study, Tainter and Patzek (2012) state: " …the

Earth has no capacity to produce giant quantities of biofuels that could rival fossil fuels in volume every year for many decades to come." Arable land requirements together with declining water supplies bear out this observation.

In 2010, biofuels (ethanol and biodiesel in total) provided one-half of one percent of world energy supplies.

Hydropower

The Sun evaporates ocean water by its heat. Wind, created by the uneven heating of the Earth's surface by the Sun, carries the water vapor over the land where, as the atmosphere rises and cools, clouds form and moisture comes down chiefly in the form of rain or snow. The water fills streams, is stored by dams, and ultimately is run through turbines that power generators to produce electric power. Hydropower is, therefore, derived from the Sun as are almost all other energy sources. Hydropower is an important and economic source of energy widely used today. The history of the development of large-scale hydropower goes back less than 150 years. When it was discovered how to generate electricity, no rivers of any size had dams across them. Only small streams were being dammed to run local grain mills through the mechanical force of a turning millwheel. No electricity was generated. Big power dams are relatively new. Even Bonneville Dam, the first on the Columbia River, did not start producing power until 1937.

The initial phase of Grand Coulee Dam on the Columbia was completed in 1950. And the final phases of construction on some of the dams in this Pacific Northwest power and irrigation complex were not completed until just the past few years. Because big dams are relatively new, their eventual impact on a region has yet to be determined. Dams that are commonly thought of as environmentally clean sources of power may actually have many negative consequences. Dams flood fertile lowlands and impede the migration of anadromous fish-like salmon. (As a result of more than 20 dams on the Columbia River and its tributaries, its legendary salmon runs were decimated and today exist at no more than three percent of historic levels.) In northerly and mountainous areas, river valleys are important winter rangelands for wildlife, particularly big-game animals. When these valleys fill with water, they are no longer winter range for animals. Also, all reservoirs ultimately will fill with sediment. Whether or not hydropower can be regarded as a renewable resource is debatable. Unless an answer can be found to the problem of reservoir destruction by sedimentation, it is not. Some smaller reservoirs have already met this fate. During the early life of big dams we currently enjoy, they do provide many benefits.

Who has the hydropower?

This resource is widespread. The United States has a modest amount, but nearly all large sites and many smaller sites are already dammed. The U.S. has already exploited most of its dam-site resources. Canada, however, still has a large number of excellent undeveloped sites. Some of them, however, would require the destruction of important wildlife habitat if developed for power. South America has a considerable amount of unde-veloped hydropower, but much of it lies along the eastern flank of the Andes Mountains in remote areas. Russia has done a great deal with large low-head dams, and still has enough undeveloped hydropower to supply the needs of an estimated 100 million more people. Asia has the largest resources of hydropower and only about 5 percent of it is developed. Africa is second with about 10 percent of its potential dam sites used. Japan and Australia have very little hydropower resources.

Europe has developed about 50 percent of hydropower potential. In Switzerland, which has the higher gradient headwaters of some of Western Europe's streams, electric power is one of their more important exports, but the amount is small. China has a fair amount of undeveloped hydro resources, but not as much as one might expect from the size of the country. Also, large developments would effectively put some very important fertile agricultural lowlands out of production. However, with 1.3 billion people needing energy, China is planning to build some major hydroelectric projects. It just completed the Three Gorges Dam, the largest in the world. With a generating capacity of 22.5 GW (1 GW = 1,000 MW), the electrical output of the Three Gorges Dam equals that of about 20 full-sized nuclear power or coal-fired generating stations.

Hydropower renewable?

Hydropower is commonly classed as a renewable energy source, but the inevitable silting up of the reservoirs, although it may take hundreds of years, creates a question about hydropower being truly renewable. For the present generation of people that had sites on which to build dams, the resource has been renewable. The fact that reservoir capacity declines slightly each year due to silting can be ignored for the time being. But for the generations to come, these existing sites that are gradually filling with sediment may prove not to be a renewable resource, but a large muddy problem. Indeed, there are instances in which "the future is now," cases involving mountainous, tropical countries with rapid, uncontrolled deforestation of steep-sided mountain slopes upstream of hydroelectric dams. In these instances, reservoirs providing storage capacity that was intended to last for centuries filled up with sediments in a matter of decades.

Hydropower without dams and reservoirs — truly renewable

To produce electricity by water power without having to build dams that interfere with fish migration and navigation or reservoirs that flood fertile lowlands would be a great advantage. Such projects are being developed to place turbines in riverbeds or on the ocean floor where currents exist. As much as 35 percent of the energy in a current has been experimentally captured by these devices.

However, because they are underwater, maintenance is a bigger problem than turbines in concrete dams, and the generators must be tightly sealed against water leakage, especially corrosive seawater. These projects are drawing substantial investor interest and more are planned. They would provide truly renewable electric power generation unlike dam-generated hydropower whose lifespan is limited by the life of the reservoir.

Solar energy

Although solar energy enthusiasts are prone to include in the term "solar energy," those secondary forms of solar energy ranging from coal and wind to hydroelectric power, in conventional usage, solar energy refers to the immediate direct use of the Sun's rays.

Nearly every cause seems to have its organized proponents. Solar energy is no exception, with a very devoted and enthusiastic following. The American Solar Energy Society based in Boulder, Colorado, says that solar energy is "The Renewable Energy Solution." Surely, solar energy is likely to be at least part of the ultimate energy mix. The Society also claims that solar energy is "free." This is a fine selling point to promote the purchase and use of solar energy capturing devices. But it is incorrect, because Earth materials must be mined and processed (and both activities require energy) to produce solar energy equipment. The equipment does not last forever and eventually must be replaced by more mined and processed Earth resources. Solar energy is far from "free." Oil and gas are free energy and are in effect, stored ancient solar energy. But it takes drilling equipment and many other devices to capture the energy and make it useful.

A grand solar plan

To some extent the enthusiasm for solar energy has gotten ahead of its development. The call for more emphasis on solar energy is widespread and promoted in many publications. DeWinter and Swenson (2006) state: "The sun is the only energy source that can meet the oil-depletion challenge. But solar energy ramp up must be large-scale and immediate." Scaling it up is an ambitious goal. In 2006, solar energy provided less than 0.01 percent of U.S. electricity. Even a large percentage increase from that small base is still a very small amount.

"A Grand Solar Plan" was the cover article in the January, 2008, issue of *Scientific American*. The authors (Zweibel, Mason, and Fthenakis) state that by 2050, solar power could end U.S. dependence on foreign oil and slash greenhouse emissions, and " … provide 69 percent of U.S. electricity and 35 percent of its total energy (which includes transportation) with solar power by 2050."

To accomplish this, solar panels covering 24,000 square miles of southwestern U.S. deserts would have to be built. Counting roads and other facilities needed to service the area, a total of 30,000 square miles would be used. This enormous land use for solar and wind energy proposals is sometimes called "energy sprawl." The existing power grid is not suitable for this project, so 100,000 miles of new DC power lines would have to be built, together with local facilities in the areas of use to convert the DC current back to AC. To compensate for the fact that the sunlight would not be available at nighttime, electricity from solar sources would be used to push air compressed to 1000 atmospheres into various Earth cavities and abandoned gas wells, to be taken out on demand and combined with small amounts of natural gas to power the turbines for generators. A government subsidy of $420 billion would be required to finance the project, but it would be recovered from various savings in the future, such as reducing the oil import bill to zero, according to the authors. It is truly a grand plan. But implementing it in total by 2050 is a very large challenge, and unlikely to be met.

Solar energy enthusiasm

Solar energy is so obvious and so universal that it has wide appeal to many people as the ultimate solution to our energy problems. "GO SOLAR" bumper stickers abound, as do others with similar enthusiastic message such as "THE SOLAR SOLUTION TO NUCLEAR POLLUTION." One observer has suggested that solar energy is as much a religion as a science. You have to be a believer and have faith. Solar energy is a very large and renewable resource, and if increasingly efficient ways can be found to harness it, solar energy will have a larger role in the future energy mix. However, it is difficult with known technology, given current technological limitations, to visualize it as a significant replacement for petroleum.

Solar energy is pollution-free only if you ignore the environmental impact of the mining and manufacturing processes required to obtain the raw materials (including such critical minerals and elements as cobalt, gallium, germanium, indium, manganese, tellurium, titanium, and zinc) that go to make the solar energy collecting equipment. As well as for its ultimate disposal. True, solar energy produces no radioactive end products, no acid rain, and no ash to be disposed. It looks so good to environmentalists, in particular, that the realities tend to be ignored or not investigated very closely.

Solar enthusiasm exceeds realities

The concept of a solar energy economy has a vocal following. Publications that claim a great future for this energy source are very popular, even briefly bestsellers. *Energy Future* (Stobaugh and Yergin, 1979) was one such book, which appeared in the decade of the two U.S. oil crises. The authors enlarged the scope of "solar energy" to include biomass, wind, hydropower, and ocean thermal electric. They confidently stated: "We believe it is possible that solar will end up little more than a mosquito bite — that is, not provide any significant addition to America's energy mix. Yet we also believe that it is entirely possible for solar to meet as much as a fifth of the country's energy needs by the year 2000 — in absolute terms, the equivalent of the current amount of imported oil." The year 2000 is history. The authors were right. Solar energy even now is no more than a mosquito bite, and the U.S. imports three times as much oil as when that hopeful statement was written.

Yet, in a recent poll of 1,000 Americans asked to identify what energy source would be used most to generate electricity in 15 years, solar energy was the easy winner. The U.S. Department of Energy, ordinarily an optimistic government agency, estimates that solar power might at best account for two or three percent of the energy supply 25 years from now. A Silicon Valley promoter of solar products, Vinod Khosla, says that improvements are not happening fast enough to make solar energy "much more than a boutique investment" (Revkin and Wald, 2007).

Heating homes with solar energy has been researched over the years. It may seem to be relatively simple to locate a house to take advantage of the Sun using the "greenhouse effect" through the windows. This "effect" describes how light enters the house as short waves but upon hitting a solid substance changes to long heat waves that cannot escape back through the glass. It is easy to do. But making a house entirely dependent on solar energy during long periods of cloudy days and during cold weather that also may have cloudy days has been more difficult. In more northern and southern latitudes winter days are short and nights are long. Solar energy has some serious limitations under these conditions.

The storage problem

A major problem is how to store solar energy. Storage on a large scale is a general problem for renewable energies like solar and wind. Some rather elaborate storage systems have been devised. In one, extensive solar heat collectors are placed on the roof and the heated fluid is piped to a large area in the basement where rocks are heated or the hot water is stored. But these systems have proved to be of limited value. Even in sunny Arizona, cloudy days can persist and one home well fitted with solar energy storing facilities was out of heat after three days of cloudy, cool weather. At best, these technologies seem to have limited application.

Various other systems for storing solar heat have been tried including using the principle of capturing the latent heat of a phase change (for example, changing a solid to a liquid). McDaniels (1994) discussed this, stating: "Numerous difficulties with this approach remain to be overcome. The materials are usually expensive and corrosive. Some materials have short lifetimes due to decomposition when thermally cycled."

It may be desirable to make as many houses as possible using solar energy as a source of heat and power. But to put this in perspective relative to the total energy used in the United States, the installation of solar energy systems in one million homes to provide their entire heating and electric needs would displace less than 0.3 percent of total U.S. energy consumption. Recently, however, photovoltaic cells have been integrated into building materials, and these appear to offer prospects for a more widespread use of solar energy.

When solar devices are used to produce electricity, the storage problem remains. During half the 24-hour day or more, the solar devices would not generate electricity, and at times during the day, variable weather conditions reduce the available amount of solar energy. At high latitudes, the angle of Sun is very low for several months and not much solar energy is received during short days. Large quantities of electricity would need to be stored, or alternative backup generating systems used.

Maintenance

There is also the problem of maintaining the solar energy gathering equipment.

In remote areas, and in satellites where cost is not a consideration, solar energy can be quite useful. And it can be economic for small, local uses such as powering relay stations for message transmission and as water heaters for domestic use. Israel has many solar water heating systems in use. Railroads and utilities use solar devices to aid in their communications systems. Many of us appreciate hand-held solar calculators and decorative yard lights.

Solar energy devices

To try to make solar energy for electricity commercially competitive with other energy sources in developed areas like the United States, a number of experimental projects have been undertaken. Solar 1, Southern California Edison's experiment, was built near Daggett, California, in the Mojave Desert. Several hundred mirrors focused the Sun's rays on a large liquid-filled tank, raising the temperature above boiling and producing electric power with a steam turbine and generator. There was also a superheated fluid storage arrangement that generated some power for a few hours after the Sun went down. But, the cost of the electric power produced was high and the project was abandoned. When I visited the site again in 1999, mirrors were broken and weeds had taken over.

The oil company, ARCO, at one time was a major producer of photovoltaic (solar) cells but apparently decided payoff was too far in the future and it sold its operations to Siemens. British Petroleum has a major solar energy division. Photovoltaic cells produce electricity directly from sunlight. Experimental banks of cells have been operating in the Mojave Desert of California for some time. A variety of efficiencies have been achieved with experimental solar cells. Most range from 10 to 20 percent, but in 1988, scientists at Sandia National Laboratories built a cell which is 31 percent efficient. In 1989, the Boeing Company achieved 37 percent. These cells require costly technology and materials to produce. However, thin layers of amorphous silicon can be deposited on metal, glass, or thin film to produce a photovoltaic cell at relatively low cost.

Other experiments to harness solar for electric power production, in part already operational, use tubes of a fluid centered in a sunlight reflecting trough, and the heated fluid is piped to a central generating station. An operation of this nature is located in the Mojave Desert.

The future

Solar energy will no doubt increase its share of the energy mix in the future. However, this is likely to develop slowly. There is a trade-off between solar cell cost and efficiency. More efficient cells cost considerably more than less efficient cells. Thus it may be just as cost-effective to use low-cost, low-efficiency cells rather than high-cost, high-efficiency cells. At this time, solar cell systems can produce electricity at a cost of about 20 to 30 cents a kilowatt hour, more than twice as expensive as conventionally generated electric power. However, predictions are that the new generation of solar cells, called "thin-film" cells, will bring down the cost to less than 15 cents a kilowatt hour. This would be within striking range of commercial competition.

Thin-film solar panels

The thin-film modules use some relatively rare materials, including indium and gallium. A major increase in demand for thin-film panels would no doubt raise their cost, which is already so high that some observers say it is impossible to produce a $1 per watt panel profitably. Also, the detailed wiring required, and other items of plant installation have not come down in comparable price, and would make cost (in the case of thin-film cells) nearly double the $1 per watt figure. The thin-film module, not yet fully tested, may have a life of only 6 to 10 years. All these factors make the thin-film modules look less attractive than at first glance. Thin-film modules do not negate the problems inherent with solar energy. Problems remain concerning the need for a dependable and continuously ready back-up load base. Periods of lower solar intensity, or none at all (night), and seasonal lower sunlight angles at higher latitudes and just cloudy days will still exist.

Who has the big resources?

All of the Earth is touched by the Sun's rays to a greater or lesser intensity at one time or another. But who has the quality solar energy — where the Sun's rays are relatively direct most of the time instead of glancing in at an angle, and where the climate has a large number of clear days. It appears to be a case of the rich getting richer, as the Arabs clearly have been blessed in this regard. The Gulf nations have abundant solar energy, as do Egypt and the other countries along the north coast of Africa all the way to Morocco. One might also cite the now relatively economically useless Sahara and central Australian deserts as great solar energy resources. Using deserts in this fashion is practical, since they are not used for growing foodstuffs, whereas in other parts of the world, covering the land with solar collecting devices makes the land unsuitable for agriculture.

Fortunately for the future of solar energy, there are a lot of deserts around the world. The Atacama Desert in northern Chile has an area that has never recorded a drop of rain and should be a fine site for reception of sunlight. There are many other areas of the world with a high solar energy input. How much the abundant solar energy or lack thereof might affect the future of a nation can hardly be visualized at this time. A lot will depend on further developments in solar energy technology. However, as solar energy becomes increasingly important, countries which have it in abundant quantity will no doubt benefit. Will an electric power grid from solar collectors on the Arabian Peninsula some-day provide heat and light to Europe like Saudi oil does today? The simple fact remains that the Sun only shines for part of a 24-hour day. Storing enough electricity from solar sources to keep a city adequately supplied at night seems an impossibility. Solar cannot be the total answer to our energy problems.

An overriding problem — low-energy density

The low-energy density of both wind and solar sources has a serious economic draw-back, which may be a limiting factor in the use of both energy sources. Deffeyes (2001) defines the problem:

> The low-energy density in solar and wind power requires large energy collectors. A normal-size nuclear plant or fossil-fuel power plant generates 1,000 megawatts. At typical efficiencies around 10 percent, a solar or wind collector has to occupy five square miles to deliver 1,000 megawatts … your problem is the capital cost of paving the five square miles with solar collectors.

Current energy income versus inherited "bank account"

Living on only what comes in each day, and surviving the cloudy days, will be vastly different from doing what we are today — drawing upon the stored sunlight of millions and millions of years in fossil fuels deposited in a bank account in the Earth by geological processes.

Howard Hayden (2004), retired physicist from the University of Connecticut, in his examination of solar energy, *The Solar Fraud: Why Solar Energy Will not Run the World*, is skeptical that solar energy will be a major contributor to the energy mix. He says, "Scientists and engineers almost universally recognize that solar energy is useful in niche applications. They also recognize that solar energy — using all conceivable technologies — will not be adequate to run an industrialized world." Later in his book, he comments on the low-solar energy density, inefficiencies in collecting it, and the very large amount of land needed to obtain enough solar energy to be useful. He further emphasizes the yet-unsolved problem of storing large amounts of solar-derived electrical energy during times when sunshine is not available at all or reduced by cloud cover. He concludes with consideration of the much greater efficiency in existing energy use:

> The least efficient lawn mower engine of today is several hundred times as efficient as the original steam engine, and fluorescent lights are hundreds of times more efficient than candles and oil lamps. Yet even if all modern efficiency improvements were retained while we tried to slip back to a solar-driven world, the solar energy available would fall far short of what is required to run the world. Solar energy always has been and will always be part of the overall energy picture. It is best described as a bit player that is destined to remain a bit player."

For all its limitations, solar energy must surely be a part of any future truly sustainable world energy mix. It is reasonable and logical that solar energy prospects in all applica-tions and devices to capture it require on-going study. McDaniels (1994), in *The Sun: Our Future Energy Source*, gives a comprehensive examination of all aspects of solar energy. Other recent studies introduce new technologies, but the basics are largely as McDaniels presented.

Given its limitations, how much solar energy can contribute to the future world energy mix is debatable. In the meantime, solar energy offers us one advantage over all other energy sources. Each sunny day we can look up and see that there appears to be an ample supply of energy for a long time to come.

Wind

Wind has been the most successful of the various alternatives to date. Among other things, it provides a supplemental income for farmers living on the Great Plains, who suffer from intermittent drought.

The Dutch did not invent the windmill, and were relative latecomers in their use. For a time, they made use of the miserably cold winds which blow in from the North Sea by constructing windmills, but only a few are still in use. Denmark is located in a similar position on the windy side of the North Sea, and uses wind power for about 20 percent of its energy.

The Persians, many centuries before Christ, were the first to use windmills and employed them in pumping water for their arid land, now known as Iran. The windmill has kept the western United States rancher in business by pumping water for cattle scattered across thousands of acres of dry range land. With the aid of a large number of batteries, windmills have helped the rancher and other remote people by storing electric power, which can be drawn upon in modest amounts.

More recently, windmills are being syndicated, and the concept of "wind farms" has given rise to limited partnerships that build windmills and sell the power to energy companies. These projects are subsidized by the federal government in the form of tax write-offs. Without them, wind power would not be economic, at least until now. Recently developed technology has made wind power more competitive with conventional power sources, and numerous wind power installations now exist across the United States and around the world, especially in more remote locations.

Wind energy will no doubt grow in use. But, like the Sun, which doesn't shine all the time, wind, caused by the heating of the Earth's surface by the Sun, doesn't blow all the time. It is undependable. One of the problems is how to integrate this variable energy source, not available all the time, into a power grid. Some advances have been made in storing electric energy from wind, but the general problem of intermittent winds remains. Britain's Department of Energy and Central Electricity Generating Board launched a wind park program in 1989 projecting that wind could contribute up to 20 percent of Britain's electricity. However, with present technology, it could take 100 square miles of windmills to produce only one percent of the country's electricity.

Rated capacity versus reality performance

The ability of wind to produce electricity is commonly based on the rated capacity of the installations, which is frequently cited by wind enthusiasts. But this is very different from actual performance due to the intermittent nature of wind power. Both California and Texas have installed substantial wind-generated electric power. But in 2006, California wind turbines produced only about 10 percent of their rated capacity. In 2007, the Texas Electric Reliability Council reported that only 9 percent of the rated installed wind capacity could be counted as dependable capacity during peak demand periods. There was such a statewide lull in wind in Texas in early 2008 that the entire grid integrated with wind power was thrown into turmoil.

In Denmark, the international showcase for electricity generated from wind power, there was almost no wind power generation in February 2003, from the thousands of wind turbines off its west coast. During August 2002, Denmark's " … wind turbines were actually a net-energy loser, as the steering mechanisms on the turbines took in more electricity than the turbines themselves produced" (Bryce, 2008).

Although wind-generated electricity is currently the fastest growing (from a small base) alternative energy source, it is clear from field experience that wind is not likely to be a dependable contributor to the future energy spectrum.

Environmental problems and some positive aspects

There are also environmental problems with windmills, in particular in regard to killing birds. The very large wind farm at Altamont, California, east of San Francisco has been studied in this regard. One study concluded that the wind farm killed more than 500 raptor birds over two years, including 78 golden eagles. Efforts to mitigate this problem have been only moderately successful.

Wind farms are not universally admired, especially by citizens who live near them. Ask the people on the western edge of Palm Springs, California. They are noisy, they take considerable maintenance, and they can easily be damaged by the vagaries of the wind, which at 50 or more miles per hour, can change direction 90 degrees in less than five seconds. This is hard on equipment.

In theory, wind has considerably greater potential for producing electric power than hydropower does simply because of the greater number of sites available. Wind farms do not flood fertile lowlands but tend to be located in higher areas, frequently in rough terrain less suitable for agriculture. In regard to land use, wind also has an advantage over solar because the collecting system does not completely cover the ground, and most of the land is available for other purposes. Wind does not blow all the time. But useful solar energy is only available for less than half the 24-hour day, and winds may blow both day and night. Windmills also can be directly connected to electric generators, whereas solar energy requires more complicated conversion equipment. Wind energy will probably have a moderately significant place in the future energy mix.

A perspective on wind energy development in the United States

In a study of wind energy prospects adjusted for population growth in the United States, a British scholar of wind economics, Andrew Ferguson, has made some interesting estimates regarding the widely promoted idea that wind energy could produce 20 percent of the electricity used in the United States by 2030. Assuming an annual growth of electrical demand of just one percent per year (a conservative estimate), a generous estimate of achieving 40 percent of the stated capacity figure (now only 20 percent) of wind turbines, and assuming an average production per wind turbine of 4 Megawatts (3 Megawatts for land-based turbines; 5 Megawatts for offshore turbines), Ferguson estimates that "72,235 turbines would be required, which is an installation rate of nine per day every day for 22 years starting in 2007. This is no mean feat when we must consider the height of many of these turbines would exceed that of the Statue of Liberty. And, of course, we must consider the energy costs of providing access roads and transmission lines other than the long-distance lines already existent" (Ferguson, 2008b).

Ferguson also points out that back-up base load power stations would be needed equal to the average power produced by the wind turbines of 114 billion watts. A large fossil fuel plant has a capacity of 1000 Megawatts, so the back-up plants required would be 114 fairly large power stations, which, under present conditions would have to be powered largely by natural gas or coal. So converting to wind power for electricity generation may not achieve the desired reduction in coal-plant emissions. All things considered, it appears that although wind power is a fast-growing alternative energy source, expectations about its ultimate contribution to our future energy spectrum may be considerably overblown.

Survival on subsidies

Both wind and solar projects are heavily subsidized, and currently receive almost 100 times more in taxpayer subsidies than oil and natural gas per unit of energy produced. Of course, this is rarely mentioned by critics of the oil industry. Other "alternatives" including biofuels (biodiesel), "clean coal," cellulosic ethanol, hybrid cars, electric cars, and nuclear energy research are already extensively subsidized or targeted for increasing public support in the United States. Ultimately, these alternatives must survive on their own economic merit. The survivor(s) almost certainly will be considerably more costly than current energy sources. Future generations face higher costs for energy and food.

True cost of wind power

Rarely are the backup facilities needed for wind power, the cost of maintaining them, and the energy cost to power them included in the full cost of wind power. Given the variability and periodic interruption of wind power, wind turbines must be backed up by a "spinning reserve" to maintain a steady flow of power into the grid. At present, these are single-cycle gas turbines, basically jet engines, attached to generators. The cost of building these plants and providing a continual fuel supply for them are part of the total cost of wind energy. So far, these costs have not been calculated, but they exist nonetheless.

Wind energy potential summary study

Probably the most comprehensive, recent summary study of wind energy prospects is that by Ferguson (2008b, already cited), which the author kindly made available to me in advance. Some of the principal points he makes include the difference between the rated power capacity of a wind turbine and what is produced under actual conditions.

In northern Europe (Sweden, Denmark, Germany, The Netherlands), the output was 22 percent of rated capacity. In the United Kingdom from 2002 to 2004, the average was 27 percent, and in the United States for the years 2000-2004, the average was 24 percent. Ferguson makes the comparison of a 1000-megawatt coal-fired plant yielding a mean production of 800 megawatts with what could be produced by wind turbines, and determines that using proper turbine spacing, an area of 16 square miles would be needed.

Ferguson (2008b) addresses the prospect of storing excess wind-generated electricity and says that it is not now possible to store large amounts of electricity. The option of using hydrogen as a storage medium is explored:

> It is frequently proposed that electrical energy could be stored as hydrogen. There are many problems with that, the first being efficiency of transformation. Hydrogen production by electrolysis is around 70% efficient. About the best efficiency to be expected from fuel cells, including the need to invert their direct current output to AC, is 60%. That makes an overall efficiency of 0.70 x 0.60 = 42%. So to deliver 1.0 kwh of stored electricity, 2.4 kwh would have to be generated from wind turbines and that is without allowing for further losses in compression which is likely to be necessary for realistic storage of a gas which

has an energy density approximately a quarter that of methane (natural gas).

Solar and wind energy in the near future

Electricity is the product of most proposed alternative energy generation devices. At the present time, conventional coal resources produce about 52 percent of electric power in the United States, and a greater percentage in China and India. In the U.S., nuclear and natural gas each contribute about 20 percent of the fuel, with hydropower contributing much of the remainder. Solar and wind are likely to be the major sources of electricity growth for the future along with other alternatives, and might make up as much as 25 percent of the energy supply by 2050 or beyond. However,

> … very few people realize just how far we have to go to reach that point. For instance, if the United Kingdom would fit 20 million roofs each with four square meters of standard silicon-based solar panels, this would generate less full-time equivalent power than a typical power station fired by gas or coal, or no more than less than 1 percent of the U.K. electricity capacity (van der Veer, 2007).

For all the enthusiasm about wind and solar power, their contributions to the world's power needs are likely to be small for decades to come. One also should note that in the U.S., solar and wind power are sometimes promoted as decreasing the amount of oil needed. But, in the U.S., oil accounts for two percent or less of electric power production.

Tidal power

Watching the surge of tide in bays and estuaries, one cannot but be impressed with the amount of energy involved in moving that much water twice a day. Harnessing the tides, however, has been slow in developing. One reason is that tidal power sites are quite limited in number because such sites must meet specific requirements. They must have a fairly high tidal range, and there must be a favorable configuration of the land. There has to be an estuary into which the tide will funnel and where it can be trapped by a dam. If the tide is sufficiently high, it can turn turbines, which power the electric generators as the tide comes into the estuary, and then it can be made to turn the turbines again as it goes out. But converting tidal areas into power sources has some undesirable environmental effects.

High tides in the world are found at high latitudes, rather than near the equator. Most of the good sites that exist tend to be in relatively remote areas. One example is Frobisher Bay in southern Baffin Island, west of Greenland, where I witnessed a 50-foot tide. It was very impressive, but is located a long way from where power would be needed. There are several sites in southern Chile where the rugged Andes Mountains reach the sea. These locations are also remote from places power could be used.

There are three places where tidal power has been developed. One is a site in northwestern Russia, on an inlet of the Barents Sea near the city of Murmansk with the nearly unpronounceable name of Kislaya Guba. Another is on the Rance River in France. The third is on Hog's Island near the mouth of the Annapolis River in Nova Scotia, Canada. This plant is different from the other two in that the tidal range is only from about 14.5 feet (neap tides) to 28.5 feet (spring tides), with the average being about 21 feet. Power is generated only during the out-going tide. It claims to be operative in a range of 4.6 feet to about 22 feet. To do this, it uses a new type of low-head turbine called Straflo, developed by Escher Wyss and installed first in 14 low-head submerged stations in southern Germany and Austria.

This project is still under evaluation. If the economics seem reasonable given the potential cost of power in the future, this sort of plant may open up substantially more sites for tidal power development. The United Kingdom is considering some sites. However, at present, the cost of power at all the plants is fairly high, although the French Rance River operation appears to be competitive with other forms of energy there. Tidal power economics are definitely best where the tidal ranges are large. This fact, combined with the need for a special shape of the coastline, limits the number of potential sites. There are apparently fewer than two dozen optimum sites worldwide, most in fairly remote locations.

The entire Bay of Fundy, with its several arms in eastern Canada lying between New Brunswick and Nova Scotia, has been under study for tidal sites. However, the environ-mental impact of interfering with the free flow of the tides is not entirely known. The Bay has abundant marine life, and is an important fishing area. It also is an important habitat for waterfowl, both indigenous, and migratory. Putting in major tidal power installations will appreciably affect the Bay's ecology. You cannot do just one thing in our complex, interconnected natural systems.

Subsea tidal turbine

Eliminating the negative environmental effects of dams on estuaries, the world's largest subsea tidal turbine (and generator) has been installed in an estuary in northern Ireland. However, a proper configuration of the shoreline, and the necessary tidal range, like tidal power dams, are required, limiting the number of world sites available.

River currents

As in the case of wind — air currents — river currents have the potential for capturing energy by turbine/generator units placed in the path of moving water. However, despite the greater energy density advantage water has over wind, numerous problems and associ-ated costs indicate that river currents are not a significant or economic source of energy.

Waves

The first patent for a wave-power energy device was issued in the eighteenth century, but until the oil crises of the 1970s, not much happened. Now, however, wave-energy research is active. At least one book has been written about wave-power, and there is already a wave-power installation off the coast of Portugal. There are plans for installations off Orkney in Scotland, and Pacific Gas & Electric Company signed an agreement in 2008 to buy electricity from a wave farm to be built off the coast of California.

But the history of wave-power has been one of many trials and tests and lots of disap-pointments. Of many such devices, none so far has ever been installed on a large scale ("The Coming Wave," *The Economist Technology Quarterly*, June 7, 2008). But experimen-tal projects continue to be launched, consistent with the worldwide drive to get more energy from any source anywhere we can.

The strength of waves is impressive, but harnessing their energy is difficult. At times, waves can be 60 feet or more in height. Yet at the same location, the ocean may be essen-tially calm for weeks. All sorts of mechanisms have been tried to capture wave energy. Japan, surrounded by ocean waves and very short of energy, has conducted research on using wave energy for electric power production since the 1970s. Dr. T. Stauffer, a research associate at Harvard University, and a student of energy economics made his judgment on wave energy. He says that harnessing the power of waves is a "Rube Goldberg idea." However, several countries including Japan, Norway, Denmark, the United Kingdom, Belgium, Portugal, and India have constructed a variety of devices to capture wave energy and convert it to electric power. These range from a tapered channel system (Norway), to a barge in which waves force air into chambers and then into turbines (Japan), to a float on the ocean surface attached to a piston on the ocean floor which moves water through a turbine (Denmark). Costs are estimated to be as low as six cents a kilowatt hour.

An experimental wave energy project for electric power production was recently installed off the Oregon coast. The large array of buoy-like generators involved was vigorously protested by local fishermen who say it prevents crab fishing in some of the best waters — another example of the frequent conflicts between power production and the biological world. I note also that as a resident of western Oregon and frequent visitor to the coast, I have seen the ocean becalmed for long periods of time — with no appreciable wave action evident. At other times, 50-foot waves and higher pound the area. Due to extended becalmed times and damage caused by severe storms, the steady production of electric power from this or similar installations seems problematical. Proponents say it would provide power to a number of homes. But like wind and solar energy, the intermittent nature of the energy source may be a severe limitation unless some economical means of energy storage can be developed on a large scale. Waves may make some contribution to our future energy mix, but it will be insignificant in the scale of things, unless, as one wry comment says, "the waves are waves of oil."

Ocean thermal gradients

This is also something called Ocean Thermal Energy Conversion or OTEC. The physics principle is that whenever there is a temperature difference between two masses, there is a potential for power generation. In this case, the ocean surface water in the tropics is warm, but the depths are cool. The warm water can evaporate a low-boiling point fluid such as ammonia, and the vapor of the working fluid drives a turbine attached to a generator as in conventional power plants. Cool water brought up from the ocean depths is used to condense the vapor, just as the cooling towers of power plants do. However, since the temperature differential in the ocean is not great, the efficiency of this operation is low, and huge volumes of water must be circulated to generate any significant amount of energy. A 250-megawatt plant (roughly a fifth or less of a conventional coal-fired plant) would need pipes about 100 feet in diameter, and have to circulate an amount of water every day equivalent to the discharge of the Mississippi River.

The OTEC system has been done experimentally off the Kona Coast of Hawaii, and on a small island off the coast of Brazil. It has not yet been done on a power plant anchored in the open ocean as some have suggested. There are no sites adjacent to the continental United States, because there is an insufficient ocean thermal gradient. OTEC has to occur in tropical to semi-tropical waters.

The physics principle of OTEC is simple, but there are some big difficulties that cause the practicality of the technology to be doubtful. Some of these are the corrosion of pipes from saltwater, and the growth of algae and barnacles on the heat exchangers that would require almost weekly cleaning. The tropical areas where the highest thermal gradients exist also are subject to devastating hurricanes with hundred-mile-an-hour winds, and thirty-foot waves. Anchoring such a large installation in the open ocean against the elements would be a problem. And carrying power to shore would require very large cables laid at great depths which would have to withstand constant flexing from the platform, due to wave motion. Using this technology on a large scale may not be practical.

The very large amount of equipment needed for significant OTEC plants, the maintenance problems, and the very low efficiency all suggest that OTEC, except in certain special local land-ocean situations, will not be a very useful technology. However, the United States and Japan have each spent more than $100 million on OTEC research, and enthusiasm occasionally runs high among government officials. I have in my files a letter from a Congressman in which he writes: "Forget about the oil companies, OTEC will be ready in five years." This was written in 1978. In spite of his early assurance, however, the OTEC energy era has not yet arrived.

Fusion — The Ultimate Renewable Energy Hope

The nuclear power we use now — fission — is based on limited supplies of uranium and thorium and, therefore, is nonrenewable. Fusion is the power that fuels the stars including our Sun. It is for all practical purposes inexhaustible even here on Earth — if it can be made to work commercially. The fuel for fusion is an isotope of hydrogen, deuterium, which exists in water, including seawater, of which there is a rather large amount.

The energy released in fusion is so great that the fusion of even the minuscule amount of deuterium in water would make a gallon of ordinary water the energy equivalent of nearly 400 gallons of gasoline.

Deuterium is abundant and easily and cheaply separated from water. However, at that point, "easily" and "cheaply" stop and things get very difficult and expensive. The fusion of two deuterium nuclei will produce helium-4 (that is, a helium molecule with an atomic weight of 4), and in the process, release huge amounts of energy. However, all nuclei carry a positive charge and repel one another. To overcome this takes a large amount of energy.

Fusion requires joining two hydrogen isotopes: deuterium, which is hydrogen 2 (atomic weight of 2), and tritium, which is hydrogen 3. Deuterium occurs in minute amounts in all water, whereas tritium is an artificial element and must be made. It has a short half-life, so that it cannot simply be stored for later use. Tritium is created by neutron capture in a lithium blanket region surrounding the fusion reaction chamber.

By heating the deuterium and tritium, their speed can be increased and if moving fast enough, they can overcome the barrier of their nuclei electrical repulsion. But the tem-perature required to produce the deuterium-tritium fusion reaction is over 100 million degrees Celsius. There is no known material that can contain such a temperature. The tokamak concept of creating a fusion reaction, pioneered at Princeton University, involves keeping the reaction confined and controlled in a magnetic field. But fusion using this technology so far has only been maintained for a fraction of a second, and the energy put into the system was more than that gained from the reaction. The U.S. government dropped its support for the Princeton project in 2008.

A fusion reaction in uncontrolled form has been generated in the form of the hydro-gen bomb. The challenge is to produce a sustained fusion reaction in a controlled situation where the resulting energy can be converted to useful ends. Bartlett (1994) writes, "The heat energy from the fusion process in the 'fusion reactor' will most likely be transmitted from the reactor to a boiler where it will convert water to steam, which will then drive tur-bines and generate electricity. If fusion can be made to supply the energy needs of society, it will probably be through this mechanism for generation of electricity." Bartlett notes, however, that the fusion process " … produces heat energy, nuclear radiation, and nuclear particles called neutrons. The neutrons will create induced radioactivity in the vessels and equipment surrounding the 'fusion reactor' so fusion is not 'clean.' The vessels and associated structures will become radioactive and this radioactivity will persist for several generations."

A new internationally sponsored fusion research facility is being built in southern France (ITER — International Thermonuclear Experimental Reactor). It has already run into unexpected problems. Nevertheless, substantial progress has been made in fusion research in recent years, although it still remains a commercially viable distant goal. The ITER experienced more problems in 2008 as costs continued to rise. Participants in the project have been asked to provide additional funding of $1.9 billion to $2.5 billion, and construction has yet to begin. Some engineers estimate that final costs will be at least double earlier figures, as more money will be needed to pay for design changes. Completion of the ITER is now expected sometime in the 2017 to 2019 time period. Even if the reactor is finished and fusion energy can be captured, there is no assurance that it can be commercialized. Fusion remains a hope, and is unlikely to assist in solving the world's energy problems any time soon, if ever. It was my pleasure one time to discuss the future of fusion with Glenn Seaborg, one of the pioneers in nuclear matters, a Nobel Prize winner in chemistry and a chairman of the U.S. Atomic Energy Commission (AEC). In his view, there was "only a 50-50 chance that commercial fusion power would ever become a reality," and if it did, it would take another 50 years or more to develop it to the point that it would be of significance worldwide. Take your choice, and if possible, stay around long enough to see who is right. Bartlett (1994) also has reservations regarding fusion as a future energy source.

Cold fusion?

For the sake of completeness, brief note should be made of the success claimed for so-called "cold fusion." This was reported in March, 1989, by two chemists working at the University of Utah. Using an apparatus consisting of palladium and platinum metals immersed in water rich in deuterium, these scientists claimed that cold fusion (at much lower temperatures than the "hot fusion" described above) had been accomplished and the amount of energy emitted from their experiment was four times the amount of electrical energy that had been put into the experiment.

This announcement created quite a stir among scientists and energy experts. A large number of experiments subsequently were conducted to determine the validity of this claim, but "cold fusion" was never achieved (Mallove, 1991). The idea has been under sporadic study and review by a number of physicists sponsored by the U.S. Department of Energy, but continues to draw skepticism. After a careful study, most physicists concluded that cold fusion does not work. In the meantime, the two chemists moved to France and continued their research in a laboratory funded by Toyota. However, the lab closed in 1998.

The Special Case of Electricity

This volume deals with Earth resources, with a special emphasis on energy resources. But where does electricity fit in? It is not an Earth resource in a strict sense. It does not exist until it is generated by some other form of energy. Yet electricity is perhaps the most essential single energy form we have. About 48 percent of our primary energy production is used to generate electricity. The hydrogen economy soon to be discussed cannot arrive on a permanent basis without electricity, because the ultimate source of hydrogen is the electrolysis of water. Electricity can be produced from a variety of energy sources, both renewable and nonrenewable. Therefore, these electricity producing fuels are vital.

Future electricity demand

Electricity has probably defined modern civilization beyond any other form of energy. Without electricity in the industrialized world, almost everything stops. Oil refineries cannot operate, water and sewage cannot be pumped. Electricity cooks and refrigerates food, washes clothes, vacuums the floor, heats our water, and cools the air. It heats my house and many others, and it changes the dark of night into light. The list could go on for many pages. The world wants to become electrified, and demand is increasing rapidly everywhere.

U.S. electricity — growth in demand vs. planned supply

The North American Electric Reliability Corporation estimates that over the next decade, 135 gigawatts (billion watts) of new capacity will be needed to meet the growth in demand. The U.S. now has plans for plants producing 57 additional gigawatts. Ninety percent of electric power is now fueled by nonrenewable coal, natural gas, or nuclear power. Renewable sources will not cover the growth in demand. While wind is gaining ground and now supplies 1 percent of power, hydro's share (7 percent) is shrinking as dams are dismantled and reservoirs gradually fill in with sediments. Solar, at 0.01 percent, is an inconsequential contributor.

Coal continues as the major electricity generating fuel

Despite a long list of objections and limitations to coal-fired generating plants, including the prospect of the U.S. coal supply declining in both quantity and quality and rising costs, it is predicted that coal will continue to be a significant U.S. source of electric power in 2030, more than twice the contribution of municipal wastes, solar, wind, oil, hydro, and nuclear combined. Unless population growth and increased electric power demand can be stopped, the choice is either more coal-fired plants, or lights and all other electric devices will be intermittently out of service. This is also true of the rest of the industrialized world, as well as countries like India and China and most of Asia that are striving for the same objectives. The result will be more coal-fired plant emissions.

Worldwide, rising populations with increasing numbers of electricity using devices are already overloading electric grids. Blackouts will become more numerous. These problems would be greatly minimized with smaller populations.

A Hydrogen Economy

Hydrogen has been suggested as a great new fuel for the future in a visualized "hydrogen economy." The first Bush Administration abandoned the 80-mile per gallon car that previous administrations had pursued after spending $1 billion in research. The administration then announced that the hydrogen economy would be the energy solution, but pointed out that its arrival might be decades away. This was a good political move for all concerned. The practicality of the hydrogen economy was beyond the term of the Bush Administration, but it made the environmentalists happy to think of this eventual non-polluting, non-oil-coal economy we would have. Author Jeremy Rifkin (2002) is enthusiastic about the coming hydrogen economy. Joe Romm, a physicist who was involved for a number of years in research for the U.S. Department of Transportation on hydrogen and other fuels, is more cautious. He spells out some of the problems in his book, *The Hype About Hydrogen* (2004). Trainer (2003) writes, "It is widely assumed that the ultimate solution to the energy problem will be via 'the hydrogen economy.' There are persuasive reasons for concluding that this is mistaken."

Hydrogen is by far the most abundant element in the universe, but on Earth it accounts for only 84/10,000^{ths} of Earth's total composition. However, it is abundant on Earth in a very accessible source — water. Natural gas, methane (CH_4) is also a hydrogen compound. However, hydrogen is not a primary source of energy because it must be obtained by using some other energy source. This is commonly done by the electrolysis of water, or by processing natural gas. It can also be produced from coal. When burned, hydrogen produces water, nitrogen oxides, and hydrogen peroxide. The latter two are pollutants, but the amounts are about one-third lower than those produced from gasolines, so hydrogen is environmentally attractive as a fuel. However, as hydrogen must be produced by means of other energy sources, the environmental impact of using these must be considered, and all have environmental problems. The most common concept for the large-scale production of hydrogen would be to produce it from water using nuclear-generated electricity, or solar-electric power. If the hydrogen economy finally does arrive, it will be at some far date in the future. Here are some facts related to such an economy.

Storing hydrogen

To be used as a fuel for transportation, hydrogen can be stored and carried in four ways: It can be compressed and contained in a high-pressure tank. It can be cooled down to a liquid and kept refrigerated. It can be bound up with a metal in the form of metal hydrides. And it can be in the form of a hydrogen-rich gas and used in a fuel cell.

If hydrogen is stored in compressed form, it must be compressed as high as 3,000 pounds per square inch, otherwise the container becomes excessively large. It can be kept in liquid form refrigerated at or below -253° C (approximately -423° F). Above that temperature, it will boil away. Liquid hydrogen can generate three times as much energy as gasoline by weight, but it also takes up three times as much space. At the normal one atmosphere of pressure on gasoline and hydrogen, a car can go 3,000 times farther on gasoline, as the energy contained in the same volume of hydrogen at normal atmospheric pressure is very small compared to that in gasoline. That is why hydrogen must be compressed, concentrated by refrigeration, or bound up in metal hydrides.

Metal hydrides appear to be one way of storing and transporting hydrogen. Hydrogen attaches itself to both iron and nickel to form a stable compound, from which hydrogen can be released upon heating. The German automotive firm, Daimler-Benz, has studied this system extensively. However, it has many limitations. If hydrogen is stored in the form of metal hydrides, " … the tanks must be heavy and expensive, for example some 30 times the weight of a car's petrol [gasoline] tank. Unless the hydrogen is pure, the hydrides will have a reduced life expectancy. The weight of the hydrogen stored is only 1to 2 percent of the weight of the metal in the storage medium" (Trainer, 2003).

Hydrogen-powered vehicles

Recognizing the eventual exhaustion of oil resources, both automobile and airplane manufacturers have studied hydrogen as a future fuel. In the early to mid-1970s, most car companies in the United States and abroad experimented with hydrogen-powered cars, but all ran up against the same obstacles: it took more energy to get the hydrogen than the hydrogen itself provided. The processes for getting that energy were polluting. And no one could figure out how to put enough gaseous or liquid hydrogen into a car to give it a decent cruising range.

The need to increase the amount of hydrogen stored in a given facility is important because at a pressure of one atmosphere and room temperature, hydrogen exists as a gas. A 20-gallon volume of hydrogen gas would propel a standard car only about 500 feet. So far a suitable method to solve this problem has not been found. Storing hydrogen as a liquid requires it to be cooled to -253° C. Storing the amount of hydrogen needed for a 300-mile driving range with metal hydrides requires a 1,000-pound storage system, which is too heavy for today's 3,000-pound car. However, some hydrogen-powered vehicles have been developed, and tests funded by West Germany's government proved that "the operation of vehicles with hydrogen is possible and controllable," according to the head of Daimler-Benz hydrogen research. Russia built an experimental plane that flies on liquefied hydrogen. Iceland has hydrogen powered buses. Whether or not hydrogen is "tomorrow's limitless power source" remains to be seen.

Hydrogen, fuel cells, and electric power

This is one vision for using hydrogen. Fuel cells can use hydrogen in a hydrogen-rich gas such as methane. The cells convert hydrogen directly into electric power, which in turn can power vehicles. But obtaining the volume of hydrogen necessary, probably by electrolysis, takes more energy than it produces. If one converts wind energy generated electricity to hydrogen with a 30 percent loss, via the electrolysis process, and converts the hydrogen back to electricity, this produces a 67 percent loss (or 40-50 percent for a fuel cell). At the end, there is little energy left with the net result that getting electric power to wheels using hydrogen is an energy-losing process (Trainer, 2003).

The arrival of the fully hydrogen economy is many years away and may never materialize. Deffeyes (2005) summarizes the economics of hydrogen: "The bottom line: The hydrogen economy has a built-in surcharge. You only get back about 40 percent of what you put in. Las Vegas gives you better percentage returns."

Walter Schroeder, President and CEO of Proton Energy Systems, a research and manufacturing facility for fuel cells based in Connecticut, wrote in 2002: "It will take a good deal more capital and discovery before fuel cells are reliable and cheap enough to replace the internal combustion engine …. Creating a hydrogen economy will take considerably longer than we had hoped." Hydrogen will not be a significant competitor to oil very soon, despite $1.2 billion of government money pledged by President Bush in his 2003 State of the Union address for a project to produce hydrogen and economic fuel cells to power vehicles. Hydrogen was described by the president as the "freedom fuel," and the "freedom car" would be powered by fuel cells, the terms implying escape from the clutches of oil in general and OPEC in particular. This is another aspect of "energy independence" promised by all presidents since President Nixon first introduced the term.

Electric car

Although the electric car was on the scene before the gasoline-powered car, the electric car has had a varied and so far rather poor reception from the public. General Motors, with their unsuccessful EV-1 (electric vehicle 1) and others have tried and are trying to produce an electric car again that would be a significant element in the automotive mix. Using a new generation of batteries — the lithium-ion battery — General Motors ("Chevrolet Volt"), Nissan, Toyota, and Renault are putting electric cars in their production mix. The "plug-in" electric car with the new lithium-ion battery, has twice the power of the conventional nickel-metal hydride battery, and can be repeatedly charged. This may make an electric car practical, especially for short trips, which is the major use of cars today. Lithium-ion batteries provide a range of up to 40 miles, and recharging is done with a power cord from an ordinary 110-volt electric outlet. Recharging can be done best at night, when power demand is lowest. This may cause some changes in lifestyles, but change is inevitable.

These electric cars are marketed to the public as "pollution free." But, electric cars are only as "pollution free" as the source that produces their electricity, and most of the world's electricity is now produced from coal. This is likely to continue for some time to come. Accordingly, the new era of electric cars will, in reality, be largely fueled by fossil fuels.

All these plans for a new generation of electric cars assume that somehow the needed additional electric power (which may be substantial if use of electric cars does become widespread) will be available. Solar and wind are unlikely to be a significant source of electric power for at least several decades. Electric cars will have to depend on conventional sources of electricity.

Bicycle efficiency

The bicycle remains by far the most efficient means of human transport. It has a calculated energy efficiency and range on flat terrain of approximately 900 miles from human power expended equal to the energy in a gallon of gasoline. The inventor of the bicycle had a great idea. Its use predates the automobile and it will probably survive long after the automobile has been consigned to the junkyard.

Arrival of the hybrid

An apparently happy combination of gasoline and electric powered vehicles, resolving the limitations of electric cars but retaining some of their advantages is the "hybrid." This may be the bridge to wherever the electric car finds its proper place. Just as it did with smaller fuel-efficient cars after the gasoline crises of the 70s, Japan again jumped ahead of U.S. automakers in introducing the hybrid car. This vehicle combines a gasoline engine with an electric drive, and has a large battery for electricity storage. In various driving conditions, there is an interplay between the gasoline engine and the electric drive with the result that mileage for a reasonably (not large) sized car can be as much as 50 miles or more per gallon of gasoline. The battery is kept charged in this system, and does not need to be independently recharged. However, the battery is expensive. Replacement cost is approximately $3,000, but it will last for at least 100,000 miles, perhaps longer. Performance is excellent with a driving range comparable to conventional vehicles.

Late to the scene, American manufacturers also brought out hybrids, which appear to be a success. If gasoline rationing should come again, which it very well may in the future, hybrids with their exceptional mileage will be in great demand. However, mileage claimed for hybrids was exaggerated. The mileage figures on the window of a new hybrid were based on laboratory runs. *Consumer Reports* (2006) tested hybrids in real world driving conditions and found that mileage was considerably lower. One hybrid rating changed from 52 miles per gallon to 37.

Currently and probably for some time to come, vehicle manufacturers will be scrambling to identify where their business is going. Sorting out the short- and long-term future of various fuels from biofuels to the presumed but doubtful hydrogen economy is a significant economic challenge to these companies. We have enjoyed a long period of stability in transport based on fossil fuels. The future promises uncertainty and instability. Some companies will survive, others will not.

In broad view

An important conclusion from this survey of alternative energy sources is that there is no single energy substitute for the quantities of oil, gas, and coal we use in the world today. Also, replacing petroleum by other energy sources to any significant degree will involve investing very large amounts of money in new processes, equipment, and infrastructure. The ease with which oil and its transport fuel derivatives, gasoline, diesel, and jet fuel (kerosene) can be handled and used is unmatched by any other fuel source. And there is nothing available to replace the amount of oil the world uses today in myriad ways.

The huge job nature has done for us in the past

The ancient biomass value in fossil fuel is illustrated by the calculation made by biologist Jeffrey Dukes, which shows it takes about 90 tons of ancient plants to produce a gallon of gasoline. So, whatever the cost of a gallon of gasoline may be, the money spent buys 90 tons of ancient plants collected and delivered! Matching that today with efforts to collect and convert such a mass to liquid fuel would be difficult indeed.

Energy and the U.S. economic engine

In reviewing U.S. economic growth, it is apparent that the cheap energy that the country had the good fortune to inherit has been the driving force in the growth of industry and all that goes with it. "…the hard fact [is] that low-cost energy is the great engine that empowers American industry and makes possible the air-conditioned, multiple-car American way of life. In the world of manufacturing and transportation, cheap energy is not some environmentally incorrect frill, it is an essential ingredient that gives U.S. industry an edge in global competition" (Carey et al., 1994). Now highly dependent on foreign oil, can the U.S. maintain an economic edge? Hydrofracking for shale oil and gas may help for a time.

Future energy mix

The one fact apparent from a study of energy futures is that the energy mix will be considerably more diversified than it is now with petroleum (oil and gas) carrying more than half the load. The energy mix has changed markedly in the past two-hundred years for the world as a whole. Some areas, however, still depend on the energy sources (largely biomass) they have used for thousands of years. In the kinds of energy sources now used around the world, parts of the world are centuries apart from others. This disparity is likely to continue.

Nations and the changes in energy mix

The survival of countries in the future with regard to energy (and this will have a lot to do with how well they survive generally) must involve an increasing amount of technology combined with such energy resources as they can obtain. The large load of energy demand in the industrial world that coal and petroleum now supply will be gradually replaced by several energy sources rather than a single source. This could result in healthier economies, since no single resource would be as critical as petroleum is now. Nations may not be so vulnerable to the disruption and cut-off of energy supplies as they have been in the past.

In the long view of the energy situation, renewable energy resources must be the ultimate energy supply. In the interim, other sources will continue to be important as alternatives to the major role petroleum plays. Coal, oil sands, heavy oil, geothermal resources, atomic minerals (chiefly uranium), and hydropower will be utilized. Increasingly, solar, wind, tides, and perhaps waves will be in the energy mix. How these changes in energy sources can be achieved by various nations will have much to do with their futures. The energy mix for each nation and for the world will continue to change, offering many challenges both to technology and world economics. The international competition for the fossil energy resources that now exist will continue and probably intensify. What military actions this competition may cause are unpredictable, but as Earth-derived energy resources are finite, one hopes that expenditures for military actions could be used instead to develop long-term renewable energy resources. Aside from avoiding the horrors of war, such action would have lasting value for creating a stable energy future.

Some reservations

As the reader has noticed in this discussion of alternative energy sources, there has been only moderate enthusiasm for some of them. Replacing current energy demand of many millions of barrels of oil each day and trillions of cubic feet of gas annually around the world is a challenge these sources would have to meet. The public does not generally realize the magnitude of this problem.

Energy source transition

In what Starr et al. (1992) call a realistic outlook on energy sources, they observe that it usually takes about 50 years to significantly shift fuel patterns. They further state:

"Both the energy input to manufacture the renewables and their initial capital cost are the issues. A basic consideration is net-energy output, or the output minus the energy input from other resources required for their manufacture. This is particularly relevant to biomass, where the energy input for their growth (for example, fertilizer and irrigation) and processing are substantial …. As yet, renewables such as solar, wind, and biomass have been able to penetrate only limited niche markets, with much uncertainty about their net-energy contribution."

Net energy, and the energy profit ratio

Gever et al. (1996) have made a special attempt to determine what they term the "energy profit ratio," which is the ratio of the amount of energy which goes into the production of a particular energy source as compared with how much comes out. As Starr, et al., pointed out, the net-energy recovery from biomass is relatively low. In the case of ethanol, it is close to, if not negative. Optimism for using biomass is not generally shared by Starr, et al. (1992), Pimentel (1987), and Pimentel and Patzek (2005, 2006), and others. Since alternative-energy sources increasingly will have to be used, it is time to determine how useful they can be in terms of the size of the population that they could support, and in what standard of living and lifestyle. Also, it is critical to invest money in research on the most promising energy/profit ratio energy source alternatives.

Renewable energy sources and the future

We now live in an industrial civilization powered almost entirely by nonrenewable energy sources, chiefly oil and natural gas, and some coal. Our "fossil fuel credit card" is beginning to reach its limits. This fact, combined with population growth, means we are putting more and more people further and further out on a limb that is slowly being sawed off. The safety net that lies below this limb is the renewable energies. The question is will this net be large enough and strong enough to support the existing population when fossil fuels are for all practical purposes gone?

Building an enduring energy safety net for the future will take time and huge investments in money both for labor and materials. Increasingly, studies are being done on the potential of renewables to carry on beyond the time of fossil fuels. Andrew Ferguson of The Optimum Population Trust has studied the future of alternatives and has concluded that alternatives have a more limited potential than is commonly realized.

In a comprehensive study titled *Can Renewable Energy Sources Sustain Affluent Society?*, Trainer (1997) states:

> It is concluded that renewable energy sources will not be able to sustain present rich world levels of energy use and that a sustainable world order must be based on acceptance of much lower per capita levels of energy use, much lower living standards, and a zero growth economy.

Trainer sums up his conclusions:

> There is no possibility of keeping this party going on renewables plus nuclear energy. It can only be kept going, for a while, by continuing to burn grossly unsafe amounts of fossil fuels. The basic cause of the global predicament is gross over-consumption, and it can only be solved by cutting levels of production, consumption, trade, investment, and GDP [Gross Domestic Product] to perhaps one-eighth of present levels, and staying down there in a zero growth economy.

Trainer goes on to say that politicians, the media, economists, and "ordinary people" are wedded to a " … fanatical obsession with constantly getting richer and consuming more and more, that is, with economic growth."

More sources?

In these two chapters, we have examined all known energy sources. One might ask, however, if this list is complete, or is there some significant energy source we do not yet see or anticipate? It is a fair question. Before the development of the atomic bomb, the poten-tial energy from the atom was glimpsed by only a few. Before Colonel Drake drilled his well, and the Industrial Revolution created countless uses of oil in huge volumes, there was no vision of the potential for this energy source. Before it was discovered how to generate electricity commercially, lightning was only an interesting phenomenon, and no one imagined that electricity would become the most essential energy resource in the modern world.

We have come a very long way in a relatively short time to understanding what energy sources exist. Even though it might seem rash to claim that we now know all the primary energy sources available, we do seem to have a rather reliable and complete view of the energy spectrum from wood and other biomass to fusion, the energy in the Sun. It is unlikely that there is anything beyond fusion that we could obtain and use, even if it existed. Between wood and fusion, there seem to be no energy sources that we suspect, and have not at least sampled and evaluated in some way. In this regard, physicist Albert Bartlett (1994) writes:

> The probability is very small that technological developments will produce new sources of energy in the next century, sources not already known in 1994, that will have the potential of supplying a significant fraction of the world's energy needs for any appreciable period of time.

It is interesting to note that Shell Oil Company made a graphic projection a few years ago of energy sources they expected to eventually draw upon to the year 2050. In the years approaching 2050, they indicated a small amount of energy coming from sources "unknown." Many of the readers of this book will be alive in 2050, so be sure to check with Shell to see what new energy source they may have turned up. It is an intriguing thought. But don't throw away your gasoline ration card that you probably will be using by 2045 (or earlier) before you know what that unknown energy source is, and if it can be put into your car's gas tank.

Future demand

There are a number of estimates (all higher) or energy demand in the future, as world population and industrialization continue to grow – or try to grow. Both the U.S. Department of Energy and the International Energy Agency (IEA) project that global energy use will increase almost 50 percent between 2006 and 2030, with oil still providing 30 percent or more of the world's energy. Whether or not projected population increase to 2030 is included in these estimates is not stated. In many, if not most instances, energy demand and supply projections do not take population growth adequately into consideration. It is difficult to see how this demand can be met. A future of less energy per capita seems certain, requiring major adjustments in lifestyles and living standards, especially in the industrialized world.

The "gap"

Looking at the longer term, by the end of this century, except for a few high value end uses (e.g. medicines), oil and gas will be gone. For all practical purposes, the petroleum interval as we now know it, will be history by 2050 if not sooner. This is the century when the new and permanent world of renewables will arrive, and the degree to which renewables can come to the rescue will be known. By 2050, there is likely to be a serious gap in energy supplies. Given the present rate of development, renewables will not be able to fill the gap caused by the depletion of fossil fuels. Kunstler (2005) recognizes this in his perceptive book, *The Long Emergency*, and foresees a gradual change back to a largely agrarian society with more localized economies.

Once fossil fuels are exhausted later in this century, renewable energy resources will be able to only sustain a much smaller population at a reasonable standard of living. When will policy makers and the general public recognize this important basic reality? Elected officials and the mainstream media either do not wish to believe the message or choose to ignore it because it is unpopular to report “bad news.” Some feel it is politically “incorrect” because restraining population growth may offend groups – ethnic, religious ,and others who decry “racist” or “bigot” when over-population is mentioned. There are also those who insist we must have “growth” for the sake of business and the economy. Such views do not recognize that this is a basic problem for the future of all humanity. But, as it is said, “The population problem is everybody’s baby.”

Lindsey Grant (2004) writes:

"Many studies have undertaken to describe how benign renewables might replace fossil fuels. A few of them have noted that population growth makes the task more difficult. Almost none of them turn the issue around and make the point that a smaller population will make it simpler.”

Grant (2005) emphasizes the ultimate importance of population size to our energy future:

> The debate has been cast in the wrong terms. The problem cannot be solved if we keep asking ‘What energy sources will be available to replace fossil fuels?’ We should instead ask ‘What populations can be supported in a decent stan-dard of living by the energy sources that will be available after this transition from fossil fuels?’

The Uncertain Voyage

In entering the energy transition to renewable resources, we enter uncharted waters heading for the far shore where we hope there will be a sustainable renewable energy resource economy. How smooth or stormy will the trip be, and what economies and life-styles will be there, when humanity arrives and makes the adjustment to new paradigms? Earlier civilizations existed without oil, gas, and coal. Future generations will do likewise, but with the advantage unavailable to earlier peoples of possessing great amounts of technical knowledge. Can that be used to raise the standard of living above what it was before the arrival of the current hydrocarbon bubble?

The renewable resource economy will have to depend largely, if not entirely, on what is available within a limited geographic range. As such, the energy mix in various areas may be quite different from one another. Just as in earlier times, humans in some numbers will survive in more localized states of culture with local standards of living dependent on what resources are at hand. How these variables will achieve equilibrium in various regions of the world is not predictable now. Since available resources will differ markedly from region to region, different cultures and living standards will exist even as they do today.

Uphill against the second law of thermodynamics

The second law of thermodynamics, among other things, posits that because obtaining work from energy involves going from a concentrated high density energy source producing work, entropy diffuses the initial energy source to lower levels. For example, gasoline combustion in a car results in the diffusion of energy in various lower forms including considerable heat. Once the gasoline is used to perform work, its energy cannot be reclaimed in its original high-density form.

With alternatives, we are trying to take diffused energy and concentrate it to a higher density energy form. Both sunlight and wind represent energy of low concentrations, which, by various devices, we concentrate into usable form. But the conversion efficiency rate is low.

Crude oil has about 18,400 Btus per pound; coal has about 10,400 Btus per pound (subbituminous, like that in the western states, has about 8,500 Btus per pound); corn contains 7,000 Btus per pound; and switchgrass, heralded to be the best route to a lot more ethanol, only contains about 6,400 Btus per pound – about one-third the Btus crude oil contains. Ethanol derived from any source has only about 60 percent of the energy of gasoline per pound, and at best, takes nearly as much energy, if not more energy, to produce as is produced.

Fossil fuels now dominate the energy mix, and it will be difficult if not impossible to replace them with energy density equivalents. Using other energy sources, in the face of the second law of thermodynamics, is an uphill struggle. "The more diffused the energy source, the more difficult it is to concentrate it into a form that can provide usable work, whether that's lighting a house, powering a car, or firing a furnace" (Bryce, 2008).

Investment needed

Predictions of future energy demands are all larger than present in part due to population, and in part due to a hoped-for rise in the standard of living in undeveloped and developing nations. To meet this demand, the IEA estimates that between now and 2030, $22 trillion will have to be invested. Some of this money will come from private enterprise, and some from government energy research and subsidies. But it is not clear that this very large investment sum will completely materialize.

Lowly asphalt, the Achilles heel of all renewables

It may sound contradictory, but one of the problems with a renewable energy future is that for most renewable energy sources, the end product is energy. There is no renewable energy that can produce the billions of tons of asphalt we need to pave our highways, driveways, and foot and bicycle paths. We cannot pave or maintain the millions of miles of roads now paved with billions of tons of asphalt with biofuels, hydrogen, or electricity from nuclear, wind solar, tidal, or wave sources. The transport system will not have 18-wheelers with a trailer or two attached, roaring down interstate highways that we see today. There is absolutely no substitute for asphalt in the volumes we now use it, which is 90 percent crushed rock and ten percent residue from oil refining. This seemingly mundane, lowly substance we take for granted and use every day will be sorely missed, revealing again how Earth resources materially affect our everyday lives. Cities and states are already experiencing more potholes in the streets as asphalt becomes more expensive and unavailable at times. Without it, our entire road transport system is in jeopardy. Railroads can only partially fill the need. They cannot reach every remote hamlet or distribute merchandise and food within a city. Asphalt is easy to put in place, and far less expensive in terms of energy expended and cost of materials than concrete. There really is no substitute for asphalt on the scale of its present use.

Hope for an orderly transition

The challenge for all of us, and the next several generations, is to make the transition in ways that preserve the essential orderly and civil elements of our social systems. Progress toward a sustainable future cannot proceed if chaos arises from the pressures of growing populations, declining nonrenewable energy resources, and the resulting gap in energy supplies that renewables may not be able to fill. Even with unlimited energy, problems would persist in soil degradation and loss that will increase food cost and decrease food supplies. No energy forms appear able to address this critical soil depletion problem. Indeed, the use of biofuels to supplant our fossil fuels, at least in part, creates further demands on soils, which are the absolutely irreplaceable basis of our survival.

Energy Future

Infinite energy not the answer

It should be added to the full discussion about energy that the idea that we need more and more energy to keep the present growth-oriented economy going with no apparent limits is a fatal road. If we had an infinite amount of energy to keep our materialistic economy growing indefinitely, the eventual impact on the environment — water supplies, degradation of soil, contamination of the atmosphere, waste disposal — would make the world unlivable. What we should logically seek is a balance among the elements of environmental sustainability, energy production, and population size.

If future energy supplies result in a smaller population, that would be a positive aspect of our environmental future. Negatives will be the problems that arise as the population is reduced. Yet, it must be done, and the sooner the effort is begun, the easier the transition will be to a renewable energy economy on which future generations must survive indefinitely. How long is "indefinitely" with regard to human lives? Deffeyes (2005) brings an interesting perspective to the question. He writes: "During the Cenozoic Period, each mammal species lasts about a million years. This does not necessarily mean that on the millionth anniversary, it's 'Bang, you're dead' and, therefore, no survivors. Often a species evolves into another species, or else splits into two species. Rather than a prediction for extinction, the million-year rule is just a geological hint that *Homo sapiens* species isn't likely to go on forever. We might have 900,000 years left." Physicist Charles Galton Darwin (1952), grandson of Charles Darwin, made the same estimate of the life of a species in his book, *The Next Million Years*.

Deffeyes continues, "The primary point of this book [*Beyond Oil*, 2005] is the disruption of our energy supplies during the next five to 10 years. But as a geologist, I have an incurable curiosity about longer time scales. Will we be able to enjoy the remaining 900,000-year life span of a typical mammalian species?" In geological perspective, the brief bright interval of fossil fuels will shortly be replaced by whatever else we can use for the future. The future is a very long time, so the options chosen had better be good and also kind to the Earth so that we do not destroy our very base of existence.

There are a variety of views about the post-petroleum future dependence on renewable fuels. Heinberg (2004) in *Power Down* presents a scenario, in which he says: "resource depletion and population pressures are about to catch up with us and no one is prepared." He describes the coming dilemma saying: "While fossil fuel depletion is a real and imme-diate crisis, it is also symptomatic of a universal ecology dilemma, which consists of three interrelated factors:

1. Population pressure
2. Resource depletion
3. Habitat destruction

His solution for the future calls for a reduced population with lower per capita energy use than now enjoyed by industrialized nations. He agrees that alternatives cannot entirely fill the gap after the end of abundant fossil fuels.

Trainer (2007) discusses renewable energy in detail. He makes a summary statement with which I am largely in agreement:

> It would be difficult to find a more taken for granted, unquestioned assumption than it will be possible to substitute renewable energy for fossil fuels, while consumer-capitalistic society continues on its merry pursuit of limitless affluence and growth. There is a strong case that this assumption is seriously flawed. The limits to renewable energy have been almost totally ignored as a topic of study, even (especially) within the renewable energy field. There are powerful ideological forces at work here. No one wants to even think about the possibility that these sources might not be able to underwrite ever-rising affluent living standards and limitless economic growth.

Lester Brown (2006) in his book, *Plan B 2.0: Rescuing a Planet Under Stress and a Civilization in Trouble*, projects a world where renewables can provide an adequate standard of living for a stabilized population. He does not estimate the size of the population that can achieve this level of life on renewables. Brown observes:

> Countries everywhere have little choice but to strive for an average of two children per couple. There is no feasible alternative …. Facing many threats simultaneously means setting priorities. Terrorism is one of those threats. No question. But it is not even close to being the top threat facing our early twenty-first century civilization. Population growth, climate change, poverty, spreading water shortages, rising oil prices, and a potential rise in food prices that could lead to unprecedented political instability are the leading threats.

However, Brown optimistically says, "What we need to do is doable …. Moving to the highly efficient plug-in gas-electric hybrids, combined with the construction of thousands of wind farms across the country to feed electricity into a strong, integrated national grid, could cut U.S. gasoline use by 85 percent." He also suggests a much-expanded use of solar power. Brown has confidence that renewable alternatives can go far to solve our energy problems.

I have reservations, as both Heinberg and Trainer do, about how well alternative energy sources can adequately support even the present population, much less the more than nine billion people projected by the United Nations to be alive by 2050.

Better use of military money

I wholeheartedly support Brown's comments regarding military budgets and priorities. Brown observes that the projected military budget for the U.S. is $492 billion, which is approximately equal to the combined military budgets of all of the rest of the world combined. He proposes an annual U.S. budget of only $161 billion that would include such social goals as universal health care, family planning, adult literacy programs, and universal primary education. Goals and expenditures to benefit the Earth include reforestation, protecting topsoil on cropland, restoring fisheries, restoring rangelands, and protecting biological diversity.

These are long-ranging improvements, enhancing vital elements of the environment we will need to live on in the future. This contrasts with money spent in far-flung military ventures, where much of the expense is for destruction and the taking of human life. Military defense is important, but so are worldwide preservation of the environment, improved living standards, and increased education.

Brown has made a thoughtful effort to present a detailed approach to a future based on renewable energy sources. His plan deserves serious consideration. Using military expenditures for constructive projects would be a laudable change. Whether or not improved living standards would eradicate terrorism based on religious belief and zeal may be questioned, but is surely worth a try. And the cost of such a "try" is modest compared to the money spent for destructive weapons of war.

Depletion of renewable resources — fatal trend for the future

Unfortunately, as Brown (2006) reports:

> We are consuming renewable resources faster than they can regenerate. Forests are shrinking, grasslands are deteriorating, water tables are falling, fisheries are collapsing, and soils are eroding.

The time scale in which renewables might restore themselves in some cases is beyond the time of the next several generations. Examples are deteriorating grasslands, soil erosion, and falling water tables. Fisheries perhaps should be included since the U.S. and Canadian codfish collapse sees no immediate regeneration. P opulations will need to depend more and more on renewables by the end of this century, and probably much sooner. The time required for regeneration of some renewables extends long beyond that. Therefore, we must recognize current use trends and correct them.

Year 2030 — wind, solar, biomass, and waste

In its *World Energy Outlook 2030*, the IEA predicts the combined energy sources of wind, solar, biomass, and waste will produce less than one percent (0.088%) of total energy demand. The IEA further projects that despite production declines, in 2030, oil will provide 93 percent of world fuel for transportation. This obviously means a less mobile society and far less transport of commodities at that time, causing a further significant change in lifestyles and consumption patterns. For biofuels to rescue the United States and replace imported oil as we now use it, an area larger than the State of Texas would have to be planted with fuel feedstocks to replace just half the oil America imports every day (*Wall Street Journal*, August 6, 2008).

Wind electricity in 2030

To obtain just 20 percent of U.S. electricity demand today by the year 2030, the U.S. Department of Energy estimates it would cost more than $2 trillion to build turbines across the entire Midwest "wind corridor" plus multiple offshore installations. A new wind electricity transmission superhighway of 12,000 miles of electric lines also would be needed to carry the electricity from the wind generation areas to population centers. This estimate does not provide for population growth.

Renewables lagging

Surprisingly, according to the U.S. Government Accountability Office (GAO), between 1973 and 2004, renewable energy as a portion of the total energy mix in the United States remained at six percent. Since that time, renewables have made gains, but progress toward replacing nonrenewable sources has been modest.

The edge of an abyss

Lindsey Grant (2008) writes that we are on "the edge of the abyss" and "the name of the abyss is energy." About the time the human population is expected to reach 9 billion or more in 2050, mankind will likely be staring into the energy abyss.

Grant also comments on the hopeful political platitudes we hear frequently. Grant writes: " …government must hear the message that the public recognizes our changed circumstances, and that politicians do not need to promise the impossible to be elected or re-elected. I leave it to a later chronicler to say whether that message will get through in the face of demands for growth from those who finance our election campaigns."

A British physicist's reality check on wind, solar, and biofuels

Physicist David MacKay at Cambridge University applies physical limitations to these three resources as they relate to Great Britain. MacKay calculates that meeting Britain's energy needs from onshore wind power, even assuming the wind blew all the time, would require covering literally the entire country with turbines. Offshore installations to achieve the needed energy also would need to be huge. For cloudy Britain, huge solar-power arrays would have to cover large desert areas in other parts of the world with the energy carried by wire to Britain. The line loss would be considerable, and other countries might not accommodate the power line corridors needed.

For biofuels, physicist MacKay reduces the problem to three numbers: solar intensity, efficiency with which plants convert sunlight into stored energy, and land available. Applying these to Britain, his calculations show that switching every piece of agricultural land to biofuel production would provide just 12 percent of the needed liquid fuel. In all these estimates, the initial cost and subsequent maintenance cost are ignored. Only the physical limitations are considered. MacKay observes that global climate change and energy policy consist mostly of "feel-good rhetoric" rather than significant action, observing that Richard Feynman's famous statement "nature cannot be fooled" supersedes any political expediency. In other words, Earth resources and their physical limits remain in control.

Oil companies and alternative energy sources — differing views

Some oil companies have been moving toward alternative energy sources: Chevron (geothermal); Royal Dutch Shell (algal ponds, trees, shale oil – Shell withdrew from a large North Sea wind project); BP (solar, wind). ExxonMobil's CEO, Rex Tillerson, said that fossil fuels (chiefly oil and natural gas) will be the major sources of energy for several decades to come, and ExxonMobil's research is chiefly directed toward "creating more efficient and adaptable renewable technologies." But Tillerson expects renewable energy to account for no more than two percent of total energy supply by 2030. His view is supported by the IEA and the U.S. Department of Energy, which predict that the fossil fuel share of energy supplies, although at lower production amounts, will remain in the range of 82 to 87 percent by the year 2030. The president of Saudi Aramco says, “Alternatives are simply not ready to shoulder the load, nor will they be in a position to do so anytime soon, given the time and effort needed for them to make a more substantial contribution to world’s energy supplies. There are expectations for an unrealistically rapid development of alternative resources.”

As fossil fuels deplete, the public appears to put increasing faith in the view that sufficient alternative energy sources will be available, probably in time to somehow replace the decline of oil production. This will not happen, and Grant’s (2008) “abyss” will very likely become a reality. In a January 2008 email sent to all employees, Shell CEO Jeroen van der Veer, stated: “Shell estimates that by 2015, supplies of easy-to-reach oil and gas will no longer keep up with demand.”

There have been two studies on the eventual arrival and effect of the peak of world oil production. One was authorized by the U.S. Department of Energy (Hirsch Report, 2005) and one originated with the GAO, 2007, perhaps the most politics-free agency within the government. Although neither study makes a firm prediction of the date of peak oil production, both indicate that the peak is inevitable within the foreseeable future. The GAO report says: “Because the decline would be neither temporary nor reversible, the effects would continue until alternative transportation technologies to displace the oil become available in sufficient quantities and comparable costs.” In this regard, the GAO concludes that, “ … even under the most optimistic scenarios, these technologies could displace only the equivalent of about 4 percent of annual projected U.S. oil consumption by around 2015.” Both reports express concern that alternative fuels will not be available in sufficient quantities in time to adequately fill the gap left by the end of oil resources.

Many in government and industry seem to believe that a seamless transition to an alternative energy economy and lifestyle, maintaining current standards of living can be achieved. An ever-expanding economy providing more jobs and evermore demand for goods is a comfortable and popular concept with the public, but it is an illusion.

Hugh Nash has remarked, “What better way is there to show our faith in our descendants’ boundless technological ingenuity than to make sure they need it?” And that is apparently what we are now doing. But, can technology come to the rescue? It cannot make a substitute for water, or make more soil as nature does naturally over thousands of years. These two things are vital to our descendants’ future. We currently are degrading both.

No free lunch

All energy, from whatever source, involves costs. The input cost of energy may be zero from solar, wind, waves, and currents, but that does not include the cost of installations and the continuing cost of maintaining them. All installations have an ultimate useful life, and must eventually be abandoned (e.g., offshore gas and oil production platforms and related equipment after the resource is depleted). There is no free lunch in the energy spectrum.

The current optimistic view by public officials and others in the ability of renewables to be available to seamlessly make the transition from fossil fuels is not borne out by the statistics so far. In 2008, former Vice President Albert Gore repeated his earlier call to generate all the nation’s electricity from renewable sources like wind, solar, and geothermal in 10 years. The chance that this can be done is zero, and it illustrates how little national leaders and the public understand the realities and the magnitude of our energy crisis now, and the prospects for the future.

Renewable resource economies — more localized

When renewable resource economies are achieved, they are very likely to be localized, as Kunstler (2005) projects. In contrast, today we have a global, largely nonrenewable resource economy.

Even as organisms evolve, economies and lifestyles change and adapt and will continue to do so. The idea that what we see about us now will always be, is an illusion. Changes are coming at an exponential rate, unparalleled in human history.

Putting renewable energy in total context with all other energy sources, the statistics are these for the world energy supply mix in 2011:

Source	Percent
Oil	36
Coal	24
Natural gas	21
Wood/dung/organic waste	10
Nuclear	6
Hydropower	2
Wind, solar, biofuels, and geothermal	1
	100

With fossil fuels due to be greatly depleted by mid-century, wind, solar, biofuels, and geothermal energy will have to make remarkable advances as energy sources to fill the impending energy supply gap.

Recent history clearly shows that a prosperous society must be supported by abundant and relatively inexpensive energy. The likelihood of meeting these needs in the future is highly problematical.

Viewing the total spectrum of renewables, the BP Statistical Review of World Energy (June, 2011) spotlights the wide gap between renewable and finite fossil fuels. Calcu-lated in terms of millions of tons of oil energy equivalent, in 2010, the latest year for avail-able data, the United States produced and consumed 1,995 tons from fossil fuels compared with 39.1 tons of renewable energy. For the world, tons from fossil fuels totaled 10,442, and for renewables 158.6 tons.

The U.S. government's long campaign to replace oil with renewables at an early date, backed by political interests requesting subsidies, surprisingly has been inspired by inter-nal reality. The U.S. Department of Energy's Energy Information Agency estimates that the timeframe to develop reliable renewable energy to replace significant amounts of fossil energy runs into decades. As of 2010, all forms of renewable energy accounted for only 3.3 percent of global energy supply.

CHAPTER 13

Water = Life

No organism can live without water. Some use more, some use less, but the need is always there. It is likely that life originated in an aqueous environment. This is why the search for life on Mars starts by looking for water, or its solid form, ice. No water — no life. By various means, advanced forms of life, including humans, have taken the water with them in order to foster life in its early stage. The chicken lays an egg (74 percent water) and the chick develops in a liquid environment. Humans do essentially the same thing. We normally live for nine months in an aqueous environment, the amniotic fluid of our mother's womb, until her "water breaks," and we are launched out on to the land. Even then the human body is about 60 percent water, and the only thing that keeps us from simply being a puddle is that, fortunately, we have some strong cell-wall structures and a mineral skeleton that keep us in "shape."

Perhaps this illustrates the saying that "you are what you eat" because much of our food is mostly water. Some vegetables like celery and cucumbers are 95 percent water; tomatoes, 93 percent; cabbage and broccoli, about 92 percent; carrots, 88 percent; and even after a potato is baked, it is 71 percent water. The appropriately named watermelon, cultivated for more than 4,000 years, is 95 percent water. Apples are 84 percent water; bananas and berries are about 80 percent. Beef and fish are more than 70 percent water and oysters are 85 percent water. Milk is 90 percent water, and soft cheese is about 60 percent. All this supports Suzuki's (2007) quote of Vladimir Vernadsky, "Life is animated water." Suzuki expands on this thought, relating it to humans:

> Basically each of us is a blob of water with enough macromolecular thickening to give us some solidarity and to keep us from dribbling away. Every day, about three percent of the water in our bodies is replenished with new molecules. The water molecules that perfuse every part of our bodies have come from the oceans of the world, evaporated from prairie grass fields, and the canopies of all the world's great rain forests. Like air, water physically links us to the Earth and to all other forms of life.

We breathe, the water we have is simply on loan. Each molecule has been used in some way or other by other organisms in the past. The air we breathe has molecules in it used by every breathing thing, from grasshoppers to lions. It may have at one time been inhaled and exhaled by a dinosaur, a Neanderthal, Napoleon, George Washington, and the Indian chieftain, Seattle. We now use it for a single breath and it moves on — to whom, to where, and on again.

Both animals and plants, in their adaptation to various environments, preserve water in many ways. Desert plants have small leaves (greasewood), or thorns without leaves (cacti), or waxy surfaces that transpire very little water. Some plants live on the barest of water supplies. In Peru, south of Lima near the site of the ancient pre-Inca community of Pachacamac, there is a plant with no roots. Why have roots if there is no water in the soil? The plant lives by absorbing water from the persistent coastal fog — the *neblina*, as it is called in Spanish. The plants have spiny leaves like a yucca. One can simply pick up a plant and set it down a dozen feet away, and it is perfectly at home.

In northern coastal Peru, it rains infrequently, perhaps once every 20 years or so. We geologists, in Jeeps, used the dry washes (*quebradas*) as roads up into the foothills. But when the rains came, the *quebradas* ran full with water for a few months. As they dried up into pools, great numbers of tiny fish would appear, apparently hatched from eggs that lay dormant for many years in the dry gravels of the wash. In a brief few weeks the fish would complete their life cycle by mating and laying more eggs in the gravel bottoms of shallow pools as the *quebrada* dried up. There, they waited another few decades for the next rainwater to repeat the cycle. In other desert regions, this event is repeated. In times of drought, a larger fish, the lungfish, simply encases itself in mud, breathes air, and awaits the next rain when it can swim around again and mate.

Freshwater and soil provide the basis for all life on land. But the amount of freshwater compared with the total volume of world water is exceedingly small. Only three percent of water on Earth is freshwater, of which two-thirds is locked in ice sheets and snow. Seven billion people now depend on the one percent of freshwater that isn't locked away in ice, the atmosphere, or deep in the ground. Total liquid freshwater is only 0.635 percent of the world's total water, of which 0.620 percent is groundwater. Using wells and pumps and from springs, we now extract groundwater, and at a worldwide rate faster than the rate of natural recharge.

Volumes of water on Earth held in various forms

Water is the only known substance that can exist either as a gas (water vapor in the air, including clouds and steam), as a liquid (streams, ponds, lakes, and the oceans), or as a solid (ice) in the range of air temperatures and pressures normally existing on the Earth. There is absolutely no substitute for water.

If a 55 gallon drum of water represented all the water on the planet, the water would exist as:

Oceans = 53 gallons + 1 pint + 12 ounces
Ice = 1 gallon + 12 ounces
Atmosphere = 1 pint + 4.5 ounces
Groundwater = 1 quart + 11.4 ounces
Freshwater lakes = 0.5 ounce
Inland seas and salt lakes = 0.35 ounce
Soil moisture = 0.25 ounce

Nearly all the freshwater in the world, not in the form of ice, exists as groundwater. It is the only source of drinking water for about a quarter of the world population.

From these numbers, it is clear that the amount of freshwater available for human use is very small compared to the total amount of water on the planet. Groundwater cannot be depleted by wells. Rivers cannot be entirely appropriated for human use, and neither can freshwater lakes, or vital parts of the environment would be destroyed. Freshwater for human use is a very limited and precious resource. And increasingly, we are polluting much of this small amount. Water is endangered by a growing population driving ever-increasing consumption. All countries face this problem to some extent, but China and India are especially challenged. Rivers around the world continue to find use as sewers for industrial and human wastes.

When this pollution reaches the oceans, as it inevitably does, ocean waters are polluted. Human-generated pollution can now be detected in many ocean biological inhabitants. We are exceeding the ability of natural systems to absorb the waste of seven billion people. What will happen with more than nine billion expected by 2050? Protecting our relatively minute amount of freshwater, vital to human existence, needs much more serious attention than it now receives.

Freshwater supplies — a current and increasing problem

In myriad ways and in many places, the lack of adequate freshwater supplies is becoming a chronic problem. An example is the southeastern Spanish province of Murcia. The Spanish Environment Ministry says that one-third of Spain is at risk of turning into a desert. In Murcia, hundreds of thousands of wells, mostly illegal, have depleted local water sources to the point of no return. Nevertheless, they have built 54 golf courses in the region over the past decade, most in the past three years.

Golf courses represent one aspect of the current affluent lifestyle in many countries. In his article, "How Green is Golf," Barton (2008) says that there are now 16,000 golf courses in the United States, roughly equal to the state of Connecticut in area. Each uses an average of 300,000 gallons of water per day. In the desert southwest (Arizona, and southern Nevada), where water use is already a major issue, golf is facing growing criticism.

Water — life's essential connection to the Earth

Water is the medium by which minerals in the soil are put into solution to be taken up by plants and in turn by animal life, all of which is dependent on plants. Water, therefore, connects all life to the minerals in the Earth on which life depends. The average adult human body is approximately 60 percent water. It is a common expression that "blood is thicker than water," but not by much. Blood, which carries nourishment to all cells in the body, is more than 90 percent water.

People existed many thousands of years before they used metals. They existed many years before they used oil, and presumably the human race will exist many millennia after oil is gone. There are substitutes for some of the various uses of metals and oil. Where there are no substitutes, this fact would be very inconvenient, but it would not be fatal.

The earliest organized civilizations developed along the banks of major rivers, the Nile, Indus, Tigris, and Euphrates. With few exceptions, our major cities are on waterways or large lakes because only surface water resources are capable of sustaining the demands of major population centers. Cities that are not on large waterways have to bring water from distant surface water sources, which may lead to regional conflicts (Ward, 2002). Arizona, Nevada, and California increasingly face this situation.

In earlier times, when nations had much smaller populations, water shortages affected only relatively few people, mostly on a local or regional basis. But with the huge growth in world population during the past hundred years, water resource problems affect millions of people in whole countries and large drainage basins, as for example, the Nile River Basin. Before we had pumps and the energy to run them, groundwater supplies were hardly tapped. But now, with technology to drill deep wells and the help of pumps and energy, we are depleting aquifers worldwide. This is another example in which technology both helps to solve a problem, in this case, water supply, and creates a problem, with its unbridled use driven by population growth. Water tables are now falling in countries that are home to more than half the world's population, including China, India, and the United States.

Water demands for food

Water enters our daily life in countless ways. It takes about 40 gallons of water to put one egg on the table, 3,600 gallons of water to grow a bushel of corn, 150 gallons to produce a loaf of bread, 1,000 tons of water to produce one ton of grain, 375 gallons for five pounds of flour, and about 5,000 gallons to make one pound of beef. For a summer barbecue, two pounds of beef represent 10,000 gallons of water, four ears of corn are 240 gallons, French fries are 24 gallons, and four servings of watermelon use 400 gallons. A family of four can then sit down to a 10,664 gallon of water meal (Brank, 1991). The Sunday paper takes about 280 gallons of water to produce, and one automobile, in all the processing of materials which goes into its manufacture, uses about 100,000 gallons of water. Then there are all the water usages around the home. In the United States and Canada, and to a considerable extent in Europe, people have generally had the luxury of ample water supplies. But that is not true of many other parts of the world such as north and east Africa, the Middle East, and central Australia. Rice, the staple food for half the world's population, is by far the largest grain consumer of water. Agriculture in total is the single largest consumer of water for human use.

Worldwide, on average, one kilogram (2.2 pounds) of wheat requires one ton of water for its production. Because 70 percent of the world's water is used for irrigation, rais-ing irrigation efficiency would be a major help in reducing water demand (Brown, 2008). This is particularly important for groundwater, because much of the water for irrigation comes from this source.

Water and biofuels

Some statistics related to water requirements for the production of biofuels are discussed in Chapter 12. A few additional facts are presented here. One of the great, but futile promises made by some "inventors," is to enable us to burn water in our cars instead of gasoline. But this goal is attained in effect when we burn a 15-gallon tank of E10 gasoline. Ten percent of that fuel is ethanol, or 1.5 gallons. It takes 2,400 gallons of water to produce the corn needed to make 1.5 gallons of ethanol (not counting water used in the processing of corn to ethanol). Therefore, we are burning 2,400 gallons of water indirectly with each 15-gallon tank of E10. Question: How many miles are we getting per gallon of water?

The expansion of farmland to produce biofuels has exacerbated world freshwater supply problems. In the case of corn, a significant part of the crop is grown in areas where water is provided by irrigation from groundwater. The extraction of groundwater in these regions is greater than the rate of recharge, suggesting further problems as biofuel production increases. This biofuel expansion includes Brazil, the United States, much of Europe, India, and China. India and China, in particular, are overpumping their groundwater.

Export/import of water — "virtual water"

Water-short regions of the world are commonly places where food supplies (mostly grains) are imported to sustain the population. An example is Egypt, where population has outstripped the country's ability to feed its people. Accordingly, Egypt is a major grain importer. Recent "bread" riots indicate that imports may not be enough to meet the demand. Because it takes 1,000 tons of water to produce one ton of grain, Egypt imports water — water that might be called "virtual water." As the population of Egypt continues to increase, where will Egypt find more "virtual water" to import to feed a larger population?

China's important great-wheat growing region, the North China Plain, is suffering drought and a decline in groundwater supplies. China has also become a major "virtual water" importer through its grain imports.

Chronic water shortages are a fact of life for 40 percent of the world's population in eighty countries (Gleick, 1992). Africa has the most water-short countries. And because the continent's fixed supply of water must support a rapidly increasing population, water shortages will only become more severe (Postel, 1992). The United Nations' *Global Population and Water Report*, published in 2003, estimates that by 2025, five billion of the world's 7.9 billion people will be living in areas where it will be difficult or impossible to meet basic water needs for drinking, cooking, and sanitation, if present water consumption rates are maintained. Between now and 2025, total water use worldwide is projected to increase by 40 percent. When basic water needs cannot be met, stresses on communities and the environment increase. A United Nations Education, Scientific, and Cultural Organization (UNESCO) report in 2003 reported that two-million tons of waste is dumped daily into streams, rivers, and lakes. One liter of wastewater pollutes about eight liters of freshwater. The report goes on to say the future of water supplies in many parts of the world looks bleak because of continuing population growth — the driving factor in the water crisis. Thanks to population growth and limited water resources, world per capita water supplies decreased by a third between 1970 and 1990.

Wide differences now in domestic water use

Personal water use differs greatly among countries. According to the World Resources Institute, the four nations that use the most water per capita daily are Australia at 476 gallons, the United States at 159 gallons, Canada at 125 gallons, and Sweden at 120 gallons. At the other end of the range are many African countries including Rwanda at three gallons, Ethiopia at three gallons, Uganda at two gallons, Somalia at two gallons, and The Gambia at just one gallon. More than half the world population lives on less than 25 gallons a day, and there is no assurance that the water is safe to drink.

Suzuki (2007) estimates that "only about 0.0001 percent of freshwater is readily accessible," and sewage and industrial pollutants contaminate a large part of what little freshwater we have.

> By official estimates, India has facilities to treat 18 percent of the 33,000 million liters of sewage its cities produce every day. In fact, it treats only 13 percent,

> because of shortages of power, water, and technical expertise in its sewage treatment plants. These figures may underestimate the problem. Measuring the sewage output of 700 million Indians who have no access to a toilet is difficult. But it is enough to suggest why most Indian rivers, from which millions of Indians draw their water, are horribly polluted. Unsurprisingly, then, despite much progress in related areas such as availability of safe drinking water, an estimated 1,000 Indian children die of diarrhoeal sickness every day" (*The Economist*, 2008).

India is expected to far surpass China in population by 2050, with 1.74 billion people compared to China's 1.44 billion. How will India manage either its sewage problem or the related problem of freshwater supply, when they cannot be managed now with far fewer people?

Given the widespread use of India's rivers as sewers, the decline of groundwater levels, and India's expanding population, " … the collision between rising human numbers and shrinking water supplies seems inevitable" (Brown, 2008).

India is in a crisis regarding both water supply and water pollution. Every day, tons of raw sewage is dumped into the so-called sacred Ganges River in which millions of people bathe. The incidence of water-borne disease is very high. Because of the prevalent sewage, shallow well contamination is common. Deeper wells have been a temporary solution in some areas for those who can afford them, including the cost of energy to lift the water from greater depths. But water tables are dropping everywhere across the subcontinent.

Despite this, the Indian government plans to sustain its current high rate of economic growth. The arrival in volume of the low-cost gasoline-powered "people's car" is part of this plan. Finite Earth resources cannot long continue to support the increased industrialization, now projected for the world as a whole this century, and water is vital for use in nearly all industrial processes.

It is said by many in India, that "India's future will be defined by water." This may also be true of China. In a sense, it should be said of all countries, some more urgently than others. Canada, for example, has an abundance of water, and it is unlikely to be a controlling factor in its future. For India, the matter of adequate safe water is already critical and likely to become more so. Across much of Africa, the same is true. There is no substitute for water, and every living thing depends on it. It is far more valuable than oil.

China's water supply is a national concern. In the five years of the mid-1990s, the water table beneath the North China Plain fell an average of five feet a year. Increased demand from farms and factories drawing water from the Yellow River, one of the world's largest rivers, resulted in the river running dry for 133 days in 1996 and 226 days in 1997. For more than four consecutive months, no water at all reached the lower portion of the river. But the United States cannot be critical because the Rio Grande and Colorado rivers are approaching the same status. They now reach the ocean as only a trickle or not at all for part of the year.

Freshwater resources can be divided into two categories: surface waters and waters under the ground — groundwater. Each has certain special uses, and problems of development and usage.

Groundwater

About 22.4 percent of the freshwater of the world is groundwater (Powledge, 1992).

Some of it occurs at relatively shallow depths, but about two-thirds of it is believed to occur below 2,500 feet. Although we are discussing freshwater, this is not pure water. Pure water does not occur in nature. Even rain as it falls picks up dust particles and carbon dioxide from the air. Water in streams and lakes naturally contains dissolved mineral material.

Importance of groundwater

In many countries, wells are the chief source of domestic water supply. Seventy percent of Chinese get their drinking water from groundwater. More than a quarter of the world population relies on groundwater for drinking, including many communities throughout the United States, especially those in small towns, as well as rural residents across the Great Plains. In desert areas, with no permanent surface water, groundwater is the only source of water available year round. For thousands of years, desert oases with springs have sustained populations that otherwise could not have lived there. In semi-arid regions, groundwater is an important supplement to the less than adequate rainfall, and allows crops to be grown where they otherwise could not survive. The High Plains of the western interior United States are an example. But unless these operations are carefully regulated, they are not sustainable.

How groundwater occurs

Contrary to common ideas, groundwater does not exist as streams, rivers, or lakes, but rather in pores and cracks in rocks and sediments. These buried water-bearing Earth materials are called "aquifers," Latin for water-bearing. Glacial and other gravel deposits are excellent aquifers. Beds of sandstone over large areas are major aquifers. The ability of an aquifer to transmit waters is called permeability. An aquifer's ability to store water is called porosity. If water in a drilled well rises above the point of being struck, it is called an artesian well, flowing or not. If the water pressure level, called the piezometric surface, is such that it raises the water above ground level, it is called a flowing artesian well.

Groundwater is commonly recovered for human use by means of wells. Some is obtained from springs. The United States uses more than 100-billion gallons of water a day, about 20 percent of which is groundwater. In some areas when shallow groundwater supplies are depleted, deeper and deeper wells are drilled. But the deeper waters tend to be of poorer quality because of increased mineralization. Pumping water from deeper levels takes considerable energy. This energy cost may increase with depth to the point that the cost of pumping may exceed the value of the water.

Groundwater recharge

The source of all freshwater, whether surface water, groundwater, or ice, is precipitation in the form of rain or snow. Groundwater resources in some circumstances are replenished quite rapidly. However, in other geologic and climatic settings, it may take decades or even centuries to replenish. In some cases, it seems clear that an aquifer has been severely injured and will never again be as productive as it once was. The amount of precipitation that becomes groundwater is a relatively small part of annual rainfall. If a region gets 30 inches of rain a year, it is estimated that less than an inch is stored as groundwater. In hot desert regions, the little rain that reaches the ground will almost all evaporate before it can percolate into the ground. The water that sinks into the ground can later be recovered by wells, but since recharge is exceedingly slow, the aquifer can quickly be overpumped.

In some regions, artificial groundwater recharge areas have been built. These are places where surface waters that are available seasonally or from streams are directed into catchment areas overlying permeable strata. There, the water sinks into the ground to be recovered later from the strata nearby or as far as the aquifer extends. A large and successful example has been built in Orange County, California, a heavily populated county in between Los Angeles and San Diego.

Groundwater mineralized

In general, the deeper the groundwater, the more dissolved minerals it contains, to the point that it may not be usable without special treatment. This increased mineral content with depth is due to two factors. The Earth is hotter. This increase in temperature with depth is called the geothermal gradient, and heats the groundwater, giving it a greater ability to dissolve minerals. Also, groundwater occurring at greater depth is more likely to have been in the ground longer than water occurring at shallower depth. This allows more time for the deeper and hotter waters to dissolve more minerals.

The solution and subsequent depositional action of groundwater has provided spectacular sights in some places. One is the great travertine terraces in Yellowstone National Park, still forming from the millions of gallons of mineral-rich hot water that pours out every day and deposits its mineral load. Dissolving the mineral calcium carbonate, limestone, and then re-depositing some of it, has formed the world's largest cavern system near Carlsbad, New Mexico, with huge stalactites and stalagmites, and other forms of dripstone.

Mining groundwater

If the recharge of water to an aquifer is less than the amount withdrawn, the water is said to be mined. This is an important fact for the arid and semi-arid regions dependent on wells for irrigation water. It is axiomatic that if an area does not have sufficient annual rainfall to grow a given crop, then withdrawing enough water annually to grow a crop means withdrawing for one yearly crop the water that accumulated over a number of years. This is happening now in a number of parts of the world, including some regions of the United States. Recent, relatively cheap petroleum and electricity available to power highly efficient centrifugal pumps have made this possible, but it is an unsustainable practice.

The overpumping of groundwater, which is now widely occurring, promotes a danger-ous illusion. Brown (2004) says: "Overpumping creates a false sense of food security; it enables us to satisfy growing food needs today, but it almost guarantees a decline in food production tomorrow when the aquifer is depleted." The additional but ultimately unsus-tainable food supplies this creates is another indication that we are putting more and more people further and further out on a natural resource limb that is slowly being sawed off.

In some places, the water being used has been in the ground for thousands of years. Such water is another inheritance from the geologic past that can be spent but once. Using many years of local groundwater, recharge in just one year cannot continue indefinitely. The water supply eventually will be exhausted. But there are exceptions to this rule. In some areas, the recharge of an aquifer beneath an arid area may be in a more-humid region, perhaps in mountain foothills some distance away. The water migrates beneath the more-arid region where it is used. However, the migration of groundwater is slow at best, and it is easy to pump out more water than can migrate in, which will cause the water level to drop or the wells to produce just the amount which percolates in annually. Accordingly, new areas brought into irrigation from groundwater may not be sustainable over the longer term. The groundwater then, like oil and coal, is a one-time crop. This is already evident in a number of regions.

Saudi Arabia has been pumping out groundwater that accumulated in past wetter times. This water lies deep and it is nonrenewable on a human timescale. In the name of food security, much of the water has been used to grow a wheat crop that the Saudis could purchase cheaper than pumping the water to grow the crop. At its peak production in the 1990s, Saudi Arabia was the second largest Arab wheat producer (after Egypt) and harvested more than twice the wheat it consumed, allowing it to export the surplus. But with its deep aquifer almost depleted, production has declined to one-quarter of its peak, and the Saudis plan to phase out wheat cultivation entirely over the next few years (Rasmussen, 2012).

Groundwater in the United States

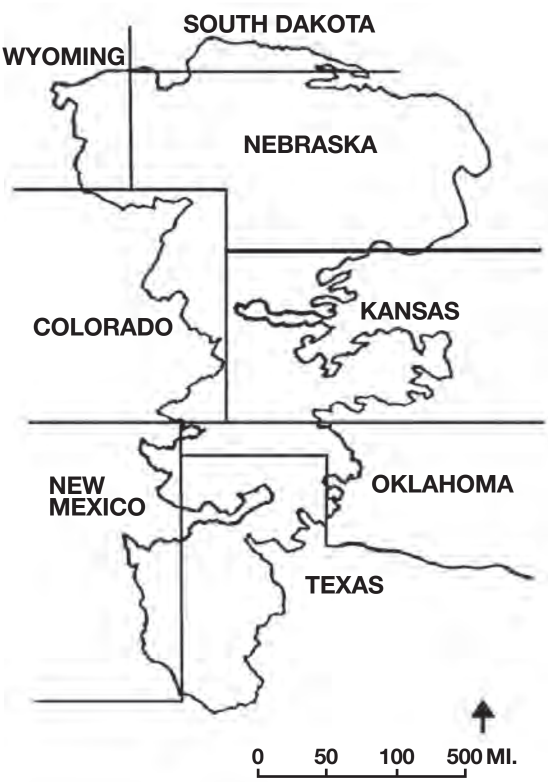
Both the United States and Canada have been exceedingly well-endowed with groundwater resources. The rapid and widespread settlement of eastern and central United States was greatly facilitated by the availability of groundwater. Rural Canada enjoys ample groundwater supplies nearly everywhere. In the United States, groundwater is a major source of domestic water supplies, and in rural areas, it is almost the entire domestic water source. More than 90 percent of people in rural America use groundwater for domestic purposes. The windmill combined with wells drilled in more remote areas of western United States have kept ranchers in business, as cattle have been watered that otherwise, without the wells, could not have survived. About 20 of the larger cities of the United States get most, if not all, of their water from wells, and in twelve states, groundwater provides more than half of the total public water supplies. Over one-third of the irrigated land in the United States is watered by groundwater. About 22 percent of the water used each day in the United States is groundwater (Glenon, 2002). In the states of Florida, Kansas, Nebraska, and Mississippi, groundwater use is exceeding surface water withdrawals. Except for Las Vegas, which, after exhausting most of its available groundwater, now gets its main water supply from the Lake Mead impoundment on the Colorado River, the state of Nevada is almost entirely dependent on groundwater.

The United States is endowed with some exceptional natural aquifers. The glacial drift of the northern states is an easily-tapped shallow groundwater resource of excellent quality, which tends to be renewed each year with the rains and melting snows. And there are some deeper aquifers. The famous Dakota Sandstone of South Dakota at one time sustained flowing wells all the way east to the Minnesota border. But as more wells were drilled, this aquifer saw its pressure reduced substantially and many once-flowing wells flow no more.

Ogallala aquifer — U.S.'s largest

Stretching from southern South Dakota to north Texas, the Ogallala aquifer underlies 174,000 square miles of the Great Plains. It is the most heavily pumped groundwater system in North America, with a maximum water saturated thickness of about 1,000 feet, and an average thickness of 200 feet. This water source has been the single most important factor in the settlement and agricultural development of the Great Plains of the western United States, much of which is semi-arid (Zwingle, 1993). Water from the Ogallala has provided water for regions that would otherwise not produce crops. And, except for minimal annual recharge, it is ancient water — an inheritance from ages past. The Ogallala is a series of inter-bedded sands and gravels created by outwash from the eroding Rocky Mountains to the west, and is by far the most important unit in the High Plains aquifer system. It is being drawn down faster than it is naturally recharged. In north Texas, the rate of recharge is only 0.1 percent annually. Sophocleus and Buchanan (2003) report: "Based on recharge studies in the state [of Kansas], the consensus is that estimated annual recharge to the area in the Ogallala portion of the High Plains aquifer is on the order of less than 0.3 inches per year." Locally, artificial recharge projects have been tried in places where there is sufficient adjacent surface water supply to do this, with modest success. But overall the situation has been described as " …taking dollar bills out of our groundwater bank account and putting nickels back in. Even with a bank account, there's an end. And that is pretty much what's happening to the Ogallala" (Zwingle, 1993).

Figure 13-1. Areal Extent of U.S. Great Plains Ogallala Aquifer



Source: U.S. Department of Agriculture

According to the U.S. Geological Survey, the Ogallala aquifer contains about 3.25 billion acre feet of drainable water. An acre foot equals one foot of water over one acre, which is 325,851 gallons. Recent counts show that more than 170,000 wells have been drilled into this aquifer to irrigate about 13-million acres of land. This acreage produces about 15 percent of the nation's total output of corn, wheat, cotton, and sorghum, and about 38 percent of its livestock. By exploiting the Ogallala aquifer, Nebraska produces 700 million more bushels of corn annually and Texas grows two million more bales of cotton than they would without the aquifer. The yearly added value of products dependant on Ogallala water is about $20 billion. Agricultural exports are a major source of U.S. foreign exchange, and the Ogallala-based produce is a significant factor in these exports. However, estimates are that about 24-million acre feet are now being withdrawn each year, whereas the recharge is only about three-million acre feet. The highly efficient centrifugal pump has been the solution to lack of water in the High Plains, but it is also now the problem.

The U.S. Geological Survey reports that since the beginning of using this aquifer, the volume of water in storage had decreased about 166-million acre feet. From the 1940s to 1980, the water level in the Ogallala aquifer dropped about 10 feet on average, but in places it dropped more than 100 feet. During the period 1960 to 1980, the water pumped from the southern part of the aquifer in west Texas and eastern New Mexico was 30 times the natural recharge. Although efforts continue to better manage this valuable resource, computer models project a continuing net water loss. The aquifer is being mined, and the saturated water thickness has decreased by more than 25 percent over an area of 14,000 square miles. Because a drop in the water level increases pumping costs, irrigation has been discontinued on about 367,000 acres, an ominous trend (Postel, 1989). In the Texas High Plains overlying the Ogallala aquifer, between 1974 and 1989, irrigated acreage decreased 34 percent because the cost of pumping the water from the diminishing aquifer was greater than the value of the food produced (Gleick, 1992).

Like other renewable resources such as soil, in the Ogallala, we are spending both all the current income — the rate of replenishment — and part of the principal — the natural capital. This will not be helpful for the survival of future generations. Worldwide, the continuing loss of soil and depletion of groundwater is leading humanity directly over the cliff.

Other U.S. groundwater problems

A similar situation exists in the upper Great Plains area where South Dakota takes water from the Missouri River, partly to try to preserve the Dakota Sandstone aquifer. But now South Dakota is facing demands from Nebraska, Iowa, and Missouri, which want to take more Missouri River water, as their groundwater supplies drop. The Missouri River in South Dakota is not a very large stream and South Dakota does not wish to relinquish its current water withdrawal from the Missouri to help out the downstream states.

These problems arise when an agricultural system is based on a depletable resource, in this case, groundwater which is not being recharged as fast as it is withdrawn to support the agricultural economy. The situation ultimately may be very much like that of metal mining areas where the ore has been taken out and now only ghost towns or greatly reduced populations remain. For a number of years, the groundwater situation in Arizona has grown increasingly critical. Each year, Arizona uses an estimated two-and-a-half million acre feet more groundwater than is replenished by natural means.

Rapidly growing communities along the Front Range of Colorado are encountering groundwater supply problems:

> In 1970, 12,000 people lived in Douglas County, Colorado, just south of Denver. Today more than 200,000 people reside there, with the population expected to double in the next 25 years. Like other counties in the Denver area, Douglas relies on 10,000 year-old groundwater from bedrock aquifers located in the Denver Basin for its water supply. The rapidly growing population, however, is sucking the supply dry.
>
> In Castle Pines North, in Douglas County, water in wells is dropping an average of 34 feet per year. In nearby Parker, water is dropping 30 feet per year. And the story is similar in other municipalities (Sever, 2004).

Natural recharge is totally inadequate to meet these demands on the aquifer. There is no obvious solution to this problem. "As much of the undeveloped land in the county has already been sold and zoned, it is unlikely that development will slow anytime soon" (Sever, 2004). It is hard to know what to say about this sort of situation. Population growth across the United States has reduced renewable freshwater per person per year from 14,934 cubic meters in 1955 to 9,913 in 1990 and to an estimated 7,695 cubic meters in 2055. Thoughtless growth carries seeds of its own demise that will not result in a happy outcome.

Land Subsidence

When fluids — oil and water — are taken out of the Earth, the ground may sink if the strata are not highly indurated — that is, fairly rigid. If the aquifer's materials are very well sorted, as for example, in the St. Peter Sandstone, further compaction cannot take place. In other places, overlying rocks are so solid that they will not compact when fluid is withdrawn. In central and eastern Oregon, water is pumped from fractured lava flows or from sands and gravels interbedded with the lava flows. The basalt lava flows are rigid and so no ground subsidence takes place. Also groundwater levels are monitored so that the rates of pumping are held equal to the natural recharge, and water table levels are maintained. However, in other areas where only sediments exist, as in the San Joaquin Valley, land subsidence due to water withdrawal continues to be a problem.

San Joaquin Valley

Galloway et al. (1999) write:

> Mining groundwater for agriculture has enabled the San Joaquin Valley of California to become one of the world's most productive agricultural regions, while simultaneously contributing to one of the single largest alterations of the land surface attributed to humankind …. In 1970, when the last comprehensive surveys of land subsidence were made, subsidence in excess of 1 foot had affected more than 5,200 square miles of irrigable land – one half the entire San Joaquin Valley…. The maximum subsidence, near Mendota, was more than 28 feet…. Most of the subsidence measured in the valley has been correlated with the distribution of groundwater pumpage and the reduction of water levels in the deep confined aquifer system.

The subsidence of the land reflects how much the aquifer has collapsed, and once collapsed, it cannot be raised again by injection of water. On the west side and in the southern end of the valley, the drop in well-water levels is as much as 400 to 500 feet, and land subsidence is evident in several areas.

Food "bubbles" and overpumping of groundwater

Food supplies that otherwise would not exist, thanks to overpumping groundwater, are labeled "food bubbles" by Lester Brown (2011a). This kind of food production now feeds 175 million in India and 130 million in China according to the World Bank. When these unsustainable food bubbles may burst is unknown, but inevitably, they will. This already happened in Saudi Arabia, where a depleted, unrechargeable aquifer has virtually eliminated a 3-million ton wheat harvest. In the Salinas and San Joaquin valleys of Cali-fornia, a food bubble may be starting to burst as agricultural production draws on dimin-ishing groundwater supplies.

These situations remind us that we are living on an Earth resource legacy that is not being replaced. We are living beyond our resource means, and we are joined by at least 17 countries with temporary food bubbles based on overpumping groundwater. The root problem is the worldwide problem: overpopulation. Population size far exceeds the sustainable world resources that exist to support it.

Groundwater loss

When an aquifer collapses, its water-bearing ability is either greatly reduced or may be destroyed. Entirely. In either case, it suffers irreparable damage, and cannot be restored. The Central Valley of California produces 25 percent of the nation's table food using only one percent of the country's farmland (Cone, 1997). The diminishing ability of aquifers to supply groundwater for irrigation is a serious loss. An agricultural economy built on a groundwater resource which cannot be renewed to what it was once will either have to contract or find some other source of water. California's Central Valley is one of the most-productive and most-valuable pieces of agricultural land in the world. Since half of the irrigation water used in the Central Valley has been groundwater, its depletion is a major economic concern. With groundwater being lost, the economy of the valley will have to adjust. Surface water brought in from considerable distances by canals is one solution being used. However, this source is limited by the increasing competition from cities for these finite water supplies, and the northern areas of California from which much of this water is obtained are becoming increasingly unwilling to continue to export their water.

Santa Clara Valley

Land subsidence in the central part of the Santa Clara Valley of California has been ongoing for more than 50 years. It was first noticed when a detailed series of re-leveling studies were done in 1932 and 1933. A level line established there by the Coast and Geodetic Survey in 1912 showed about four feet of subsidence in the San Jose area. A subsequent study by the U.S. Geological Survey published in 1988 showed that since 1933, the San Jose land surface had subsided a total of about 13 feet (McArthur, 1981). This large amount of subsidence presumably is due to the rapid and intense development of the San Jose area since 1933. The principal cause is the continual pumping of groundwater. This same study found that the artesian water level had dropped as much as 200 feet since 1916. Now, however, thanks to imports of surface water and a reduction in groundwater withdrawal, the water level has recovered 100 feet or more, but the land subsidence remains.

The California Central Valley in total

This comprises both the San Joaquin Valley in the south and the Sacramento Valley in the north. It has more than 100,000 irrigation wells, and groundwater pumpage greatly exceeds the natural recharge rate (Bertoldi, et al., 1991). The valley has the largest volume of land subsidence in the world caused by human action, mostly due to excessive ground-water pumpage. In the Sacramento River Delta region, about 450 square miles of road has subsided, in some places more than 20 feet.

Houston-Galveston area

The greater Houston area, possibly more than any other metropolitan area in the United States, has been adversely affected by land subsidence caused by groundwater pumping and also by oil and gas extraction (Galloway et al., 1999). Excessive withdrawal of groundwater has caused the land to subside as much as eight feet. The area affected covers several hundred square miles and the economic damage from this subsidence now exceeds a billion dollars.

Arizona

In Arizona's Salt River Valley, where fields have been irrigated by groundwater for many years, the water table has dropped more than 300 feet in places. This has caused sub-sidence of the surface in a number of areas. The Central Arizona Project aqueduct, which brings Colorado River water to Arizona, had to be especially constructed to compensate for continual land subsidence near Apache Junction. Elsewhere, in Paradise Valley, a resi-dential complex northwest of Phoenix, a 400-foot long fissure opened as the apparent result of groundwater withdrawal. Many more fissures are now occurring in the basins of parts of Cochise, Maricopa, Pima, and Pinal counties — all areas of groundwater pumping for agriculture (Galloway, et al., 1999).

Groundwater Mining and Saltwater Intrusion

There is an additional negative impact from mining groundwater. Along the coastal plain of the southeastern United States, several excellent freshwater aquifers dip gently toward and eventually into the sea, as, for example, in Virginia. But because they end in saltwater, keeping the saltwater out depends on a steady flow of freshwater from the higher level of the land toward the ocean. If too much freshwater is drawn out, the hydraulic pressure of the freshwater is reduced, and there is a landward invasion of saltwater into the aquifer. This has been a problem in the Norfolk, Virginia, area, and occurs elsewhere along the Atlantic coastal plain.

Salinas Valley

On the Pacific Coast in the highly productive Salinas Valley of Monterey County, California, overpumping also has caused the aquifers to be invaded by saltwater. By 1993, saltwater had destroyed about 100 wells in the valley, and sea water had moved more than seven miles inland in some places. William Hurst, General Manager of the Monterey County Water Resources said: "If nothing happens to slow this down, you won't be able to grow much of anything in this valley, and people are going to have to get drinking water from somewhere else"(McCoy, 1993).

Particularly delicate freshwater-saltwater relationships exist in some of the Pacific Islands where thin lenses of freshwater sit on top of saltwater in the very porous coralline limestones. If the freshwater is withdrawn faster than its recharge rate, saltwater rises and contaminates wells. Reversing this situation takes considerable time. The development of tourism in some of these islands has increased the demand for freshwater and exacerbated the problem of saltwater intrusion.

Groundwater Withdrawal/Subsidence — A Worldwide Problem

Land subsidence due to excessive groundwater withdrawal is a worldwide concern. At Osaka, Japan, subsidence has been about 10 feet, resulting in millions of dollars in damage. The Tokyo area has seen subsidence in places in excess of 12 feet, with damage between 1957 to 1970 of an estimated 225 million dollars. Thailand (Bangkok area), Italy, and England (the London area) have also experienced land subsidence due to excessive groundwater pumping.

Mexico City

Probably the most spectacular area of ground subsidence has occurred in the Great

Valley of Mexico, the site of Mexico City with more than 20 million inhabitants. Here the land has dropped as much as 28 feet in places. Buildings continue to sink and damage is estimated to be more than 500 million dollars.

Various and costly effects

Ground subsidence is costly in other ways. Sewers may be impeded, and in some cases, the flow even reversed. Bridges, tunnels, railroad lines, power lines, and highways are all adversely affected. Cracks occur in foundations of buildings. A railroad derailment was caused by land subsidence and the shifting of rails. The mining of groundwater has become a substantial economic liability in many areas. But subsidence and damage continue to grow, although in some places regulations are now in place to prevent further excessive groundwater removal.

Agriculture vs. power plants

Power plants, both nuclear and coal-fired, need water for cooling. Currently in the United States, about 39 percent of freshwater is used to irrigate agriculture. About the same percentage is used for cooling towers of power plants. As more power plants are built to supply the energy demand of an increasing population, there will also be increased demand for water to irrigate the crops to provide food for the increased population. People need power and people need food. Water is the vital link.

The Groundwater Heritage

From time to time, especially in the Middle East, large groundwater-based irrigation projects are proposed and many already exist. It is doubtful, however, that these will be viable very long into the future because most of them draw upon water inherited from the geologic past, which cannot be replaced by the present sparse rainfall.

Sometimes there are statements made that beneath the desert sands, there is a huge underground lake. The "lake," of course, is simply sandstone, gravel deposit, or a porous rock saturated with water. Almost always, the groundwater in the deserts took hundreds if not thousands of years to accumulate. It also may be moderately to highly mineralized. Withdrawing this water at a rate needed to sustain substantial agriculture over any long period of time is probably not possible. It is an interim illusionary solution at best.

In the United States, the early settlers occupied a land where there had been no withdrawal of water except from the surface springs, and seepage into streams. Withdrawal and recharge of groundwater were in natural balance. But the groundwater heritage from ages past is now being used in quantities that clearly cannot be sustained. In other parts of the world, growing populations also are drawing more and more heavily on ground-water supplies. The efficient management of these resources as a continually renewable resource is vital. Unfortunately, this is not being done in many areas. Irreparable damage has already been done to some aquifers as they collapse.

Groundwater problems are usually not large enough in scale to affect a nation as a whole. Although India and China may prove to be exceptions. In smaller countries and those in more arid regions, as, for example, in Israel and parts of Africa, the effect of reduced or destroyed groundwater supplies can be significant. Nevertheless, even in larger countries such as the United States where the Great Plains, and the highly productive San Joaquin Valley of California are affected, the long-term adverse results of mining groundwater are likely to be substantial and important on a national scale. This is already a national problem for Israel, further increasing the tensions in that unstable region.

Groundwater in Summary

Like oil or minerals, groundwater often can be a one-crop resource. If the rate of recharge to replace the water withdrawn takes years or even centuries, for all practical purposes, that groundwater is a crop that can be harvested only once. If excessive groundwater withdrawal results in the collapse of the aquifer and land subsidence, then a lesser amount of the groundwater obtainable from that aquifer will become a permanent situation. If a region is developed on the basis of overdrawing the groundwater, this can continue for a time, but ultimately the development must stop and then contract, unless other water supplies are brought in. Parts of Arizona are vulnerable in this regard. Groundwater is an exceedingly valuable resource and every effort should be made to keep it free of pollutants. If it is a renewable groundwater situation, it should be managed on a sustained yield basis. Some areas are now using groundwater on that basis but, unfortunately, other places are not, creating seeds for future social and economic problems. Communities can be and have been abandoned because of misuse of groundwater. The problem should not be allowed to spread but, unfortunately, it continues to do so.

Surface Water

Throughout history, the distribution of surface water, springs, streams, rivers, and lakes has largely determined where people lived. The Nile Valley, often called the cradle of civilization, is a classic example. That thin ribbon of blue that traverses the desert has been and continues to be the lifeline for all Egypt. The Tigris and Euphrates rivers of the Middle East similarly nourished civilizations. The Columbia River system of the Pacific Northwest, with its great salmon runs, provided the chief food supply for many Native Americans, and now provides irrigation water for the arid parts of Oregon and Washington east of the Cascade Mountains.

Rivers also have provided the initial access to many areas and transport and travel routes. Lewis and Clark traveled up the Missouri River, crossed the Continental Divide in the Rockies, and then floated down the Columbia. Until recently, when a few roads have been cut through the jungle, the Amazon River was the only pathway of consequence through the heart of Brazil. It remains a main artery by which ocean-going vessels can travel 2,000 miles through the interior of Brazil all the way to Iquitos in northeastern Peru.

Surface freshwater is a renewable resource in most places, but it has limitations. One is that it is not an infinite resource. At any given time, it is in fixed supply, but supply fluctuates with the weather from year to year. It can be used faster than it can be renewed, like groundwater, and often is. Both surface and groundwater are far from being evenly distributed over the Earth.

Some Details of Surface Water Distribution and Use

Groundwater can supply small to medium sized populations, but the answer to any major water supply need is surface water. This is illustrated by the fact that nearly all larger cities are located on or near large surface water supplies like rivers. Examples are London and the Thames; Paris and the Seine; Vienna and the Danube; the Rhine with its many cities including Bonn; New York and the Hudson; Minneapolis/St. Paul, St. Louis, New Orleans all on the Mississippi; and Montreal and Quebec City on the St. Lawrence.

Some cities draw from a network of smaller streams. Denver, Salt Lake City, and Seattle all obtain water from a number of streams in adjacent mountain areas. Some cities are located on major freshwater lakes like Chicago on Lake Michigan, Detroit on Lake Huron, and Irkutsk in Siberia on Lake Baikal.

Diversion of Water

Civilizations and cities have grown up without oil, but all must have water. The growth in water demand in cities has been phenomenal, caused by the huge migration of populations from rural to urban areas as the world has changed from a predominantly agricultural economy to an agricultural/industrial economy. A few cities are not on major bodies of freshwater. In the United States, these include Phoenix, Tucson, Salt Lake City, and most notably, Los Angeles and all its satellite communities. These essentially desert cities, first located on small streams that provided a small water supply, quickly outgrew these limited supplies and now must draw water from distance sources. Obtaining sufficient water is now a continuing problem, both to these cities, and to the areas from which the water is taken. The water demands of the Los Angeles area have reached hundreds of miles into rural regions.

In the Los Angeles area, residents used 26 million gallons of water a day in 1900. Now, they use much more than that in one hour. On the east side of the Sierra Nevada in the Owens Valley, numerous signs posted on small streams say that the water belongs to the Los Angeles water system. Many of these streams now do not reach the valley floor, but are fully diverted. The same situation exists in the Mono Lake basin, which gradually is drying up because the streams that replenish it have been tapped and taken 350 miles away to Los Angeles.

Los Angeles has altered the natural environment hundreds of miles away in areas east of the Sierra Nevada, particularly in the Mono Lake and Owens Valley areas (Reisner, 1993). Mono Lake is an ecologically unique, biologically productive saline lake without an outlet. In addition to its eerie appearance in an arid landscape, it is noted for the brine shrimp that thrive in its salty waters, fed upon by millions of migratory birds. In order to sate the thirst of its ever-growing population, in 1941, the City of Los Angeles began diverting waters from the lake's tributary streams (Mono Lake Committee, 2012). By the early 1990s, the lake surface had dropped more than 40 feet from its pre-diversion level and Mono Lake had lost more than 30 percent of its surface area. In the 1990s, an agreement was reached to reduce the Los Angeles take of the Mono Lake drainage water, so that the lake level can be partially restored, a process that continues to this day.

To the south, Owens Lake once covered an area of more than 100 square miles until the Owens River, which fed it, was diverted into the Los Angeles Aqueduct in the 1920s. Now the lake bed is a mostly dry salt flat; occasional winds whip up alkali dust storms which impair air quality and make breathing hazardous for Owens Valley residents (Reheis, 2006). Under a settlement to reduce these adverse effects on air quality and human health, the lake bed is now kept partially flooded. An added benefit is that waterfowl and shorebirds have begun to return (Owens Valley Committee, 2008).

Aral Sea

This is perhaps the most spectacular example of the results of water diversion. Almost 100 percent of the Syr Darya and Amu Darya rivers in the former Soviet Union have been diverted to grow crops, chiefly cotton, which requires a great deal of water. As a result, the Aral Sea, formerly fed by these rivers, lost 40 percent of its surface area between 1926 and 1990. Its volume fell by 65 percent, the salinity more than tripled, and all 24 species of native fish died. The Aral Sea once had an important fishing industry which produced 44,000 tons of fish annually, supporting 60,000 jobs. Now that is all gone (Postel, 1995). More recently, however, efforts are being made to restore the sea.

Dams

Reservoirs made by dams provide much of the water needed for irrigation. China's agriculture is heavily dependent on irrigation. China has the most dams with about 22,000. The United States has 6,575 large dams; India, 4,291; Japan, 2,657; Spain, 1,196; and Canada, 793 (Gleick, 2003). Whereas dams save water for later use, they are wasteful because they lose a lot of water due to evaporation, especially in drier, warmer climates. They also have significant environmental impacts.

Irrigation water

Land that does not get sufficient rainfall must import water, either from the ground beneath or from distant surface sources to irrigate fields. Irrigation projects use very large volumes of water, and have an environmental impact on the place from which the water is drawn. The water may be taken from an adjacent stream or lake, another drainage basin, or it may be taken from the ground beneath the irrigated fields.

Importance of Irrigation — and Its Problems

With these factors in mind, how important is irrigation water? The fact is, it is very important. Worldwide, irrigation is by far the largest consumer of water, currently accounting for 70 percent of all water withdrawals. Irrigated land around the world increased from 40 million hectares in 1900 to more than 274 million hectares in 1999, and is still expanding. India, China, the United States, and Pakistan in that order account for slightly over half the world's irrigated lands (Postel, 1999; Gleick, 2003).

Seventeen percent of the world's cropland is irrigated, but, because it is managed more carefully than other land, it produces about 40 percent of the world's crops. Half of China's cropland is irrigated, and nearly all of Egypt's cropland is irrigated. Accordingly, being able to move water from one site to another for irrigation will continue to be important for the future of many nations. But moving water for irrigation from one place to another, or drawing it out of a river upstream from another region or country can cause conflict, and water is likely to be an increasing source of conflict as populations in arid and semiarid regions continue to increase against a finite water supply (Klare, 2001).

Egypt is entirely dependent on water from the Nile River, almost all of which (97 percent) originates in other nations. Egypt has signed a water agreement with Sudan regarding the Nile, but the seven other upstream nations with expanding populations in the Nile basin have not signed.

The Klamath Basin problem — conflicts among endangered species, Native American treaty rights, and farmers

In a minor but exemplary way, recent problems regarding the multiple demands for water in the Klamath Basin of southern Oregon are instructive when conflicting legal demands exceed water supply. This is an example of why you cannot do just one thing in nature.

The Klamath Basin lies in a semi-arid region of sage brush and juniper. But, enough water flows in seasonally to maintain a marsh and two shallow lakes, remnants of what was a much larger body of water during more moist glacial times. The U.S. Bureau of Reclamation encouraged farmers to move into the basin and allocated water for irrigation. The basin is the headwaters of the Klamath River, which flows southwest through northern California to the Pacific Ocean. The river has the third-largest salmon run on the Pacific Coast and American Indians of the region, under treaty rights, were assured enough water in the river to keep the salmon run healthy. Designated by the Environmental Protection Agency as an endangered species, the Klamath River sucker fish inhabits the shallow Upper Klamath Lake. In 2000, a drought began in the region, and protecting the fish had priority. The irrigation water was substantially reduced and farmers suffered accordingly. The flow of the river also was reduced to save water in Upper Klamath Lake for the sucker fish. As a result of disease induced by low water and crowding in the Klamath River, about 30,000 salmon died, nearly wiping out one year's entire run. Both the farmers and the American Indians were outraged. To alleviate the situation, the government loaned money to the farmers to drill a large number of wells in the basin. But these new wells caused the water table to drop to the point that other wells, including long-established domestic wells for rural residents, went dry.

The problem is not yet entirely resolved. Neither economists who claim that by raising the price of a resource, more of the commodity will appear, nor even the Congress of the United States by passing a law, can increase the amount of water that nature brings to the Klamath Basin. The Earth's natural systems run the show.

The Klamath River Basin is simply a case of too many demands — by farmers, American Indians, salmon, and the endangered sucker fish — on a finite water supply. This scenario will occur increasingly in this century as human and biological demands exceed the carrying capacity of the Earth's environment and resources. There are limits (Hardin, 1993).

With no additional freshwater supplies to tap and the continuing growth in human population, the per capita amount of water available continues to drop. Supplies differ widely from region to region. Canada currently enjoys the greatest amount of freshwater per capita, while several countries in Africa already have critical shortages. A human can survive the absence of food much longer than the absence of water.

Importing Water

Hebei Province in northern China is a prime grain-growing region. But it depends largely on irrigated agriculture from groundwater, and its aquifers are running dry. In 1993, the area had more than 1,000 lakes. But by 2004, it had only 83 because its groundwater was drawn down. In this and other Chinese provinces with declining water supplies, especially groundwater, grain production is declining. Peak Chinese grain production was 392 million tons in 1998, but by 2004, it had fallen to 350 million tons. It is estimated that in twenty years, China will need to import 175 million tons of grain, which is more than current total world grain trade (Fulford, 2003). Because 1,000 tons of water is required to produce a ton of grain, in effect, China will be importing a huge amount of water. The main grain crop in the United States is corn, some of which is grown by irrigation. It takes 3,600 gallons of water to produce a bushel of corn, so each bushel of irrigated corn sent abroad is exporting 3,600 gallons of United States irrigation water, and our groundwater reservoirs are generally declining. It also takes energy to pump the groundwater, so along with the water goes energy resources. So, in buying grain from the United States, China is effectively buying both water and energy.

Irrigation water: long-term effects

Water reaching farmland as rain contains no dissolved minerals, but both surface water and groundwater do. Over the long term, the use of surface water and groundwater for irrigation will result in the accumulation of salts. If these salts cannot be flushed out, the soil will eventually become too salty to be productive. Currently, just in the state of California, 500 million dollars is lost every year in the form of fields that must be abandoned due to excess salt.

Water for Power and Industry

Running water through turbines is an important source of energy, particularly in countries with limited fossil fuel resources. This applies to much of Africa, a region that has a very large hydropower potential. However, development of this energy source must be weighed against environmental impacts, and the fact that dams have a limited lifespan.

Water for energy production

Water is not only directly involved in producing hydroelectricity, but it is also important in producing almost all other sources of energy. Water is used for mining coal and uranium. It is used for water and steam flooding oilfields to obtain the maximum amount of oil from the oil reservoir. Water is used in the cooling towers of electric generating plants using coal, natural gas, oil, or the atom as fuel. Water is also needed for manufacturing solar cells.

Synthetic fuels: shale oil, oil sands, and water

The state of Colorado has the world's largest and richest oil shale deposits. It also has the unique distinction of being the only state in the Union that has no streams flowing into it except for a short 30-mile loop the Green River makes into its extreme northwestern corner. Water supplies, therefore, are exceedingly critical. The very slender Colorado River carries only five cubic miles of water a year. The Amazon River, by comparison, flows four cubic miles a day. Development of the large oil shale deposits on the western slope of Colorado, if some process could ever make them profitable to recover, would require large amounts of water. The Colorado River would have to be beheaded. There are already more water claims on the river than there is water to supply them. Water used for shale oil production would be water that could not power hydroelectric dams, which would be an energy cost that would have to be subtracted from whatever energy recovery the oil from oil shale might offer. Irrigation systems and municipal water supplies downstream on the Colorado in Nevada, Arizona and Southern California would be adversely affected. Immediate conflicts would arise. The absence of an adequate water supply may keep the oil shale of western Colorado from ever becoming a major fossil fuel source.

At the Athabasca oil sands operations in northern Alberta, about eight tons of water are required for every ton of final oil product. This does not include the water needed to supply the demands of the residential and commercial communities that provide support facilities for the oil sands operations. At present, there is barely enough water to support the operations. So water may be the limiting factor for any expansion.

Water in all industry

Water is a vital resource in all industry. The average automobile, in various ways the materials are processed, accounts for approximately 100,000 gallons of water. Paper making, textiles, oil refining, petrochemical manufacturing, food processing, concrete buildings, roads, and electronic industries all require vast amounts of water. A modest computer chip factory will use two- to three-million gallons of water a day. Water is the true life fluid of industrial civilization, as well as for all humanity.

Water and Conflict

Conflict over water is recorded as far back as 4500 B.C. when two cities, Lagash and Umma in Mesopotamia (now largely Iraq), were in dispute over river water supplies. Water has potential for causing an increasing number of small disputes and major international conflicts. Some conflicts already are occurring. Gleick (1993) writes, "Today, the realization that renewable freshwater availability is finite, while population growth will continuously increase water demand, is starting to cause serious concern among developing nations." Even within the relatively well-watered United States, conflicts have arisen. At one time, Arizona actually called out the National Guard in a dispute with California over water.

Water crossing borders

Both surface water and groundwater migrate. Because of this, a single water source may involve many people, many communities, and, in some cases, several countries. Worldwide, 47 percent of the land is involved in international water systems. There are 214 multinational drainage basins. This means 40 percent of world population lives and depends on water from international drainages. As populations grow, the potential for international conflict over limited water supplies increases. The Indiana Center on Global Change and World Peace predicts that over the next half century, water will replace oil as the prime trigger for international conflict.

Cities versus rural

Half the world's population now lives in cities. In only a 30-year period from 1950 to 1980, cities such as Bogota, San Paulo, and Managua tripled in size. Over this same time period, the move to cities in Africa was even more dramatic. Nairobi, Dar es Salaam, and Lagos have increased in population more than sevenfold (Gleick, 1993). When the demand for water in urban areas increases, agricultural areas face competition for water supplies. But without the agricultural areas, the cities could not survive. In California, the problem is growing more acute, but the cities have the votes to determine where water will be used. So, the rural areas are losing. Cities are destroying their own life base, but cities keep growing, causing increasing conflict over water.

In 2002, six of the seven states that have an agreement to share Colorado River water, decreed that California would have to reduce its demands to its agreed share, as it had been allowed to draw more water from the Colorado River than it was allocated. This would have seriously reduced the water supply to the southern California cities. To alleviate this problem, the cities purchased water rights that Imperial Valley farmers had on the Colorado River.

Some Current International Water Problems

Israeli-Palestinian groundwater problem

Along with the political problems of the West Bank in Israel, is the fact that the hills there provide the water recharge for Israel's underground aquifers. The rainwater that soaks into the hills of the West Bank area moves south down beneath the land occupied by most of the people in the central region of Israel. This amounts to about one-third of the total water supply for that country. Increased Arab settlements in the West Bank with their corresponding larger demand on both the surface and underground waters of the area are causing water supply problems to the south in Israel, and will continue to do so (Klare, 2001).

The seizure of the West Bank by Israel in the war of 1967 originated in 1964, when Arab states, Syria in particular, announced plans to divert Jordan River water for their own use. Israel made several military strikes against the project. Animosities intensified and contributed to the outbreak of the 1967 war when Israel seized the West Bank and the Golan Heights. At the time, an Israeli official said that Israel was so dependent on the water that it could never return control to the Palestinians. One of the first actions Israel took was to declare the water resources of the West Bank under military control (Gleick, 1993). But, in 1994, Israel did nominally return the West Bank to the Palestinians. While Israel held the West Bank, its wells were strictly controlled. The Palestinians complained that Israel drilled deep wells that dried up the shallower Palestinian wells. At that time on the West Bank, all the Israeli settlements had running water, but more than half the Palestinian settlements did not. Now, the Palestinians have control of the West Bank, and both its surface and groundwater remain major issues.

Water conflicts will grow as both Palestinian and Israeli populations continue to increase using a finite water supply that cannot be expanded. Israel also competes with adjacent Jordan for water. Jordan's chief negotiator on water rights, Munther Haddadin, said, "…it's a zero-sum game. What is taken by Israel is taken away from other people. And what is taken by other people is taken from Israel."

This is certain to cause more trouble. Recent statements by Israeli Water Commissioner Tzemach Vishai that, "we want…Israel to control the water supply," and by Israeli Defense Force Colonel Raanan Gissin that, "we are always ready to do battle over water," suggest the difficulties lie ahead.

Euphrates River: Turkey, Syria, and Iraq

This river originates in the mountains of southern Turkey and flows through the very water-short countries of Syria and Iraq to the Persian Gulf. The river is important for hydroelectric power, drinking water, irrigation, and industrial use. In 1974, Iraq massed troops and threatened to bomb the Ath Thawra Dam in Syria, claiming the dam had reduced the water flow to Iraq.

Currently, Turkey is building a huge water project on the Euphrates, which concerns Syria and Iraq. It ultimately will consist of 22 dams to be used to irrigate 1.5 million hectares, and will also produce electric power. The huge Atatürk Dam is already in place, and water from its reservoir will flow through the world's two largest irrigation tunnels 25 feet in diameter to irrigate the Harran Plain 40 miles distant (Postel, 1995). But this diversion will reduce the flow of water into Syria by an estimated 40 percent, and to Iraq by as much as 90 percent (Gleick, 1993).

Water Wars

It has been said that the ultimate battle in the Middle East will not be fought over oil because oil will long since be gone. It will be fought over water. Postel (1992) identifies nine out of the 14 countries in the Middle East that already experience water-scarce conditions. It is likely before the "ultimate battle," that local wars will be fought over this vital resource. The former General Secretary of the United Nations, Boutros Boutros-Ghali, an Egyptian, predicted, "the next war in our region will be over the waters of the Nile, not politics." Jordan's King Hussein said that water is such a vital issue that it could "drive nations of the region to war." With many other areas beginning to exceed their resources, water wars may not be confined to the Middle East.

One region likely to see future water conflicts is the Nile River Basin. Klare (2001) in his book on resource wars, wrote that along with Egypt, " …other states are also facing very high levels of population growth, and so will need to increase their own withdrawals from the Nile. Indeed, population growth in this area is advancing by some of the highest rates found anywhere in the world…. These extraordinary numbers suggest that competition for Nile River water can only grow more intense as the new century proceeds."

India, Pakistan, and China are currently in a dispute about the distribution of water from three rivers that affect their water supplies. Growing populations in all three coun-tries seem certain to intensify the dispute in the future.

This emphasizes the fact that population and population growth remain the number one problem of the world this century. Regardless of what resources, food, water, soil, or energy supplies, the overriding consideration for the future is demand and demand = population. It is as simple as that. As world population continues to grow, the estimated global freshwater demand by 2030 is projected to be 6,900 cubic kilometers; the current reliable supply is 4,200 cubic kilometers.

Rivers are a huge and important natural resource. In his classic volume, *The Nile and Egypt*, Emil Ludwig wrote: "The Nile is Egypt and Egypt is the Nile." How important is the Nile to Egypt? Ninety-nine percent of Egypt's population lives on the three percent of land bordering the Nile.

Oil, natural gas, and coal will eventually become insignificant in world economies and societies, but water and soil will remain vital to human survival. Therein lie the seeds of almost certain future conflicts.

Desalinization — freshwater from the sea

Middle East countries (Gulf region) with ample energy and very limited freshwater supplies have obtained most of their freshwater by desalination for years, as have some islands in the Caribbean. Only a few such plants exist in the United States. The largest is at Tampa, Florida. But many more are planned as more and more people live in coastal areas where groundwater and other freshwater supplies are limited. Some 20 desalination plants have been proposed in California, and others are being considered in Texas and Georgia. There are about 1,700 desalination plants in the Middle East, converting 5.5 billion gallons of seawater a day to freshwater. Worldwide capacity is about 7.6 billion gallons a day (Fischetti, 2007).

Saudi Arabia has the world's largest number of desalination plants, 33, which produce 30 percent of all the desalted water in the world. However, economic viability of desalina-tion in any region is directly related to the regional cost of energy. At present, desalinized water costs between $1 and $8 per cubic meter, compared to between $0.01 and $0.05 per cubic meter for conventional water supplies paid by western U.S. farms, and $0.30 charged to users in U.S. cities (Gleick, 1993).

There are several processes through which saltwater is converted to freshwater. The two principal methods are Multi-Stage Flash distillation (MSF) and Reverse Osmosis (RO). The MSF process introduces hot saltwater into a chamber at such a reduced pressure that part of it flashes into vapor, which is then condensed as freshwater. The remainder of the saltwater, now slightly cooler, then passes to a second chamber at a lower pressure so that more is evaporated. This process is repeated in a number of stages, usually 20 to 30, until the saltwater is cool. This is an energy intensive procedure widely used in the arid Middle East, where the chief fuel used, natural gas, is abundant.

Multistage flash and reverse osmosis are the technologies used in 88 percent of current plants. Waste steam heat from fossil fuel power plants provides energy for multistage technology.

In other areas, the RO process is more common. This process uses no heat, but depends on the ability of semi-permeable membranes under certain pressure conditions to let water molecules through, but to restrict the passage of salt molecules. The energy cost in the RO process stems from creating and maintaining the pressures required to make the process work.

Over the world, desalination plants supply just one-thousandth of total water use. Desalination can produce enough water for households, but whether it can be a major factor in world water supply is in question. With regard to total freshwater supplies, the amount obtained by desalination will remain negligible. As petroleum resources diminish in the Persian Gulf region, the MSF desalination process eventually may not be feasible, and surface water supplies will be inadequate for the projected population. What then?

To some extent, the same problem faces California, which now has 11 desalination plants with 23 more planned. They use the reverse osmosis process, which is energy intensive. California already has energy supply problems, and energy is likely to continue to be increasingly expensive (as it will be worldwide). Therefore, the economic feasibility of the planned plants is questionable. All these problems could be avoided if the population was the size that could be accommodated by the existing renewable surface water supplies. At some time, this has to happen.

In the meantime, to alleviate the immediate water problem, both Los Angeles and San Diego are treating wastewater back to potable standards. Thus, it is "toilet to tap." To demonstrate the water's safety, the mayor of Los Angeles made a public demonstration by drinking some. This was only moderately assuring to some people who continue to buy bottled water.

Water and Health

The one specific material required by the human digestive system is water. Water is also the medium that most easily transmits a variety of serious, even fatal, diseases such as typhoid fever, amoebic dysentery, and cholera. In many parts of the world, safe drinking water is not consistently available. It may be contaminated by disease-causing organisms, and it may also be contaminated by inorganic materials. In the years 1991 and 1992, 700,000 cases of cholera transmitted by contaminated water were recorded in the Caribbean region, causing 6,400 deaths. In India, hundreds of thousands of children die each year of diarrhea caused by polluted water. Africa has a similar problem.

It is estimated that in developing nations, 90 percent of infectious diseases are caused by polluted water. Surprisingly, unpolluted water is still not available in places where one would think otherwise. In first class hotels in China when I visited them last, each room was provided with a pitcher of water along with a small container and a little oil-burning stove with which to boil the water. What must the situation be in the countryside? I have the good taste not to detail my unfortunate experiences with water during my work and travels in South America.

The future of any nation depends on the health of its people and the most fundamental necessity for health is safe drinking water. In this regard, the industrial nations that supply consistently clean water to their citizens have a great advantage over countries that do not have safe water supplies. It takes energy to purify and distribute safe water, and that is probably the most important single use of energy.

Water and the Future

After oil and other mineral resources have been depleted, water and soil, essential to all life, will remain to be managed and used. Water, for the most part, is a renewable resource but its rate of renewal differs greatly from place to place. In the case of groundwater, some is so deep and is replenished so slowly that for all practical purposes, it is nonrenewable. In some regions, groundwater supplies now are recognized as nonrenewable resources with the recommendation that they be mined just like other nonrenewable resources, such as coal and metals. To build an economy on that resource must be recognized as temporary. Unfortunately, the use of such nonrenewable water for food production creates a false sense of security, and populations that depend on that resource ultimately must make severe adjustments for which they may not be prepared. Groundwater is being used faster than it is being replenished in parts of China, Russia, India, Mexico, in all countries in the Middle East, in many countries in Africa, and in the United States. China faces an especially severe problem. With its people accounting for 22 percent of the world's population, China has only eight percent of the world's renewable freshwater (Postel, 1992).

Lester Brown notes that irrigated lands are a mainstay of China's food supply, "With 49 million hectares, China has more irrigated land than any other country. This compares with some 46 million hectares in India and 20 million in the United States…. Far more important to China than to those other nations, irrigation covers roughly half of the total cropland area and accounts for nearly four fifths of the all-important grain harvest… water scarcity is one of the more difficult issues facing the government of China."

The preservation of water supplies, and maintaining their quality, together with the stewardship of soil will have more to do with the destinies of nations than will all other activities related to the Earth. Nations that have abundant water supplies will have a much more stable future than those who do not. Those nations include Canada, Russia, most European countries, and the United States.

The Colorado River — a case study

Although most of the United States is one of the better watered countries, the U.S. Southwest is not so fortunate. Much of it is desert, and it has only one main river, the Colorado. The river grows U.S. and Mexican crops, generates electricity, and delivers water to some of the nation's driest and hottest cities, including Phoenix and Las Vegas.

In 1922, the seven states affected by the Colorado River drew up a compact agreeing how its water should be shared. The regional population was still small and the river flow seemed ample for the future. But a recent study of tree rings provided an unsettling discovery. The study indicates that the past two-hundred years in the Southwest have been abnormally moist, and we are now beginning to enter a more normal, drier period. The great growth of population in the Southwest has been encouraged by an illusion of greater water supply and the flow of the Colorado River as measured early in the last century on which water allotments were based. Recent studies show that when the Colorado River was divided up among seven states in 1922, it was flowing at its highest level in 500 years.

When the Colorado River was divided among the states, the region was largely agricultural. Dramatic population growth has shifted the demand to cities, especially in three urban areas, Denver, Las Vegas, and Phoenix. Denver, on the east side of the continental divide, has been diverting some of the west-flowing headwaters of the Colorado eastward by tunnels through the mountains. The Denver metro area population was 334,465 in 1920. In 2003, it was 2,526,525,and it is projected to be 3,282,000 in 2020. Clearly, the solution is to have a population size that the limited waters of the Colorado can sustain.

Unwilling to face the basic problem, but instead to continue to encourage "growth" of population in the Southwest, several proposals for increasing water supply have been suggested. One is to build a 280 mile-long pipeline to bring water from northern Nevada to Las Vegas. This idea is not very popular in northern Nevada. Dean Baker, whose ranch straddles the Utah-Nevada border, says: "Southern Nevada thinks it can come up here and suck all these springs dry without any problems." He points out that springs have already run dry from farmers' wells in that region. Baker adds, "We have done this ourselves. Now imagine what pumping for a whole city is going to do." Having done a Ph.D. thesis project based on Nevada geology, and from working on various projects in Nevada as a geologist, my observation is that Baker is right. I don't believe northern Nevada has any water to spare for Las Vegas.

In addition, several dams including the huge Glen Canyon and Hoover dams provide large amounts of hydroelectric power for the region. Every increase in population means less water passing through the turbines turning the generators of the powerhouses. The minimum water level of Lake Mead behind Hoover Dam needed to generate power is 1,083 feet above sea level. In 2004, the lake level fell to 1,127, leaving a scant margin of 44 feet. For Lake Powell behind Glen Canyon Dam, the level in 2004 was just 95 feet above the point where power generation is lost.

The Colorado River provides two vital resources, power and water, and population growth is continuing to erode the river's ability to provide these basic needs. Yet there is no urgent move to stabilize the region's population. It is shortsighted, which Hardin (1999) says in his book, *The Ostrich Factor: Our Population Myopia*. "We bury our heads in the Southwest desert sands, and ignore the basic problem. But problems do not disappear because they are ignored. They only grow. The saga of Colorado River waters will provide interesting reading as the Southwest continues its population growth." In a shortage emergency, Arizona would be the first to suffer.

The scramble for Colorado River water is simply one more example of the problems caused by continued population growth. This 1,400-mile slim blue thread is the lifeline of more than 20 million people, a number growing every day in the seven affected states and Mexico. But the volume of water in the river does not increase, and no amount of technology can increase the natural flow. This is another illustration of the control Earth resources exerts over nations and individuals and of the inevitable necessity of living within natural limits (Hardin, 1993).

Population Versus Water

The trend is ominous. Brown et al. (1999) write: "Whenever population is growing, the supply of freshwater is declining. As a result of population growth, the amount of water available per person from the hydrological cycle will fall by 73 percent between 1950 and 2050. Stated otherwise, there will be scarcely one fourth as much freshwater per person in 2050 as there was in 1950."

Brown, an agriculturist first, is concerned with population and with the water supply on which agriculture depends. He writes (2008):

> With the vast majority of the 3 billion people to be added to the world by 2050 coming in countries where water tables are already falling, water refugees are likely to become commonplace. They will be most common in arid and semi-arid regions where populations are outgrowing the water supply, and sinking into hydrologic poverty. Villages in northwestern India are being abandoned as aquifers are depleted…. Millions of villagers in northern and western China and parts of Mexico may have to move because of lack of water.

Surface water, and to a considerable extent, groundwater supplies are renewable, but at any given time there is only so much available. So renewables also have limitations. Grant (2000) asks:

> Can we even imagine how much less intense life would be, and how much less deadly droughts would be, if particularly in arid areas, there were one-third the population and, therefore, three times as much water per capita as now, coupled with modern capabilities to manage it?

Any population growth, slow or otherwise, continues to make the problem worse.

"Shortage" vs. "longage"

Regarding the use of the term "shortage," Hardin (1991) observed: "If a community requires 100 units of energy to live for a year (at a specific standard of living) but is able to secure only 99, it is automatically said that 'there is a shortage of energy.' Instead of speaking of a shortage of supply, we could just as truly say that there is a longage of demand." As we seek practical solutions to problems, why do we never use the word "longage?" Rising populations in the Middle East are facing a longage of demand on their water supplies. In an increasing number of countries, the "longage of demand" on water supply is now reaching a critical point. Based on data from NASA and the World Health Organization, severe water shortages affect more than 400 million people today and will affect four billion people by 2050 (Vergano, 2003).

In the future, we will experience more "shortages" of various resources. The problem can also be described as a "longage" of demand caused by population growth. That word and concept would be worthwhile to introduce into our daily conversations, and provide a needed perspective on the future.

Priorities

Even as populations grow, increasing the demand for more clean water, overpopulated countries such as India, Pakistan, and Ethiopia continue to spend 10 to 15 times as much on military hardware as they spend on water and sanitation. It is difficult to understand how military expenses can so greatly exceed expenditures for the most basic human needs.

This is a worldwide problem of government priorities. Around the world, more than a billion people lack access to safe drinking water, and 2.5 billion lack access to adequate sanitation. Sewage treatment and wastewater disposal require large amounts of water, so sanitation and water supplies are intertwined problems. Water would be a far better long-term investment than preparing for war.

Chapter 14

Soil — The Most Valuable Mineral Complex

To walk across a field or through the woods is to walk on a complex of minerals to which we owe our very existence. Without the mineral complex called soil, no useful crops could exist. Soil, water, and air are the three elements absolutely essential to human survival. Oil, natural gas, coal, metals, and nonmetals are secondary. "Currently, more than 99.7 percent of our food comes from soil, while less than 0.3 percent comes from the oceans and other aquatic ecosystems. This 0.3 percent is decreasing as the population grows, along with overfishing and pollution" (Pimentel, letter June 10, 2008).

"Dirt"

Soil is much more than mere dirt beneath our feet. It holds the nutrients that produce our food. A shovelful of dirt can be home to more creatures, including earthworms, insects, and microbes, than there are humans on the Earth. It is that soil is so alive that makes it fertile and productive. Civilizations have fallen because their agricultural practices degraded the soil, which much of the world is still doing. More carbon is stored in soil than in all the plants on Earth.

In an outstanding and comprehensive study of soil, *Dirt: The Erosion of Civilizations*, Montgomery (2007) details the vital role of soil in civilization. Balancing other factors in the demise of civilizations, he makes a number of observations on the role of soil in civilization's survival, and how current agricultural practices are not sustainable. Around the world, an estimated 24-billion tons of soil are lost annually, the equivalent of several tons per person. Soil loss is ten times or more the rate that it is being replaced by nature. Montgomery makes the critical observation that "despite such global losses, soil erodes slowly enough to go largely unnoticed in anyone's lifetime." History recounts numerous civilizations that destroyed their soil and thus destroyed themselves. "With just a couple of feet of soil standing between prosperity and desolation, civilizations that plow through their soil vanish." In the United States, despite the efforts of the Soil Conservation Service, soil loss exceeds the rate of formation by several times.

> Modern society fosters the notion that technology will provide solutions to just about any problem. But…technology cannot solve the problem of consuming a resource faster than we generate it; someday we will run out of it…. Civilizations don't disappear overnight. More often they falter and then decline as their soil disappears over generations…. Despite the capacity of modern farms to feed enormous numbers of people, a certain amount of fertile dirt must still support each person. This blunt fact makes soil conservation central to the longevity of any civilization.
>
> While the world's population keeps growing, the amount of productive farmland began declining in the 1970s and the supply of cheap fossil fuels used to make synthetic fertilizers will run out this century (Montgomery, 2007).

Oil supply currently has our attention and oil is what we think of as a strategic resource. Yet, soil is more important both now and in the longer time frame than oil. Still, do we think of soil as a strategic resource? Oil will fade from the scene and people will still survive, but if the amount of topsoil is reduced, all terrestrial life, plant and animal, will decline with it.

It has been said correctly that, civilization depends on the top six inches of the Earth's surface. The world over, soil averages less than one foot thick. "Soil is a fragile, finite resource. It plays unique roles in maintaining air quality, storing water and nutrients for plants, and filtering contaminants from surface waters" (Loynachan et al., 1999). Soil must be tended carefully for it can be lost or significantly degraded rapidly. Goudie (2000) writes:

> Humans live close to and depend on the soil. It is one of the thinnest and most vulnerable human resources, and upon which, both deliberately and inadvertently, humans have had a very major impact. Moreover, such an impact can occur with great rapidity in response to land-use change, new technology, or waves of colonization.

A nonrenewable critical inheritance

Soil, on a human timescale, is a nonrenewable resource. Over eons of time, the effects of water, temperature, and vegetation, even from its most primitive forms, gradually produced soil from the Earth's rocky surface. As this process continued, the result was a gradual build-up of soil that could support complex vegetation. These life forms combine sunlight, air, and water using the process of photosynthesis to create vegetation on which all animal life depends. With the arrival of humans and organized agriculture, especially the mechanized agriculture of the past century, the balance between natural soil production and soil loss has turned markedly negative.

> The world is now running a soil deficit, one that is measured in billions of tons per year and that is reducing the Earth's productivity. In some ways, the most fundamental ecological deficit the world faces is the loss of soil through wind and water erosion. Soil erosion is not only widespread, but it is not reversible in any meaningful human time frame (Brown et al., 2002).

Rates of soil loss have been measured in many parts of the world by various methods to understand the effects of human habitation and cultivation. In Colorado, Carrara and Carroll (1979) determined that the erosion rate over the past 100 years has been about 1.8 millimeters per year. This compares with the previous 300 years when rates were between 0.2 and 0.5 millimeters a year. Studies in China, New Guinea, and elsewhere also show marked increases in erosion rates due to human activity. A striking example occurred in New Zealand, where erosion rates were determined by filling an estuary with sediment. In pre-Polynesian times, rates of sedimentation were about 0.1 millimeter annually. During Polynesian times, the rates increased to 0.3 millimeter annually, and since the arrival of Europeans in New Zealand, with land clearance and widespread cultivation beginning in the 1880s, the rate has risen dramatically to 11 millimeters per year (Goudie, 2000).

Our industrial civilization is preoccupied with the matter of oil depletion and what energy sources might at least partially replace oil as it depletes. But civilization existed, cities were built, and people lived in places like the Mediterranean region in reasonable comfort without petroleum. But they could not have survived without fertile soil, nor can we. So our concern should be for the preservation of the vital six inches or so of the Earth's surface that will have to sustain civilizations indefinitely beyond the oil era. Oil is not the long-term crisis, soil is. We are losing this vital material, in some areas very rapidly, and in other places, it is already gone. Some earlier peoples did not safeguard soil well. For example, where wheat fields once flourished, the ancient Greeks allowed sheep and goats to overgraze. The resulting soil erosion has left only barren hillsides of limestone.

Soil and civilization

"Betraying ecological illiteracy, most people are unaware of their dependence on a thin sheet of topsoil," writes Eckholm (1982). He notes, "Soil destruction has contributed to the fall of past civilizations, yet this lesson of history is seldom acknowledged and usually unheeded. Today's cropland losses impair the wellbeing of the living as well as the generations to come. Yet in this matter as in others, societies seem incapable of acts of foresight."

Hillel (1991) describes a number of striking examples of the destruction wrought in ancient times by the poor management of soils. One example is Utica, a city 30 kilometers northwest of Carthage in North Africa. It was founded by the Phoenicians at the mouth of the Bagradas River. But because of excessive sedimentation due to poor agricultural practices, the remains of the city are now seven kilometers from the coast and under about 10 meters of silt.

Soil Degradation

Geologists use the term "erosion" to include the breaking up of rock material and its removal at the Earth's surface. But soil scientists generally use the term erosion to mean only the active transport of soil by various processes, and do not include the weathering and breaking down of rocks. It is used here with that meaning. The slow removal of soil by natural erosion processes is generally beneficial to the total ecological scene. Material is carried into lowland areas and water bodies, forming marshes and deltas, home for myriad life forms. Over extended periods of time, some of the sediment was carried into basins where buried vegetation eventually formed coal. In other geological settings (mainly marine basins marginal to continents) the sediments buried organic material, becoming part of the process of forming oil and natural gas.

The slow natural removal of soil commonly allows time for replacement soil to form, and a balance is maintained so there is no net loss of topsoil. The key word here is "slow."

When these processes are accelerated, problems begin. For the most part, this acceleration across the world's agricultural areas has been caused by human action.

Erosion from human activity

The weathering of rocks that breaks them down into small particles is a beneficial process. But if their subsequent removal is beyond the natural rate of erosion that nature replaces over time, the result is soil loss. The great enemy of soil and, therefore, civilization is civilization itself as we know it — the human-induced accelerated rate of erosion. On a global scale, McNeill and Winiwarter (2004) identify three waves of erosion. The first was when farming expanded out of river basins to adjacent foothills, putting slopes under cultivation, and converting some forests to farmland. This began in the second millennium B.C. and continued for 3,000 years. The second wave of erosion started in the sixteenth century and continued into the nineteenth century when the Eurasian steppe, the South American pampas, and the North American prairies were put under cultivation.

> The third wave of erosion began after 1945 when rapid population growth and other factors propelled a new frontier into the world's thinly populated tropic rain forests. Heavy rains and steep slopes in, for example, Rwanda and Guatemala, have lately brought about some of the highest recorded rates of soil erosion. At the same time, however, effective soil conservation has spread since the 1930s, especially in North America and Europe. Nevertheless, in global terms, the past 60 years have brought human-induced soil erosion and destruction of soil ecosystems to unprecedented levels (McNeill and Winiwarter, 2004).

Table 14-1 shows relative rates of soil erosion depending on the type of ground cover.

Note that the complete removal of 18 cm of soil in a virgin forest would take about half-a-million years, and soil formation, although not easy to measure, would surely proceed fast enough to replace the loss. But removal of the same amount of soil from bare ground takes only 18 years in the conditions studied. Such a rate cannot possibly be matched by natural soil-forming processes. Soil can be removed by running water, wind, or simply gravity in the form of soil creep, slump, or landslides, especially on steeper slopes. Even raindrops, as they splash on bare soil, move Earth particles slightly down slope. This factor of soil movement is greatly reduced if the ground is covered by vegetation. But if the soil is bare, for example, after plowing, erosion can be quite rapid. At present, statistics are clear that the worldwide removal of topsoil exceeds its formation (Brown and Wolf, 1985).

Table 14-1. Calculated Time Required to Remove 18 Centimeters of Topsoil from an Erodible Soil in the Southern Appalachians Region. Slope: 10 percent

Type of Ground Cover	Years to Complete Erosion of Soil
Virgin forest	575,000
Grass	82,150
Rotation cropping	110
Cotton	46
Bare ground	18

Source: Hardin, 1966

As populations grow and flat valley land is mostly occupied, agriculture pushes into more marginal lands, the adjacent steeper slopes, and mountain regions. Here the potential for soil loss is greatly increased. Brown (1978) says, "Once the natural cover is removed from unterraced mountainous land, the topsoil quickly washes into the valley below." Major world nations including India and Pakistan, the Andean countries of

South America, and those of Southeast Asia are affected like this. The net result is that as populations increase, the available agricultural land is decreasing. Brown (2006) reports, "Expanding world population has cut the grain land per person in half from 0.23 hectares in 1950 to 0.10 hectares in 2004…. This ongoing shrinkage of grain land per person makes it more difficult for the world's farmers to feed adequately the 70 million or more people added each year…. The shrinkage in cropland per person not only threatens livelihoods; in largely subsistence societies, it threatens survival itself. Tensions within communities begin to build as landholdings shrink to an area smaller than that needed for survival."

A subtle activity

Evidence of soil erosion can be dramatic in the form of landslides, slumps, and gullies on steep hillsides. But for the most part, it is a subtle insidious process. Brown and Wolf call it the "quiet crisis." Wilken (1995) calculated that six metric tons of soil removed from one hectare will reduce the level of topsoil by only one millimeter. Therefore, the loss of six tons is hardly detectable, but if continued long enough, it has a devastating effect. Soil degradation in its various forms is much like a cancer upon the Earth. It is not easy to detect in its early stages, but left untreated, it can ultimately be ruinous. Worldwide, it should be treated early, but this generally has not happened. In some regions of the world, however, efforts are being made toward long-term soil conservation and meeting with some success.

In 1972, the U.S. National Academy of Sciences concluded that: "Soil erosion is slowly nibbling us to death." In more rugged areas, the erosion is more obvious, and sometimes dramatic, where sudden mass soil movement is marked by great scars and gullies. In areas of low relief, soil erosion is a slower, but still significant process. In the United States, there have been massive losses of cropland in areas with only a modest slope. In a Virginia soybean field "sheet and rill" erosion caused soil losses of 80 to 100 tons per acre per year. Regardless of how the soil is removed, it is an unfortunate fact that the top thin zone of soil (usually less than six inches) contains the most nutrients and is what disappears first.

Related effects of erosion

In addition to the loss of soil, increased erosion has other negative effects. Reservoirs behind dams are silted in rapidly by excessive erosion of the soils in the drainage area. The Archicaya Dam in Colombia was three-quarters filled with sediment after only 10 years. Waterway navigation channels must be dredged due to the deposition of sediments, and fish spawning areas and coral reefs can be degraded or destroyed by sediment. Water storage facilities are lost. The total cost of such damage in the United States has been estimated to be about $4.1 billion a year. A dollar spent on soil and water conservation returns its investment many times over in saving reservoirs from siltation, saving rivers from dredging, saving fish spawning grounds, preventing flood damage to property, and reducing the need for building levees (Pimentel, 1993).

Six thousand years ago much of the Middle East was covered by a mixed oak forest. This was cut down to make way for growing wheat. When the soil was too depleted to grow wheat, sheep were turned onto the land, and when it could no longer support vegetation, the loose cover was washed away down to bedrock and is now barren. This is the history of many of the rocky slopes visible today.

The dust storms of the Great Plains and the Southwest United States in the 1930s degraded large agricultural areas. This led to the abandonment of farms and the mass exodus of people. The social impacts are recorded in literature such as John Steinbeck's classic *The Grapes of Wrath*. Fortunately, with careful soil management since that time, much of the region has been reclaimed, demonstrating that proper soil conservation practices can make a significant difference. But overall, the U.S. is losing the race to prevent soil loss. Pimentel et al. (1995) report:

> About 90 percent of U.S. cropland is losing soil above the sustainable rate. About 54 percent of U.S. pasture land (including federal lands) is overgrazed and subject to high rates of erosion …. One-half of the fertile topsoil of Iowa has been lost during the last 150 years of farming …. Similarly, about 40 percent of the rich Palouse soils of the northwest United States has been lost in the past century.

In other parts of the world, soil degradation continues at an alarming pace. The World Resources Institute (1994), in collaboration with the United Nations Environment Programme (UNEP) reports, "It is estimated that since World War II, 1.2 billion hectares, or about 10.5 percent of the world's vegetated land, has suffered at least moderate soil degradation as a result of human activity. This is a vast area, roughly the size of China and India combined." The report goes on to say that the greatest degradation is in Africa, which is the site of the largest expected percentage increase in population over the next several decades.

There are various causes and degrees of world land degradation, some of which can be reversed. Degraded land can be restored in some cases if proper measures are implemented.

Loss of grain production

The ominous result of worldwide soil erosion is that the capacity to grow food crops has been impaired to the point where it cannot keep up with population growth. Pimentel, et al. (1995) say, "Because of erosion-associated loss of productivity and population growth, the per capita food supply has been reduced over the past 10 years and continues to fall. The Food and Agriculture Organization of the United Nations (FAO) reports that the per capita production of grains, which make up 80 percent of the world food supply, has been declining since 1984." These authors further say:

> Not only is the availability of cropland per capita decreasing as the world population grows, but arable land is being lost due to excessive pressure on the environment. For instance, during the past 40 years, nearly one-third of the world's cropland (1.5 billion hectares) has been abandoned because of soil erosion and degradation. Most of the replacement land has come from marginal land made available by removing forests. Agriculture accounts for 80 percent of the annual world deforestation.

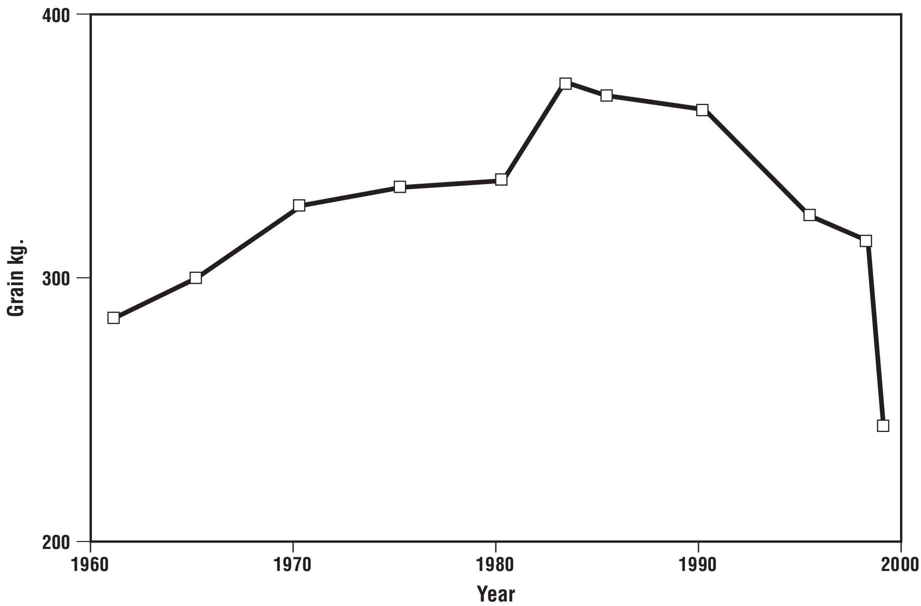
Decline in world cereal per capita grain production 1961-2000

The very serious decline in world per capita cereal grain production is shown in Figure 14-1. This is due to a combination of several ongoing factors: growth of world population; decline of fertility of arable soils; and loss of total area of arable soils due to various causes including water-logging and salinization. Pimentel and Pimentel (2008) report that "Worldwide, more than 20 million hectares of agricultural land is abandoned annually because of soil erosion and salinization. During the past 40 years, about 30 percent of total world arable land has been abandoned because it was no longer productive."

Other factors include the declining amount of groundwater for irrigation because of worldwide overpumping, and having less surface water available for growing season irrigation due to loss of snowpacks in headwater mountainous regions such as the Rocky Mountains of the United States and the Himalayas of Asia.

All this means a much tougher challenge to feed a growing world population. The World Health Organization noted in 2004, that there are already 3.7 billion undernourished people, the largest number and proportion of need ever recorded. Figure 14-1 shows why there is serious doubt this challenge can be met.

Figure 14-1. Per Capita World Cereal Grain Production 1961-2000 (Kilograms per person per year)



Source: Data from Food and Agricultural Organization (FAO), United Nations Quarterly Bulletin of Statistics, as graphed by Pimentel and Pimentel, 2008

The FAO reports that the quantity of food per capita has been declining since 1984 based on available cereal grains which make up about 80 percent of the world's food supply. "Increases in food production per hectare of land, have not kept pace with increases in population, and the planet has virtually no more arable land, or freshwater to spare" (Pimentel and Wilson, 2004). Yet world population continues to grow even in the two most populous nations – China and India. Contrary to widespread belief, China is still growing, and India, the second most populous nation, has a current growth rate of 1.7 percent, which means its population will double in 41 years. Yet India lives on an area approximately one-third the size of either the United States or China. The U.S. population of 313 million is projected to increase to somewhere between 423 million and 439 million by 2050 (Population Reference Bureau, 2011; U.S. Census Bureau, 2008).

> In 1960, when the world population numbered only 3 billion, approximately 0.5 hectare of cropland per capita was available, the minimum area considered essential for the production of a diverse, healthy, nutritious diet of plant and animal products like that enjoyed widely in the United States and Europe….

> Globally, available per capita cropland is now about 0.23 hectare" (Pimentel and Wilson, 2004).

With the continued loss of soil and increased population, we now have less than a year's supply of grain in storage. The world essentially lives from harvest to harvest, with little cushion for bad crop years. The number of countries with growing populations and falling soil volume and fertility is increasing, with the result that more and more countries now depend on imported food to sustain their populations. There are fewer and fewer nations with grain surpluses.

Although it is now a net importer of many agricultural products, the United States is one of the few countries with a surplus of grain for export, although this surplus is diminishing. Also the amount of cropland per person is falling thanks to "growth," which is still the economic theme of our society. There is already about 0.4 hectare (1 acre) of cropland per person tied up in urban buildings and highways. Available cropland has shrunk to about 0.5 hectare (1.2 acres) per person and is still declining as population and urban growth continues. The last crop of farmland is asphalt and concrete.

Salinization

Some soil is destroyed in place, without being eroded away. Soil can be damaged by becoming salty, not simply from common salt but also from a large variety of other compounds, and from a variety of processes. Rising water tables can bring salts in solution to the surface where, from evaporation, they remain as residue. Contamination of the soil by gypsum is a common byproduct of this process.

Irrigation seems to be the chief cause of salinization, and as more and more lands are being irrigated, the problem is increasing. Worldwide, irrigated land expanded from eight million hectares in 1800 to 48 million in 1900, and now has increased to more than 100 million hectares (about 247 million acres).

Warren Hall of the Office of Water Research, Department of the Interior, observes: "Salt problems are particularly insidious. They do not come charging at you with trumpets blowing and battle flags flying, a sight to set stirring the hearts of activists in any century. Rather they have quietly destroyed without fuss or fanfare, more civilizations than all of the mighty armies of the world."

The flood plain of the Euphrates and Tigris rivers, comprising what is called Mesopotamia or the Fertile Crescent (also known as the "cradle of civilization") and considered the site of the "Garden of Eden," once supported over 17 million people using a system of canal irrigation. But the region is now a glistening desert of salt. Salinization destroyed the fertility of this once highly productive land. Modern Israel, also in a desert region, uses a shallow drip irrigation system, which decreases the risk of salinization caused by the "wicking up" of groundwater containing salts.

The current irrigation practices widely used in many parts of the world will ultimately destroy soil fertility through salinization. Both groundwater and river water contain salts, that are left behind in irrigated soil. Farmers in the Imperial Valley of California combat these hazards by flushing their soils with surface water from the Colorado River into the inland Salton Sea (inadvertently created in 1905 and now too salty for most species of fish). But most irrigated regions do not have an adjacent topographic low area into which soil salts can be flushed. China, with a large percentage of its agricultural area supported by irrigation, is particularly vulnerable to soil salinization.

All water except precipitation contains minerals in solution. River water carries varying amounts of salts. Because of agricultural irrigation and the use of fertilizers upstream, rivers generally become more salty downstream. This is true of the Colorado, which in its lower portions has seen its salinity increase by 30 percent in the past 20 years. It became so salty before it entered Mexico that Mexico's complaints prompted the U.S. government to build a desalination plant near the border.

If various salts cannot be removed in some fashion, their accumulation will either reduce the productivity of the soil or completely destroy it for agricultural purposes. This has happened historically and is now occurring in many areas of the world, especially in the Middle East. In the Euphrates River Valley in Syria, for example, some 110,000 hectares (272,000 acres) of irrigated land have been degraded by salinization, of which about 20,000 hectares (50,000 acres) has had to be totally abandoned. Salt degraded soils are found on all inhabited continents, and now account for about 10 percent of the total surface of dry land.

Water lost in transit

In some cases, irrigation water is transported hundreds of miles from its source to the fields which use it. In California, a great deal of water is brought from the northern part of the state to the southern regions through an intricate system of aqueducts, canals, and pipes. During transit, considerable water is lost through evaporation and by seepage loss in canals.

Groundwater and salinization

Irrigation projects using groundwater are especially susceptible to salinization because groundwater usually carries more dissolved solids than surface water does, particularly as deeper and deeper well waters are be used.

Waterlogging

Soils may hold so much water that they cannot be worked agriculturally, and regular crops cannot be grown. Waterlogging may be the result of poor surface drainage, poor subsurface drainage, or a rising water table.

Acidification

This can result from a variety of factors. It usually seems to be the result of continual leaching of soils from heavy rainfall. Soils in the wet tropics are the most obvious examples of acid soils (Millar, 1951). Acidic soils may develop from the reaction of some bedrock minerals with the atmosphere and moisture. They also may result from acid rains, just as lakes have become acidified by sulfuric acid (H_2SO_4) resulting from the mixture of rain with industrial sulfur dioxide (SO_2) fumes. Furthermore, when rain falls, it becomes slightly acidic just by reacting with carbon dioxide, which occurs naturally in the air to form a weak acid known as carbonic acid (H_2CO_3). In addition, organic acids may be released from vegetation. Whatever the cause, strong acidification of soils usually results in a marked decrease in plant productivity.

Compaction

The use of heavy machinery on agricultural land can cause compaction. But the major cause of compaction worldwide is heavy grazing by livestock. This can greatly reduce the ability of the soil to absorb and hold moisture, and is now a widespread problem in Africa.

Nutrient removal

Continual rainfall on soil derived from the ancient underlying bedrock makes no sense, and will gradually leach away the trace elements until only a laterite, a mixture of hydroxides of iron and aluminum, remains, as in the Amazon region. Laterites are a very poor base for rooted plant life.

In nature, terrestrial organisms bring nutrients into their systems, which remain near the organism, thus completing a closed cycle that may be repeated many times as successive organisms use the same nutrients. But in cities where most humans now reside, nutrients are brought in for subsistence. Then in many cases, they are collected and discharged into systems that eventually carry them to the ocean. In some cities that are unable to process human waste, it is simply dumped into rivers and streams untreated. In both cases, the nutrients eventually reach the oceans, but form an incomplete cycle. In this way, the soils gradually become impoverished. Soils may supply the same amount of food as before, but they are becoming less and less nutritious.

Economic growth and loss of topsoil

The ultimate loss of soil in an area is accomplished by simply paving it over. This is being done all over the world, as part and parcel of "growth," the favorite pursuit of cham-bers of commerce and developers of various sorts. Growth is the presumed evidence of economic success and progress. This includes building houses, apartment complexes, factories, parking lots, and shopping malls. Every day in California, more than 100 acres of farmland are lost to various kinds of development. In the United States as a whole, one million acres of cropland a year have been lost every year since 1945. An area equal to the state of Ohio is now occupied by buildings and pavement in the United States. And this "growth" continues.

Unfortunately, in nearly all agricultural areas today, the net result of all processes affecting soils is that soils are being lost faster than they are being formed. Pimentel, et al. (1993) state, "Worldwide degradation of agricultural land by erosion, salinization, and waterlogging is causing the irretrievable loss of an estimated 6 million hectares each year.… Not included in the land degradation data is agricultural land being lost to urban areas and roadways. For example, from 1945 to1975, an area of agricultural land similar to the total state of Nebraska was covered with concrete." The loss of land to urban development continues as population grows.

In California, the city of Sacramento and other communities like Modesto, Visalia, Bakersfield, and Fresno steadily encroach on some of the most fertile agricultural land in the world, the Central Valley (comprised of the San Joaquin Valley to the south and the Sacramento Valley to the north). In Oregon, the well-watered Willamette Valley is the most agriculturally productive area in the state, but it is also a region where shopping malls are replacing fruit and nut groves. In places where my children picked beans for spending money, the fields now grow condominiums, retirement homes, subdivisions of private homes, apartment houses, and car dealerships. Where once I flushed a pheasant in a western Oregon field, there is now an entrance to a J.C. Penney store in the Valley River Center Mall. From coast to coast, with minor variations, this is the story in the United States, and in many other parts of the world. Cities grow and agricultural land shrinks. Cities sometimes have been aptly compared to bovine feed lots — large numbers of organisms in a small area, totally dependent on imports of both food and water. Without the hinterland of farms, cities could not exist. No farms: no food. Preserving the agricultural base against city encroachment is vital to the existence of both.

Renting farmland

Arable lands are becoming scarce, and in some countries like Saudi Arabia, Abu Dhabi, and Kuwait, they are virtually nonexistent. Even farmers in the United States and Australia have started to look overseas for farmland, regarded by some as the most valuable of all commodities. Along with freshwater, they are probably right. "Globally, farmland is disappearing at an alarming rate. According to estimates, approximately 50 million acres vanish each year to urbanization, population growth, and economic and industrial development" (Garber, 2008). There actually may be some benefits from renting farmland abroad, as countries with capital and farming expertise may be able to improve farm practices in some less-developed areas, and in the process, provide models from which local farmers may learn.

Buying farmland

Using their transitory huge oil revenue, most of the Persian Gulf countries (Iran is an exception in part) import almost all of their basic food supplies. In 2011, Saudi Arabia spent $8 billion for imported food and the United Arab Emirates (Abu Dhabi and others) imported $5 billion of foodstuffs. These numbers are growing. With a view toward the future, these countries are looking for what they obviously lack but urgently need for the future — fertile soil.

Recently both Abu Dhabi and Saudi Arabia decided to buy farmland wherever they can to support their rapidly growing populations. This move by countries well endowed with oil, reinforces the view that fertile soil and freshwater will become the "oil" of the twenty-first century and beyond. The balance of economic power will shift accordingly. But this time, power may find a permanent address as the two bases of human survival come clearly in focus.

The UNEP estimated in 1986 that over the last 1,000 years, humans have turned about two billion hectares of productive farmland into wasteland, which is more than the total now under cultivation. Another 100 million hectares of irrigated land have been lost to salinization, and 110 million hectares are experiencing reduced productivity. Humus is the most important single component of soil. Its loss has been accelerating from about 25 million tons per year prior to the industrial revolution, when farming was not mechanized and population was very much smaller, to 700 million tons per year during the past 50 years (Meadows, et al., 2004).

Soil, Conflict, and Migration of People

Brown has observed that in Africa especially, rising populations and shrinking per capita farmland is causing local and regional warfare. Because of a lack of life-sustaining soil, hundreds of thousands of people are being killed in conflicts over land. There is extensive starvation, and massive migrations of people into refugee camps where hundreds of thousands more die of hunger and disease. Brown describes how, in Rwanda, with an average of seven children per family, siblings who inherit land further fragment the small plots. People try to find new land by moving into steeply sloping regions. "By 1989, almost half of Rwanda's cultivated land was on slopes of 10 to 35 degrees, land that is universally considered uncultivable" (Brown, 2006).

In 1950, Rwanda's population was 2.4 million but it expanded to 7.5 million by 1993, and now it is 11 million. As population grew, the demand for firewood exceeded what for-ests could sustain, and then crop residues were used for fuel. Not returning this organic material to the soil caused the fertility to decline and food production became inadequate to feed the population. This resulted in massive slaughter by the Hutus, " … an estimated 800,000 Tutus and moderate Hutus in 100 days. In some villages, whole families were slaughtered lest there be survivors to claim the family plot of land" (Brown, 2006). This is just one of an increasing number of clashes over the possession of fertile soil, illustrating what a vital resource it is.

A personal note

As I review soil and population growth, I have become aware that I am here in the United States because of population pressures on Sweden's soil. There, the rule was that the eldest son inherited the family farm. This was also true in the other Scandinavian regions. The result was that when the North American Continent became accessible to the mass migration of relatively poor people, a large influx of northern Europeans came across the Atlantic to homestead land.

Both my maternal and paternal grandparents moved from land-short, overcrowded Sweden to (at that time) the relatively sparsely populated and fertile lands of the United States. They went to Illinois and to Iowa, both agriculturally rich areas. Because of the "pull" of fertile North American soil, and insufficient arable soil in Sweden to support and retain the growing population there, I was born in the United States. This was my personal geodestiny, not unlike many others. Fertile soil availability moves people.

Soil Formation and Renewal

Soil formation is an exceedingly slow process. In Hawaii, a study based on the many lava flows of various ages has shown it takes at least one-thousand years for the first centimeter of soil to form from rock (Logan, 1995). As soil begins to form, plant growth provides organic material (humus), which further enhances the fertility of the soil by making the soil loose (friable) and able to hold moisture and air.

The importance of retaining so-called "agricultural waste" in the soil (and not converting it to fuel) is clearly described by Pimentel and Pimentel (2008):

> Fertile soils typically contain about 100 tons of organic matter per hectare (or 4 percent of the total soil weight)…. Soil organic matter is a valuable resource because it facilitates the formation of soil aggregates and thereby increases soil porosity. The soil organic matter improves soil structure, which in turn, facilitates water infiltration and ultimately the overall productivity of the soil. In addition, organic matter aids cation exchange, enhances plant root growth, and stimulates the increase of important soil biota.

Combining the Sun's energy with Earth materials, including water through the process of photosynthesis, produces vegetation on which all animal life depends. The food chain always goes back to plants, and land plants, with the exception of a few low forms such as fungi and lichens, depend on soil.

Lands that are continually leached by heavy rainfall eventually become relatively infertile, the classic example being the Amazon Basin. Immediately along the rivers where sediment has washed in from other areas, the land can be fairly productive, but on the higher areas away from the river flood plains, the land has been continually leached literally for millions of years and almost no usable mineral nutrients remain. This has given rise to the "slash-and-burn" type of agriculture commonly employed in the tropics. The land is cleared, the native vegetation is burned, and crops are planted in the slightly enriched ashy soil. This process yields one or two years of meager crops. Then the few nutrients in the soil and ash are exhausted, and the process is repeated elsewhere. The leached residual red clays, when cleared of their normal jungle cover, tend to bake like a brick under the tropi-cal sun and become essentially non-productive.

Renewal processes, reclaiming soil

Once soil is lost, renewing soil is simply back to the process of making soil again from bedrock. The natural production of new soil is so slow that in human terms, it cannot be a factor in restoring soils to an area. Obviously, it is best not to lose the soil in the first place.

Soils carried away by streams are lost to the region from which they are eroded, but to some extent some of these soils are reclaimed – used again. This may occur in the flood plains along rivers, and in delta areas. These areas are the recipients of the topsoil from areas upstream that were eroded, and are relatively fertile. Sediment builds deltas and wetlands, which are nurseries and habitats for many forms of wildlife. People, accordingly, are lured to these areas because of their productivity. However, this may have a negative side effect in loss of human life and property because of the floods that bring the soil. Also, storms in these low-lying delta areas, which occur frequently in such places as the Ganges River delta in Bangladesh, can be catastrophic.

Floods can also bring in sediment that is not mature soil and not very fertile. This may cover more fertile lowland areas, as happened in the lower Mississippi River Valley in the great floods of 1993.

Can soils that are degraded but not yet totally lost be reclaimed by human effort? They can to a degree. However, studies indicate that even with widespread use of a variety of fertilizers, these are not a complete substitute for the nutrients originally in the soil. It has been demonstrated that raising organic matter in the soil by the annual application of manure or by use of leguminous green manures increased yields of wheat, sugar beet, and potatoes beyond any that were achieved with equivalent inorganic fertilizer no matter how much additional nitrogen was added. Also, synthetic fertilizers are made in part from fossil fuels and by processes that use fossil fuels, which are finite. These fuels and fertilizers must be purchased. Worldwide, many poor farmers who might benefit from using fertilizer on their impoverished soils cannot afford them.

A chemical dependency and "ghost acres"

Using fertilizers on once highly productive lands to restore some of their productivity or to raise the productivity of land which is still in good condition, creates a temporary illusion of productivity that really does not exist. The acres of productive "land" that fertilizer, in effect, creates are sometimes referred to as "ghost acres." The sad fact is that in many farming areas of the world, agricultural soils have developed a chemical dependency. As long ago as 1977 to1979, over 96 percent of U.S. corn acreage received nitrogen fertilizers, 88 percent received phosphorus fertilizers, and 82 percent received potassium fertilizers. For wheat, the comparable numbers were 63 percent, 42 percent, and 18 percent.

Ammonia, the basis of the various ammonia fertilizers, including the important hydrous ammonia and urea, is now produced almost entirely by using natural gas as the source of the hydrogen in the ammonia compound, NH_3. It can also be obtained from coal, another fossil fuel. Beyond that, hydrogen would have to come chiefly from the hydrolysis of water, requiring large amounts of electricity, which must be generated by some other energy source, such as dams, or oil or coal-fired plants, or by natural gas-turbine generators.

Hillel (1991) observes, "The two major innovations [of the industrial revolution] were the introduction of motorized machines and the advent of chemical fertilizers and pesticides. Machinery and chemicals became the hallmarks of the new agriculture as it entered the modern era."

Pesticides and, especially, herbicides (selective weed-killers) are almost entirely produced from petroleum, which also powers farm machinery. Thus, the high productivity of modern agriculture is another byproduct of the short-lived Petroleum Interval. That world population and its vital agricultural base have become so dependent on this finite source of raw material is deeply worrisome.

Phosphorus is found in commercial quantities in only a few places, with Morocco, the United States, and Russia having the great majority. The third widely used fertilizer is potash, the term used for potassium chloride. Potassium is needed in every living cell. Potassium deposits are fairly widely distributed, the largest of which are in Saskatchewan, Canada.

Ammonia compounds, phosphate, and potash are all basic to worldwide agriculture. The use of artificial fertilizers is a habit, like other chemical dependencies, which may be hard to break, and kicking the habit may be difficult. Beyond a certain amount, additional fertilizer will not increase soil productivity, and may actually be detrimental to the soil as well as increase the salinity of the runoff water to the streams. Increasing the amount of fertilizer used may result in diminishing returns or no additional returns at all. Greenland et al. (1998) estimate that the world's arable land currently in use for crop production is somewhere between 1.5 and 1.8 billion hectares (3.7 to 4.5 billion acres).

However, much can be done to preserve soil by processes other than using fertilizers. The acidity of a soil may be reduced by adding lime, which is not a fertilizer but simply a common natural rock material. It is just finely crushed limestone, widely available. Beyond that, there are many ways in which soil can be preserved and improved, including contour planting, building terraces, strip cropping, crop rotations, no-till planting, tree-shrub hedges, use of mulches, and other management procedures. These are useful in all agricultural areas but are particularly valuable in less-developed countries which cannot afford fertilizers. Training students from these lands in relatively simple and low-cost agricultural practices is probably some of the best money spent for the benefit of future generations.

Primitive methods

"Night soil" is used as fertilizer in some countries, but it has the severe disadvantage of being a means to spread disease. Animal manure is also used, and it is a good soil conditioner. In some parts of the world where the soil is poor, manure, chiefly cow dung, has to be burned for fuel instead of being returned to the Earth.

Volcanic fertilizer

In some regions, nature renews leached soils. On the islands of Indonesia, particularly Java, which has one of the highest population densities in the world, volcanic activity frequently dusts the countryside with a fresh layer of ash, which quickly weathers in the warm moist climate to release new minerals, producing a fertile soil. Without these volcanic eruptions, it is doubtful that Java could sustain its present population, and there would surely be trace element deficiencies without the mineral renewing effects of the ash falls. The slopes of Mount Vesuvius have seen several destructive volcanic eruptions. Soon after each eruption, people move back up the slopes and replant vineyards and other crops. The newly deposited mineral-rich ash soon breaks down to produce bumper harvests. In that sense, volcanoes are a valuable mineral "mine," and a unique mine in that its minerals, unlike other mines, are renewed from time to time with each volcanic eruption.

Mineral-rich glacial soils

In a different geologic process, nature recently (in geologic time) renewed the fertility of a substantial portion of northern Europe, and the Upper Midwest area of the United States, including the very fertile state of Iowa. Iowa and adjacent parts of America's agricultural heartland produce wonderfully rich crops full of the nutrients needed for good health. The roots of these crops reach into glacial drift — a deposit of various minerals transported from the north by glaciers in the quite recent geological past. These fresh rock and soil materials are derived in large part from granitic areas that have an abundance of the minerals needed for healthy plant and human growth. After depositing this rich load, the glaciers retreated and weathering began to make these elements available for plant life. Also in these climates, the cold winters tend to preserve the rich black humus from the decayed vegetation of the previous year. It was this rich mineral inheritance from nature that the first European settlers found, and from which people in the Upper Midwest still benefit, and will for generations to come. It is a mineral heritage imported duty-free from Canada by glaciers.

One can see readily, however, that it would have been a vastly different story without the glaciers. The road cuts and quarries in this region reveal that beneath the relatively thin cover of glacial drift, lie hundreds to thousands of feet of leached marine clays and nutrient-poor limestone laid down in ancient seas that covered this part of the United States 300 to 500 million years ago. Fossil corals, cephalopods, bryozoans, trilobites, and other forms of ancient marine life lie beneath the glacial debris in Iowa in relatively infertile clays and limestones and would be difficult material in which to grow 150 or more bushels of corn per acre. Also, the corn grown would be deficient in a number of vital trace minerals.

However, in some places, due to careless plowing and the absence of soil conservation practices, the tan and gray ancient marine clays are beginning to show through the tops of hills, indicating that this rich glacial heritage is already beginning to be lost. Unlike volcanoes, the glaciers are not likely to return anytime soon to refurbish the mineral content of the soils.

Situation of Individual Nations

Soil management and conservation is of utmost importance to all nations. Pimentel conducted a comprehensive survey of worldwide soil conditions (1993). Europe has the largest, best area in terms of productive soils. Canada and the United States are also very fortunate, geologically endowed with some of the richest soils in the world. But studies show that these regions continue to lose soil far more rapidly than they should to allow for sustainable future agriculture. Soil loss is winning over conservation.

In the Middle East, in Asia including India and adjacent countries, and in Africa, the problems of soil conservation and fertility are the most severe. In part, this is because of the ancient history of agriculture in these regions, and partly because of the increasing population that cultivates more and more marginal lands. Marginal agricultural lands generally are those on steeper slopes, with less soil initially, and are subject to much faster erosion than are the more arable lands of low relief.

South America, particularly because of the clearing of forest cover in the Amazon Basin, is another area of major soil degradation, although even initially the Amazon Basin soil was not very fertile. The steep terrain of the Andes Mountains is another region of rapid soil erosion. However, using terracing techniques developed during the time of the Inca Empire, some localities are managing their soil relatively well. Worldwide, however, land degradation is proceeding much faster than the rate of soil replacement. Even the relatively recently settled Australian continent is facing massive degradation of its soil, much of which was not very fertile initially.

China is a special concern for the world in terms of food for the future. Brown (1995a) in his epic study *Who Will Feed China?*, notes that China's population is increasing while its cropland is shrinking. China is large in area, but only about 10 percent of it can be farmed. Demand for arable land is so high that the Chinese government is recommending cremation rather than the use of burial mounds. At the same time, China is "getting wheels." At least 10 automobile manufacturers have opened plants in China, where "… there is now an army of bulldozers cutting their way through the Chinese countryside building highways across rice paddies and wheat fields, leaving the nation with ever-less cropland to satisfy its rising demand for food" (Brown, 1995a).

A substantial part of China's cropland is irrigated, some 49 million hectares. Irrigation water comes from both surface and groundwater sources. But groundwater levels are dropping and are not sustainable at the present rate of use. This will compound the problem of water scarcity. There are now only four regions that have soils productive enough to be grain exporters. These are North America (Canada and the United States), Western Europe, New Zealand, and Australia. Australia, however, is marginal, with poor soils and frequent droughts. Meanwhile, domestic demand is increasing in all four regions, reducing the amount of grain available for export. Who will feed China?

Population and Soil

Soil formation is not keeping up with either erosion or population growth. From 1951 to the end of the twentieth century, the amount of arable land to support each person in the world was estimated to have fallen by more than 50 percent. This is primarily due to population growth. When soil degradation is factored in, the problem becomes even more severe.

It is significant and ominous that the regions with the poorest soils, Asia and Africa, are experiencing the highest growth rates of population. From 1961 to 1984, the population increased 70 percent, but only 15 percent more arable land was able to be developed. During this period the world over, population increased 55 percent but only nine percent additional arable land was made available.

Brown and Wolf (1985) have summarized the situation: "Throughout the Third World, increasing population pressure and the accelerating loss of topsoil seem to go hand in hand."

Soils and the Future

If productive soil does not exist in rocky areas, or is lost in some fashion in other regions, the populations of these places still have to be supported by soil that exists some-where else where food can be produced. People living in paved-over cities have to depend on soil elsewhere. Urban dwellers should be concerned about the soil basis of their existence, and wherever that "elsewhere" is. But city denizens seldom regard soil erosion as their problem. It definitely is. Because the world is becoming a more and more integrated economy, the loss of productive soil in one place has a rippling effect, because it creates a need for other areas with soil to produce more food to make up the loss.

Soil cultivation usually results in soil loss. This means that with the shipping of every bushel of wheat or corn, or any other agricultural product, some soil nutrients are shipped along with it. One of the most important exports the United States uses to mitigate its current large balance of payment deficit, is agricultural products. Being a young land in terms of exploitation, the United States still has large regions with rich soils. But because its soil loss exceeds soil formation, the United States is also, in effect, exporting some of its soil through its agricultural products.

With a growing population, the possession and preservation of large areas of productive soil will be very important to the future of the United States. This is also true of Canada, Australia, Argentina, and other relatively young countries in terms of cultivation. Preserving their productive soils is one of the most important things these nations can do.

Countries where agriculture has been practiced far longer, particularly India and China, home to nearly 40 percent of the world's population, have much less fertile soils on average than the more recently settled regions. Their future is far more precarious. In some places, soil loss is already a disaster. Wilken (1995) makes the general calculation that, "…if the amount of land in production remains constant over the next 40 years, farmers will nearly have to double their yields to feed the growing population." It is doubtful that can be done. Generally, flatlands are already being farmed. The unattractive prospect is to put more marginal land into production, which tend to have relatively short useful agricultural lives. Soil conservation needs to be given increasing attention in all countries, but, unfortunately, it is not. David Pimentel says, "The public has clamored for action to plug the ozone hole over Antarctica, stop acid rain, halt the greenhouse effect, and save the forests, yet little has been said about the soil loss that could destroy the hopes of a stable and fruitful earth a century from now."

We are losing ground, but a recent study paints a somewhat more hopeful picture, noting that improved soil practices such as no-till farming have reduced water erosion by 40 percent and sowing cover crops can improve soil fertility. But many areas do not use soil conservation measures and soil degradation continues. The International Soil and Reference Information Centre in the Netherlands surveyed more than 250 experts on six continents. Their reports indicated that of the 11.5 billion acres of vegetated land, 17 percent was degraded, largely through erosion; of this land, one in six hectares could no longer support crops. The report was based on opinion rather than direct field data. Nevertheless, it is clear that soil degradation is an ongoing concern.

Africa

Having supported human populations the longest of any continent, more than two-thirds of Africa's soils are depleted. Poor agricultural practices, people stripping the land for fuel, their animals eating the vegetation, have all destroyed the plants that held the soil in place. Water has eroded the soil and with it, the nutrients needed to grow crops. Many scientists familiar with the situation believe the destruction of the soil is beyond repair for at least several lifetimes or even longer. With continued population growth and pressure on the land, no significant reversal of the soil degradation trend is in sight.

Haiti

Haiti is a classic example of a nation that initially had very limited Earth resources, which has now degraded or in places totally lost the one Earth resource it had — soil. It is now a destitute country without a functioning society and is dependent for the foreseeable future on international food welfare and other assistance from foreign governments.

Degradation can be reversed

In some regions where land degradation could be reversed, the knowledge and effort are lacking. Very early, the Soil Conservation Service was established in the U. S. Department of Agriculture. Brown (2006) writes: "The U. S. approach to controlling soil erosion by both converting highly erodible cropland back to grassland or trees and adopting soil conservation practices offers a model for the rest of the world." This is certainly a commendable approach, but against the tide of rising world population, may be difficult to achieve. Putting organic material back into the soil by the application of manure, or other organic materials tilled into the soil can be quite successful. It is perhaps the single most important thing that can be done to restore soil fertility, for the organic material loosens the soil and holds moisture.

Amazon Basin soils

Although the Amazon Basin soils are leached by rainfall (creating what have been called "wet deserts"), archaeologists have discovered isolated areas where societies lived and greatly improved their impoverished local soils from 2,500 years to 500 years ago (Mann, 2008). This was done by dumping charcoal, food refuse, and other wastes including human excrement into soils, greatly enriching them in plots ranging in size from two to three acres up to 30 to 40 acres. These were truly early organic gardeners. The charcoal and other soil amendments greatly increase the numbers of microbes, which in turn, enhance the fertility of the soil. Tests in 2006 by a U. S. and Brazilian team of scientists found that these plots had a far greater number and variety of microorganisms than typical tropical soils — they were quite literally much more alive.

These fertile plots, termed terra preta (black earth), sustained entire settlements over many centuries, some becoming so important to survival that they caused Indian groups to go to war over them. Thus it seems that through careful management, involving considerable hand labor as is still done in some countries or regions (vineyards of southern France, terraced rice paddies in the Philippines, and other places), soil fertility can be maintained and even improved. This may provide a glimpse into future agricultural practices, as hand labor returns to replace fossil-fuel powered machinery.

Organic farming

The expanding trend in some regions of what is called "organic farming" is commendable. This has been practiced for centuries where societies lived close to the soil, and understand the realities. Organic material is carefully returned to the soil. Using no petroleum-based pesticides, herbicides, or fertilizers and preventing soil loss makes organic farming far more labor intensive than the mechanical farming of large areas. Organically farmed produce often costs more, but in the longer term, it is cost effective and should be promoted. It is quite likely that a century or two from now, a substantially greater percent of the population will be working the land. Hand labor may be more common than mechanical farming. And the remaining productive soil may be much more carefully nurtured.

Loss of vital natural capital

The alarming fact, confirmed by the U. S. Department of Agriculture (2006) and cited by Friedemann (2008), is that, " …on over half of America's best crop land, the erosion rate is 27 times the natural rate." This is natural capital being lost that should be preserved indefinitely on a renewable basis for present needs and for all future generations. This is the very basis of survival. This grim fact of soil depletion must not be glossed over and lost beneath the host of trivialities that seem to occupy our day-to-day attention.

Renewing the soil sustainably

Over the centuries, subsistence farmers using hand labor renewed their soil by feeding the land with organic nutrients to equal what crops took from the soil. This meant everything but the grain itself went back into the soil. In just a teaspoon of healthy agricultural soil, Suzuki (2007) relates that there are "about 600-million bacteria" as well as many other organisms, which combine to replenish the nitrogen in the soil as well as convert organic plant material to usable nutrient form for further growth. Suzuki goes on: "Technologically advanced nations have not been using the soil in a sustainable way; instead, they have been 'mining' the soil by removing its organic contents without replacing it, thereby compromising its future productivity for the sake of the enormous harvests of today." This fact is worth repeating.

Year-round plant cover preserves soil. Seasonal crops allow bare fields to be exposed to wind and water erosion, producing more runoff, and can erode as much as a hundred to a thousand times faster than comparable vegetation-covered soil. Modern agriculture, unless drastically modified to preserve soil, has within it the seeds of its own destruction. In the geologic past, the natural balance between soil loss and soil production allowed terrestrial life to sustainably live off this incredibly thin layer of soil — calculated by Montgomery to be slightly more than a ten millionth of the Earth's radius. It is this thin skin of soil on which all human life depends.

Montgomery (2007), although clearly pointing out destructive trends relative to soil erosion and fertility, also reports that there are successful soil conservation practices. Contour plowing and cover cropping have been known for a long time.

> Crop rotations, mulching and the use of cover crops are ancient ideas. So is terracing, which can reduce soil erosion by 90 percent, enough to offset the typical increase in erosion rates from cultivation … soil erosion is not inevitable. There are productive profitable farms in every state — and probably every country — that operate with no net loss of topsoil [but] despite substantial progress and advances in soil conservation in the past half century, society still prioritizes production over long-term stewardship of the land.

For many problems in this world, existing knowledge properly applied can go far toward creating a sustainable future.

Conservation tillage

This is a method of farming that is spreading, which is the most sustainable. It involves discing only the top few inches of soil and discing in crop residues from the previous year. It substantially cuts soil erosion by providing myriad tiny dams retaining moisture and preventing loss of soil, which occurs with deep plowing. Also, the shallow discing and the inclusion of biomass from the previous crop encourages earthworm and bacteria growth, both important in soil fertility. The crucial factor in this kind of farming is the return of biomass to the soil.

Population, agricultural production, and petroleum

The progression of farming through the ages has brought us to the present, where the use of petroleum has allowed vast land areas to be put into agricultural production with a minimum of hand labor.

Albert Bartlett observes that modern agriculture is based on petroleum-powered machinery and on petroleum-based fertilizers that reflect a succinct definition of modern agriculture: "Modern agriculture is the use of land to convert petroleum into food."

Clearly, the extensive use of petroleum in modern agriculture has been a major factor in the growth of human population. But, after the peak of world petroleum production, how will the world cope in terms of food production? If organic farming without using petroleum-derived petrochemicals including fertilizer is to be widespread, it is another reason why soil must be carefully tended now. Greater concern for soil is clearly vital to our future.

Increased industrialization and the great desire of countries to get on wheels is now converting large areas of productive farmland to non-farm uses. The land is being paved over. China, where population is outstripping domestic food production, is nevertheless developing a motor vehicle economy that will mean loss of still more cropland. In 1994, the Chinese government said that automobile manufacturing was scheduled to be one of four growth industries in the next two decades. Cars in China, which numbered 1.15 million in 1990, reached 22 million in 2010. Even more are projected for the future. China is now embarked on a massive highway construction program. Brown (1995a) adds, "In addition to factories, housing, and roads, farmland is also being claimed by shopping centers, tennis courts, golf courses and private villas." Asphalt is assaulting agriculture. When and how does it stop?

Chapter 15

Minerals and Health

What may be the earliest record of minerals applied in medical and health matters is that found in Egyptian hieroglyphics and described by medical doctor John Nunn (1996), in his study of ancient Egyptian medicine. This monumental work first required the author to be able to read and interpret hieroglyphics and then find the passages that referred to medical matters.

Nunn provides a table of minerals that were used in various ways by the Egyptians as treatments and cures. Salt (sodium chloride or NaCl) was one of the most common of the minerals. Nunn writes: "Warm solutions of salt are mildly emetic. It was often included in prescriptions with many components…. Salt had a very wide use, being taken by mouth, by enema, as an anal suppository, and as local application to the eyes, ears, and especially the skin, where it was held in place by a bandage." He further notes the use of natron (a mixture of evaporates including sodium chloride, sodium sulphate, sodium carbonate, and sodium bicarbonate). "Its use in a solid state or as a paste would have a powerful osmotic effect, drawing out fluid and reducing swelling…. Its most extensive use was as an external application, often under a bandage."

Nunn goes on to cite other minerals used by the Egyptians, including various copper compounds that have an anti-bacterial effect. "It would, however, be hard to say whether the Egyptians recognized the anti-bacterial effect or were merely influenced by the decorative appearance of malachite." (It has a strong green color.) Some minerals such as those in powdered granite were used by the Egyptians more in hope and superstition than by observable positive results.

This chapter is chiefly about modern concerns of the health of individuals and nations as a whole with regard to the various effects of minerals and their distribution.

The weathering of bedrock, or in some areas, the presence of glacial drift or other transported Earth materials determines what elements are found locally in soil for plant nutrients. Minerals affect the physical health of individuals and of domestic and wild plants and animals which humans consume or use.

The bedrock or overlying transported rock materials can be quite different from place to place. In the past, and even at present, many populations derive their sustenance from relatively small and local areas. Therefore, there is a possibility that vital trace elements needed for proper nutrition can be missing from the diet of a population in a particular locality. This can apply to regions as large as some countries.

Diet, Disease, and Trace Elements

The human body is structured on a mineral compound — the skeleton — that is chiefly calcium phosphate with minor amounts of other minerals. Minerals are part of us. There are at least 17 minerals essential to human nutrition. The study of the importance of trace elements in human as well as animal and plant nutrition has revealed some interesting facts about their distribution and their relationship to diseases in various parts of the world.

Human Health and Minerals

There is evidence from the geographic distribution of thyroid disease, hypertension, arteriosclerosis, cancer, tooth decay, and several diseases of animals that a definite relationship exists between the geochemistry of the Earth in those places, and these medical conditions. Trace elements in human diets are very important. Their presence is related to regulating the dynamic processes of enzymes, and minute amounts are needed to modify the kinetics of enzyme reactions.

However, excessive amounts of certain minerals can have a negative effect on health. The vegetables grown in New York and Maryland soils are relatively high in iron, manganese, titanium, arsenic, copper, lead, and zinc compared with most other soils. Helen Cannon of the U.S. Geological Survey concluded that the available information suggests a correlation of this fact with the occurrence of certain diseases. Another study in an area known for abnormal concentrations of selenium suggested that high mineralization was a possible factor in an unusual cancer-mortality pattern in that area and has prompted further investigation (Spallholtz et al. 1981).

Salt

It is interesting that two elements, sodium (Na), which is highly explosive if placed in water, and chlorine (Cl), which is a deadly gas, combine to form the common salt (NaCl) needed in human nutrition. This mineral is probably the first mineral that humans specifically sought for their diet. In medieval times, humans used 10 to 20 times as much salt as today's average American. Salt at that time was highly prized and sometimes kept in elaborate precious metal containers as much as two feet high. It was an honor to be seated nearest the salt container at the table. Salt in solution is literally part of the lifeblood of humans. As salt travels through the various human organ systems, it has a variety of effects. The extensive research and literature of salt in human metabolism is beyond the scope of this discussion, but two brief mentions are made here.

Salt is necessary in moderation and dangerous in excess. In heavy physical work, where sweating is extreme, the replacement of salt by salt tablets is a common practice. Loss of salt can cause weakness, nausea, and even fainting. However, excessive salt may also have undesirable effects. Salt in human diet has been correlated with an increase in blood pressure (Faelton, 1981). A number of studies show that people who live in areas where the drinking water has a high sodium content have a markedly greater risk of high blood pressure (Schroeder, 1993). A current treatment for the control of blood pressure is the reduction of salt in the diet.

Iodine

Iodine deficiency is one of the most widespread mineral medical problems in the world. Lack of a very minute amount of iodine in the diet can stunt both physical growth and mental ability. Iodine is essential to life. It enables the thyroid gland to produce the hormones necessary to develop and maintain the brain and nervous system. When the levels of thyroid hormones fall, the heart, liver, kidneys, muscles, and endocrine system are all affected adversely. Lack of iodine in the diet of pregnant women can adversely affect their baby. Seafood and food grown in iodine-sufficient soils provide adequate iodine in human diets. It is estimated that about 1.5 billion people in at least 110 countries are threatened by iodine deficiency. The chief regions where deficiency occurs are in mountainous regions and areas prone to frequent flooding, which washes out iodine in the soil.

The solution to the problem is very simple. Iodine capsules can be swallowed, or in many countries, iodine is simply added to common table salt (iodized salt). Making iodized salt widely and cheaply available in iodine-deficient areas is being done by government and private organizations. Kiwanis International has such a program. The amount of iodine needed is exceedingly small. One teaspoonful of iodine consumed over a life-time in tiny amounts every day is all that is needed to prevent iodine deficiency disorders such as goiters.

Selenium

This is an element that seems to cause and cure a variety of human ailments. A study of 45,000 Chinese reviewed the occurrence of Keshan disease (Faelton, 1981). This is a form of heart disease, mostly affecting children up to the age of eight or nine years. Its symptoms are enlargement of the heart, low blood pressure, and a fast pulse. A high death rate was clearly related geographically to the amount of selenium in the soil. The disease occurs in a wide band of land running from the northeast coast of China towards the southwestern border of the country. In this area, the soil and crops grown are deficient in selenium. Within this region, children given selenium showed a lower incidence of the disease, but it did not diminish in other affected areas where the children were not treated. It was found that, " … the dramatic responses to Se [selenium] supplementation by individuals suffering from Keshan disease suggest that selenium may yet help mankind overcome two of its most damaging disease conditions" (Spallholz, et al., 1981). The other disease referred to is a form of cancer for which selenium appears to be a useful trace ele-ment in treatment.

In the United States, an area along the coastal plain of Georgia and the Carolinas has come to be termed the "stroke belt." It also has a higher than normal incidence of heart disease. As in China, the area is low in selenium. Although studies are not yet complete, it appears that death rates from a variety of cancers are lower in areas of the United States where local crops take in larger amounts of selenium from the soil. A report from Finland concluded that men with low levels of selenium in the blood were more likely to develop cancers of the lung, stomach, and pancreas. Women also had a marginally higher risk of these ailments, and the report noted that the Finns do not get much selenium in their natural diets.

Selenium poisoning

Too high a concentration of some elements, however, can become a negative health factor. We have just noted that selenium in minute quantities is important to health, but selenium poisoning can occur from an overdose of this element. In late 1988, a general selenium poisoning warning was published by the *Sacramento Bee* (California) reporting investigations that discovered selenium contamination in the marshes, lakes, and streams, in particular, on the Kesterson National Wildlife Refuge in California's Central Valley. Large numbers of waterfowl died from selenium poisoning. Fish and game in Wyoming, Colorado, Utah, Montana, and Nevada, as well as California, contained excessive amounts of selenium. Eighty-one percent of the trout, carp, perch, catfish, and goose eggs collected throughout the West exceeded the 200-microgram safety limit and 67 percent were over the 500 level of toxic effect. The samples averaged 974 micrograms, or nearly double the level at which poisoning symptoms begin to appear in healthy human adults.

The most notable case of excessive selenium was in Sweitzer Lake at the state recre-ational area by that name near Delta, Colorado. The water tested 51 parts per billion of selenium, which is 10 times higher than the Environmental Protection Agency's limit for protecting freshwater fish species.

Products for human consumption were studied and half the foods tested, such as steak, liver, poultry, eggs, and vegetables from areas in Oregon, Montana, South Dakota, Nebraska, Wyoming, and Colorado were found to exceed the safe level of 200 micrograms of selenium. The true magnitude of this situation in the western United States has yet to be established, but clues already indicate the problem could be large. However, in spite of all the studies that have been conducted, the precise role of selenium in human health, particularly with relation to heart disease, has still not been conclusively determined. Research continues.

Chromium

Chromium is a relatively rare element in the United States, which imports nearly 100 percent of its supplies. There are small deposits in Montana and Oregon and a few other places, but for the most part, both North and South America are deficient in chromium. Is this chromium deficiency identifiable in humans, and is it significant in terms of health? The answer appears to be yes to both questions. People in the Middle East have about 4.4 times as much chromium in their bodies as Americans, and Asians have five times as much. In studying death rates and causes, it was found that chromium in the aorta was too low to be detected in every person dying of coronary artery disease, one form of arteriosclerosis (Underwood, 1962). Chromium's presence has been found to be important in reducing cholesterol levels, which apparently relates to its absence in people dying of coronary artery problems.

Chromium also appears to be helpful to athletes where high muscular strength and endurance are important. Studies show that strenuous physical exercise can deplete the body of chromium. The fuels that muscles use are carbohydrates, which need chromium and insulin for proper metabolism. However, some studies suggest that chromium picolinate, the most popular of the chromium supplements sold widely in health stores, may cause chromosomal damage that ranged from threefold to eighteen fold the amount that occurred in other cells exposed to other chromium compounds. Such damage is considered an indication of a substance's cancer-causing potential. Thus, just as other minerals can be helpful or harmful in various amounts and forms, chromium also has a variety of impacts on human health.

Iron

Iron is absolutely vital to human life. It is the vehicle in the hemoglobin of red blood cells that combines with oxygen to carry life-supporting oxygen to the entire body system. Although iron is a common element in the Earth's crust, some geological regions have very little. Children living on certain iron-deficient soils in Florida (soil derived almost wholly from limestone) were found to be anemic. Treating the children with iron greatly improved their condition, usually as soon as four to six weeks.

Phosphorus and potassium

Every living cell must have two elements, potassium and phosphorus. Phosphorus tends to get locked away in mineral compound form quite easily instead of freely circulating. Bones and teeth are calcium phosphate. Simply to build the bones of 1.3 billion Chinese takes a lot of phosphorus. It has been suggested that phosphorous deficiency accounts for the typically small-bone structure of many Asians. Keeping phosphorus in circulation so that all people can get their needed share is somewhat of a problem already. It may be more so in the future.

Phosphate is used as fertilizer for almost all food crops and thus enters the human system. But if the trend of current usage continues, the world's supply of phosphate may be depleted by 2050. If world population growth can be slowed to just one percent annual increase (compared with current 1.2 percent), world phosphate supply would last 82 years. Phosphate is a basic building block of plants and for which there is absolutely no substitute.

Although modest amounts of phosphate are mined elsewhere, Morocco has almost half the world's known phosphate deposits. Geology may have destined Morocco to become an especially critical nation to the world economy, even as the oil-rich nations are now.

Potassium is as vital as phosphorus, but it is far more widespread in the Earth. This is fortunate because potassium is vital to human health in a variety of ways. It enables the nerves to "fire" their messages — the heart beating and muscles contracting. It helps to control blood pressure, and prevent bone loss and kidney stones.

Canada has more than half of the world's known deposits of potash, the principal commercial source of potassium used in fertilizers. Among common foods, bananas are a good source of potassium.

Silver

"Silver's ability to kill germs was put to work long before anyone suspected the existence of microbes. Silver wraps were used for wounds in ancient Greece and Rome, while silver vessels helped purify water. In the nineteenth century, doctors learned that silver nitrate dropped into newborn's eyes could prevent infections leading to blindness. Though silver was largely replaced by antibiotics after the discovery of penicillin, it is still used in burn units and elsewhere to prevent infection" (UC Berkeley Wellness Letter, January 2007).

Zinc

Zinc oxide, a white powder, is commonly prepared in an ointment (20 percent zinc oxide) and is found in nearly all home medicine cabinets. It is slightly antiseptic and is used to cover abrasions and small wounds. Physicians early learned that zinc acetate, an eye drop solution used with newborns, prevented blindness.

Arsenic

Naturally occurring arsenic in drinking water is a fairly common problem in several parts of the world. In Taiwan, drinking water from wells caused arsenic poisoning in hundreds of persons. The arsenic exceeded 70 parts per million and many of the affected Chinese developed skin cancers as well as general arsenic poisoning. In 1983, a massive case of arsenic poisoning was reported in Bangladesh. Arsenic has been reported in many wells across the country.

Lead

Lead is a metal that has been used for more than 2,000 years. The Romans made their water pipes from lead, some of which are still well-preserved in the ruins of Pompeii. It has been suggested that the Romans suffered from lead poisoning because of using lead in their water supply systems. Pliny, the Roman naturalist and writer, described a disease among slaves that was clearly lead poisoning. The U.S. Geological Survey, in analyzing municipal water supplies in one hundred of the largest cities in the United States looked for 23 trace elements, and of these, 16 were found in sizable quantities. Of these 16, five are essential and 10 are biologically inert. Only one, lead, is toxic over a lifetime. The maximum concentration of lead found was 62 parts per billion, which exceeds the federal lead safety standard, which is 50 parts per billion. The lead that was found occurred in water supply systems that included some lead pipes where the water was soft (low in minerals) and acidic. The lead was not an initial constituent of groundwater. All of which suggests that the Romans, indeed, might have picked up lead from their water systems.

For many years, lead was an important ingredient in paints. But it is now banned as a health hazard.

Radon gas

Recently, especially in the United States, considerable concern has arisen regarding radon gas as a possible health hazard. This gas is derived from a series of radioactive decays that start with uranium. Actually, radon gas itself has a very short life. It is the subsequent, longer-lived decay products that cause cancer. These can accumulate in houses and other closed structures.

The occurrence of radon gas and its derivatives is definitely related to the geology of the area. Uranium, in particular, occurs in certain black shales underlying wide areas of the interior U.S. from western New York to Kansas. The granitic rocks are the original source of most the uranium which, upon weathering, is transported in the oxidized form and then is immobilized in the reducing environments of organic-rich muds, which when compacted, are black shales. Both black shale and granitic bedrock areas usually show a higher than average radon gas presence. Certain other rocks may also produce radon, and the geological associations of radon are becoming well documented. Geological mapping is proceeding to identify the rocks that are potential sources of radon.

"Hard" water

The term "hard" water is loosely applied to water containing more than normal amounts of minerals, particularly calcium in soluble form. Calcium exists in large quan-tities in the form of calcium carbonate, the mineral that forms limestone. Limestone is widely distributed in the eastern, midwestern, and southern portions of the United States.

The state of Texas has a thick blanket of limestone over much of its 265,000 square miles. Water in Texas is exceptionally hard, and the teeth of native Texans are notably better than the teeth of people living in soft water areas such as the U.S. Pacific Northwest. Since teeth, like bones, are composed of calcium phosphate, children growing up in calcium-deficient water areas tend to have poor teeth. In contrast, the dental decay rate (caries) in Deaf Smith County, Texas, is the lowest in the nation.

Heart disease has been studied perhaps more thoroughly than any other human ailment, and there seems to be at least one conclusive relationship to minerals. In England, Wales, the United States, Canada, Sweden, Finland, Ireland and Japan numerous studies have shown that areas with relatively soft water, water with few dissolved minerals, have a higher than average death rate from heart disease. Hard water areas, where water is drawn from wells in limestone, appear to have populations with significantly lower rates of heart disease, including both cardiovascular and coronary heart disease.

In Japan, a relatively small country, the relationship of minerals to cardiovascular disease has been defined quite well. Northeastern Japan has an abundance of sulfur-rich volcanic rocks. Rivers there carry relatively soft water because the high sulfate produces acidic water which is soft water. These areas proved to be places where the death rate from apoplexy (death due to rupture of a blood vessel) was substantially higher than in areas to the south where river water was relatively hard. Various regions of the United States reflect the same relationship — a negative correlation between heart disease and the hardness of local water. Soft water may be fine for your car battery, and for washing your hair, but it is bad for your teeth and heart. It should be noted, however, that the precise factors that create this correlation between heart disease and hardness (or softness) of water are still undetermined. Just exactly what hard water does to inhibit heart disease is unknown; the correlation simply exists.

Miscellaneous minerals and heart disease

Other relationships between heart disease and the geology of an area have been observed. For example, in Georgia, nine northern counties have low rates of heart disease, whereas in south-central Georgia the death rate from heart disease is appreciably higher. A detailed geochemical analysis of the soils and the plants in the two areas disclosed that in the northern (low-death rate) area, manganese, vanadium, copper, chromium, and iron are more abundant than in the south-central (higher-death rate) area. These elements are among those trace elements known to have beneficial effect on heart disease.

Minerals and cancer

The scourge of mankind, cancer, also appears to have some definite geological associations. But, as in the case of heart disease, exactly what causes many cancers is unknown. In West Devon, England, it seems clear that a high incidence of cancer is related to groundwater obtained from a distinctive rock in the area from which exceptionally highly mineralized water is obtained.

The geography of esophageal cancer near the Caspian Sea in Iran also shows a distinctive pattern related to soil types. The soils of the eastern portion of this area are saline, in a relatively dry area. Westward, the amount of rainfall increases and the salinity of the soils markedly decreases because the rainfall washes away the salts. This trend correlates with a marked decrease in esophageal cancer. A follow-up to this study found that other areas of the world with a high rate of esophageal cancer have much the same mineral content in the soils. One such locality was found in Puerto Rico. Another area with excessive esophageal cancer, with a dry climate environment, that in turn affected the mineral environment (high salinity) similar to the high-cancer incidence area in Iran, is located in the Turkoman semi-desert region of the former USSR.

Silicon, uranium, and lungs

Locally, the effects of certain minerals in an environment can be quite striking. Women living in a particular silver mining area in Bohemia would outlive three or more husbands who worked in the mines. These silver mines are a major source of uranium. The miners did not know it at the time, but they were being subjected to excessive radiation while working underground, and also were subject to lung problems from silica dust, resulting in silicosis. The fine silica dust also had uranium contamination.

Fluorine and calcium

It appears that fluorine, like many other elements, can be beneficial or toxic depending on the amount. Found naturally in some drinking waters, in moderate amounts (about one part per million), fluoride (fluorine in various compounds) appears to be a substantial deterrent to tooth decay. On the other hand, excessive quantities of fluoride in drinking water causes undesirable bone changes, as well as mottling of the teeth. The function of fluoride in both teeth and bones is to help retain calcium. Where the water is deficient in fluoride, for example in certain areas of North Dakota, there is an increase in osteoporosis. This is reduced bone strength due to leaching of calcium, an ailment that tends to affect older persons, especially women.

Medical advances have resulted in populations with increasing numbers of older persons, so the problem of osteoporosis is becoming more common. Bone density increases until about age 40, and for a time remains stable, but in later years begins to decline. Calcium supplements can be a substantial help. Vitamin D helps absorption of calcium, and is usually included as part of many calcium supplements. Adequate magnesium is also necessary for the body to utilize calcium efficiently. Calcium-magnesium supplements are readily available.

There is also evidence that calcium fluoride pills can decrease the incidence of hardening of the aorta. Deficiencies of magnesium, calcium, and lithium are correlated with an increase in cardiovascular troubles in general. Regions of hard water commonly have these minerals and reduce the incidence of these health hazards.

A study by a number of dentists in Oregon concluded that fluoridation of water was a special benefit to poor people who do not have as much money to spend on regularly scheduled dental care as more affluent individuals. Getting free dental care from the fluoridated water was to their advantage. However, it should be noted that there is considerable controversy about the overall effects of fluoride on the human body. Some studies indicate it may cause genetic damage, and there are possibly other negative effects.

Minerals in medical procedures and treatments

A variety of minerals are used in medical procedures, as for example, the use of radium in the treatment of certain cancers. Radioactive tracers are used to obtain information about circulatory problems and in a number of other medical procedures. A barium compound is used in studying the human digestive tract with a fluoroscope. Barium is also used as a material to weight drilling muds in oil-well operations. It is a versatile mineral!

Minerals in Agriculture and Health of Livestock

Selenium

Selenium deficiency is one of the earliest cases of mineral deficiency observed in livestock. Marco Polo described it during his travels in China, noting that the hoofs of cattle went bad and were dropping off. He did not know, of course, that it was due to an absence of selenium, but he did relate the disease to a particular region. Subsequent studies of that region in China have identified it as selenium-deficient.

In British Columbia, cattle are injected with selenium to cure muscular dystrophy. In New Zealand, where there is no natural selenium in the soil, selenium must be included in fertilizer to prevent decimation of the sheep on which New Zealand depends for substantial income. Selenium is a catalyst to the enzymes which, combined with vitamin E, operate to ensure the production of viable offspring.

Too much selenium

It has been observed for a long time that in some parts of South Dakota, cattle may be victims of selenium poisoning due to an excess of the metal in the local soil. This causes something called "alkali disease" or "blind staggers." Wyoming ranchers cannot successfully graze sheep on a particular geological stratum, specifically the Niobrara Chalk, or on certain areas of the Mesaverde Sandstone in the spring, especially in wet years, due to selenium poisoning. The sheep lose muscular control and frequently die. Selenium poisoning is widespread around the world, occurring in Canada, Mexico, England, Wales, Colombia, Argentina, Israel, Zaire, Nigeria, Kenya, India, South Africa, Australia, and Japan.

An extreme case of selenium poisoning occurred in the northwestern part of the San Joaquin Valley of California, when the San Luis Drain was not completed into San Francisco Bay, but instead emptied into the Kesterson National Wildlife Refuge wetlands area. These waste irrigation waters were high in selenium, and as they accumulated and evaporated, the selenium content in Kesterson increased to highly toxic levels. This caused deformities in birds of many species. Men were hired to go through the refuge and discharge firearms to prevent waterfowl from staying there and nesting. So far, toxic effects are confined to the wildlife of the refuge. But there is concern that the selenium will ultimately get into the groundwater of the area, which is used for human consumption.

Iron and copper

A number of years ago, the term "salt sick" was applied to animals that exhibited weakness, failed to fatten, and in general were anemic. It was discovered that cattle developed this trouble when they foraged only on grass grown on certain light-colored sandy soils and some peat soils. Examination of the soils showed they were deficient in both iron and copper compared with other soils. When iron and copper were added to the soils, the problem disappeared. Copper deficiency may cause a cardiovascular disorder in cattle called "falling disease." It can result in heart failure, and the animal will suddenly die, frequently after excitement or strenuous exercise.

Magnesium

Another example of a particular element's influence on livestock is a condition known as "grass tetany," which has been reported in Ohio. This is the result of the absence of magnesium in the diet needed to maintain normal magnesium levels in the serum of the blood. Cattle do not have a readily usable magnesium reserve, and the symptoms of grass tetany can develop quite rapidly, in 24 to 48 hours. Cattle can die within a few hours. Female cattle are particularly subject to this danger shortly after giving birth to their calves. It was found that this affliction occurred mainly in a 26-county area where the soils are primarily derived from sandstones and shales, both of which were deficient in magnesium. The apparent solution to this problem was to increase the magnesium content of the soil by applying dolomite, a high-magnesium content limestone. Fortunately, this is a long-term solution, because dolomite weathers slowly and gradually releases magnesium to the soil over a period of as much as ten years.

Sodium

There is a large moose population living in Isle Royale National Park in Lake Superior. The island vegetation is so low in sodium that it can supply only about a tenth of the needs of the moose. However, the moose overcome this problem by eating aquatic vegetation with up to 500 times the sodium that the island land plants contain.

Minerals in Agriculture — the Plants

Many minerals are critical for plant growth, or in some cases may inhibit plant growth. A few are cited here.

Boron

This element can be toxic to some plants, and is carried in irrigation waters derived from boron-rich geological terrains. Because boron is quite soluble, water in boron-rich regions will easily pick up that element. The problem with boron is that the range between nutritional deficit and toxic levels is very narrow. As boron cannot be precipitated or easily removed from water by other methods, the solution is to dilute it with water containing no boron. But insufficient boron can also be a problem. Peanuts with a boron deficiency tend to be hollow, a situation called “hollow-heart.” Boron deficiency also negatively affects the growth of white clover.

Copper, zinc

These are important trace elements for many plants. In some areas, for example, the addition of 10 pounds of water soluble copper sulfate per acre more than tripled the production of oats. Correcting a zinc deficiency markedly increases corn production (Cannon and Davidson, 1967).

Salt

There are many kinds of salts, but the one that causes most agricultural problems is sodium chloride. Many plants are highly sensitive to high chloride concentrations. Salty waters, either from surface or groundwater sources, can be very destructive to plant life. When the Romans finally destroyed Carthage, the area of the city and its surroundings were plowed and then covered with salt. The buildup of various salts in irrigated areas can eventually destroy the soil’s ability to grow plants. Rainfall is devoid of salt, but all irrigation water, either from surface water or groundwater, has some dissolved mineral materials in it. Salts not flushed out will destroy the soil’s plant growing capability. Some well water, especially deep-well water, is too salty to be used for irrigation.

Mineral fertilizers

This is a very large subject and many detailed studies have been made on plant nutrition. Just as animals, including humans, need certain minerals to survive and grow properly, the same applies to plants. Soils are analyzed and the deficiencies of minerals relative to the crops to be grown on them are added. Chief among the elements that have to be added are copper, iron, zinc, magnesium, nitrogen, and phosphorus.

As more and more studies are made of such details about soils, their mineral constituents, and the requirements of plants and animals that depend on these soils, the missing minerals are being replaced by specifically designed fertilizers. Thus the problem of mineral deficiencies is being gradually reduced.

Fertilizers not a complete substitute

Most farming now, however, is concerned with the crop yield, that is, the quantity of the product rather than the quality. High crop yields may not translate to a high nutrient content. Fertilizers can stimulate crop yield, but may not replace all the nutrients taken from the soil by successive croppings. Some crops grown on poor-yield unfertilized soils may have more mineral nutrients in them than crops grown on soils which, by using artificial fertilizers, are high yielding. This may be a serious and growing problem. The use of commercial fertilizers in the United States increased 16 times between 1955 and 1980, and continues to increase. The solution to this problem appears to be to use organic fertilizers such as animal manure, and green manures (plant debris) and to plant legumes that fix nitrogen in the soil. But the manure approach to fertilizing is more labor intensive than using artificial fertilizers. Therefore, it may not come into widespread practice, given the economics, but it is usually part of organic gardening.

Mineral-rich glacial soils

The importance of mineral-rich glacial soils to human longevity was reported by a panel headed by Dr. Howard Hopps, Professor of Pathology at the University of Missouri. The study compared death rates of men ages 35 to 74 in two 100,000 square mile areas. One was in the glaciated Upper Midwest mineral-rich soil and groundwater area, and the other was in the southeastern coastal area of parts of Virginia, the Carolinas, Georgia, and central Alabama. This latter area has a meager supply of minerals in its drinking water and soil. The report found that for every 100 men in this age range who died in a given year in the Upper Midwest region, 200 died in the coastal area.

The panel reported that cardiovascular diseases, primarily heart attacks and strokes, accounted for most of the differences in deaths between the two areas. Hopps noted that the Upper Midwest was left rich in minerals and trace elements by the glaciers that "ground up the rocks and made minerals in them available." These minerals include iron, copper, manganese, fluoride, chromium, selenium, molybdenum, magnesium, zinc, iodine, cobalt, silicon, and vanadium. In the southeast, Hopps found that, "the minerals have been leached out of the soil for millennia." He also observed that the differences were consistent, stating, "no county in the Minnesota part of the region, for example, was above average in deaths. It seemed to be an inescapable conclusion that a lot of people in the Upper Midwest must be living a lot longer." The study focused on white men to rule out the possibility of regional racial makeups affecting the results. The study concluded that trace minerals in the soil and water contribute to relative longevity for persons living in this area of glacially transported materials, compared with other areas without these new rocks from which to weather out vital elements into the soil.

Soil types and bacterial diseases

The presence of certain bacterial diseases can also be related to soil types. For example, the distribution of anthrax has been shown to be geologically related to a considerable degree. Anthrax is an infectious disease in warm-blooded animals such as cattle and sheep, and can be transmitted to humans. It is frequently fatal. It develops in areas where the soil pH is higher than 6, and the minimum temperature is 60° F. Soil conditions favorable for anthrax are associated with limestone terrains, alkaline alluvial soils, and clay soils where there is a hardpan layer. The occurrence of anthrax is rare on well-drained sandy soils or shale soils.

Minerals and national health

Can minerals in the soil, or lack thereof, affect the health of an entire population as large as a nation? Perhaps. Some recently established small-island nations of the Pacific are simply atolls — that is, coral reefs. Corals are very selective in what they use to make their reefs. The material they use is nearly pure calcium carbonate. If not for the fish that the inhabitants of these islands incorporate into their diets, their daily meals would be markedly deficient in vital minerals, because soil formed from pure limestones is very poor in essential trace elements.

More recently, with the development of international trade, isolated nations throughout the world can import a variety of foodstuffs that augment local diets and provide a greater spectrum of minerals. However, some nations lack the financial resources to import substantial quantities of food, and remain dependent on local plant life. As more and more intensive agriculture depletes the minerals in the soil in these communities, malnutrition becomes evident in their populations. This is especially true in Africa.

Minerals and healthy nations

On a larger scale, lands that have been leached by rainfall over thousands, and in some cases millions of years, like many parts of the Amazon Basin in Brazil, clearly are not nearly as fertile as the relatively fresh glacially derived soils in the Upper Midwest of the United States and of northern Europe. Correspondingly, the populations of these respective regions would be expected to have different levels of health. The advantage clearly lies with the population deriving its sustenance from fresh, mineral-rich glacial soils. Over centuries, the vitality or lack of vitality of the citizens of a nation due to the mineral content of the bedrock and its derived soils, or its transported soils, may well be a contributing factor to its destiny. Nations with better minerals in their soils will be nations with healthier populations. The health of its citizens can greatly affect the economic strength of a country. Examples frequently appear on the screens of worldwide television broadcasts, as under-nourished peoples migrate back and forth just to seek bare sustenance.

Wildlife

Most of this chapter has concerned the importance of minerals in human nutrition and for domesticated livestock, but minerals are also important in the diets of wildlife.

Serengeti Plains

It was long observed without knowing the cause that certain regions of the Serengeti Plains of East Africa attracted a particularly large number and variety of animals. Botany Professor Samuel McNaughton of Syracuse University measured the levels of 19 minerals in some of the Serengeti grasses and found that grasses in regions the animals favored had much higher levels of minerals, particularly phosphorus, magnesium, and sodium than grasses in adjacent areas.

Salt licks

Around the world, animals have shown the importance of minerals to their health by visiting natural mineral licks. These are commonly called "salt licks" although other minerals besides common salt may be involved. There are a variety of minerals that animals need in their diet. Jones and Hanson (1985), made an extensive study of the effect of minerals on the health of large game animals in North America based on salt licks.

A large salt lick in Kentucky attracted many kinds of recently extinct animals, such as the mammoth. Thomas Jefferson, third president of the United States, heard about this area and collected large quantities of bones from the salt lick in what is now called the Big Bone Lick, in Boone County, Kentucky.

Salt licks were also important to human populations because they lured animals and, therefore, were places where humans could hunt successfully. Native populations also used licks for their own supplies of salt. After the U.S. was settled, licks continued to be important to the local residents to harvest game.

Therapeutic mines, crystals, and metals — hopeful illusions

Some parts of the "health" industry are based on folklore. The ancient Greeks and Romans ascribed various powers to crystals and the lore continues. Quartz crystals are sold as aids in cures for various ailments despite the fact that quartz is an entirely inert mineral. Copper bracelets are also sold as a health aide. There is no scientific evidence for such claims.

Therapeutic ("health") mines exist in some mining districts. Interestingly, these mines are usually located close to well-traveled highways and not in more distant, difficult road-access areas. The idea is to sit in the mine and benefit from emanations of radiation or whatever the mine is reputed to have. There are no scientifically demonstrated health benefits from these situations. Financial benefits may accrue to the proprietor, and sitting in cold, damp mines may have a negative effect on rheumatism and arthritis.

Summary

It is said, "You are what you eat." We are made from what we take from the Earth. The complex chemistry of the human body is still, in many ways, a great unknown. But among the things that are known is that minerals, in varying amounts down to very minute traces, are critical to good health. Obtaining these minerals in food is vital to survival. The geology of the Earth controls the natural distribution of these minerals, and, in turn, affects the futures of people.

Chapter 16

Minerals From the Ocean

Minerals have been extracted from the sea for thousands of years. The Chinese took salt from the sea as far back as 2,200 B.C., and India's rulers appointed a "superintendent of ocean mines" as early as the fourth century B.C. Diamonds and other precious stones, corals, conch shells, pearls, and salt were taken from shore areas and shallow ocean shelves. These are still being obtained at various locations around the world. For example, Angola still mines diamonds offshore.

Nations and coastlines

Nations have their own relationships with oceanic minerals. First, there are nations with a coastline who extend their territorial rights out into the sea. Earlier, these rights commonly extended out three miles, according to the international protocols. Now these territorial rights have been extended to 200 miles under the 1982 United Nations Convention on the Law of the Sea.

Second, there are nations with little or no coastline. These countries have to obtain minerals from the sea by using the technology to go to the deeper ocean areas beyond the usual 200-mile limit and in some fashion, mine the ocean floor. They would presumably rent marine harbor facilities from some accommodating coastal country. Or these landlocked nations could get a share of what would be mined by other nations by treaty.

Landlocked countries

For many years, there has been a proposal in the United Nations by landlocked countries to have such a treaty enacted. But so far, it has not passed. Many of these landlocked nations tend to be smaller and less-developed countries. Their lack of technology and, in many cases, the lack of finances makes them unable to mine the ocean floor. Larger nations with extensive coastlines are the potential developers of ocean minerals. These nations also, as might be expected, oppose any treaty that requires them to share the wealth with landlocked countries. The U.S. is among those that voted no.

U.S. 200-mile limit

The U.S. has plenty of territory to explore. In 1983, President Reagan proclaimed the ocean area from a line three miles offshore of the coast of the U.S. and its island territories to a distance 200 nautical miles out to be the U.S. federal government Exclusive Economic Zone. Ocean areas within three miles of the shore belong to the states. Presumably this 200-mile offshore zone is U.S. territory for mineral exploration and development, as well as for management of fisheries. Counting its islands in the Pacific including the Hawaiian Islands, Midway Island, Wake Island, Guam and the Northern Mariana Islands, American Samoa, and Howland and Baker islands, the U.S. has a huge amount of ocean floor on which to prospect. The total area is 3.9 billion acres. This compares with total onshore U.S. territory of 2.3 billion acres.

How valuable this may be is uncertain because the sea floor is known in detail only in very few places. The side of the moon facing the Earth is much better mapped than are the ocean floors. The economics of recovering minerals from these 3.9 billion acres is also not well known. It is a vast frontier for the future.

The three zones for extraction of ocean resources

The mineral wealth of the oceans is found in three zones. The uppermost is the ocean water itself. Although it contains minute amounts of nearly all elements and minerals, only a few can be economically recovered from their dilute state in the ocean water. The second zone for resource extraction is the ocean floor. One example in this zone is manganese nodules, but other resources also exist. Sea floor mining has seen only limited development, but may expand in the future. The third zone lies beneath the ocean floor, from which oil has been extracted to depths of 20,000 feet or more. This zone is being exploited, but deep-ocean drilling requires very large and expensive equipment as well as a high level of applied technology. Discovery of large oil and gas reservoirs are necessary to justify the enterprise.

Extracting mineral wealth from any of these zones is far more expensive and often times dangerous than from onshore deposits. But as onshore resources diminish in both quality and quantity, the oceans are the last frontier of exploitation. There is no better symbol of the high-stakes risks and dangers of this frontier mineral extraction than the tragic case of British Petroleum's Deepwater Horizon-Macondo Well blowout, explosion, and oil spill in 2010, which claimed the lives of 11 oil workers and spilled 4.9 million barrels (210 million gallons) of crude oil into the Gulf of Mexico.

Petroleum search going seaward

Petroleum in large quantities exists near continents where sediments have been deposited along with organic materials from the ocean. Given the right set of geological circumstances, some of these sediments with organic debris, have developed significant oil accumulations. In recent years, increasing amounts of petroleum are being recovered from beneath the sea, as land areas are becoming drilled up. The first major offshore oil production came from shallow Lake Maracaibo, Venezuela, beginning in the 1930s. In the late 1930s, U.S. offshore oil production began in the Gulf of Mexico at the High Island Field near Texas. In 1946, the first oil was produced in the Gulf of Mexico out of sight of land, and since then, wells have been drilled more than 100 miles offshore.

In Norway, there is no onshore petroleum production nor is there likely to be. And in Britain, there is very little. The North Sea is the oil province of both countries, and for Denmark and the Netherlands as well, of which each has a small share.

Even the countries around the oil-rich Gulf, including Saudi Arabia, Kuwait, Iran, Qatar, and the United Arab Emirates, are increasingly moving their oil exploration off-shore. The Gulf of Thailand and the South China Sea have recently come into production, and Brunei gets most of its oil offshore. Much Indonesian oil is produced from beneath the sea. Australia's oil and gas production is almost all offshore. Nigeria, Trinidad, and Angola produce most of their oil offshore. Canada has moved offshore of Newfoundland to develop the Hibernia Field, as there are few remaining onshore prospects in eastern Canada. Canada is also moving exploration north along its Arctic coast. Mexico's big oil discoveries in recent years have occurred offshore, including their largest field, Cantarell. The U.S. has been drilling in the Gulf of Mexico for many years, as well as offshore Cali-fornia, although the latter area is now off limits to oil exploration.

In Alaska, the Cook Inlet area, adjacent to Anchorage, has been an oil and gas pro-ducer for years, and such oil exploration frontiers that exist in Alaska are along the coast and offshore. Alaska has a land area of about 586,000 square miles, but given its geology, it is exceedingly unlikely that significant amounts of oil will ever be found more than 50 miles inland. Some Alaska North Slope production is offshore, and more is planned.

Oil exploration is now moving into ocean waters deeper than 10,000 feet. We have now reached what Campbell calls the "end game" for oil from the ocean because the deep ocean does not have sediments thick enough for economic oil accumulation.

Placer deposits

For many years, shallow water sand and gravel shelves have produced tin in Malaysia, Thailand, and Indonesia. Elsewhere, along the coast of Africa, similar types of deposits are mined for diamonds and for gold. Shorelines that formed at lower sea levels during glacial times, and are now in shallow near-shore waters, were the basis for a brief gold rush to Nome, Alaska, around the turn of the century. Gold-bearing sand and gravel deposits have been dredged in New Zealand and the Philippines.

Japan, from time to time, has mined off-shore iron-bearing sands. However, tin sands and diamonds have been the most valuable items recovered from shallow ocean placer deposits, but the total amount has not been large.

Sand and gravel

These ordinary materials that are now being recovered from near-shore shallow water areas are currently the most important economic minerals mined from the sea. In areas where the development of such resources on-shore for urban areas is difficult because of environmental regulations, and the land resources that can be developed are much more distant, simply dredging sand and gravel from the adjacent ocean floor is convenient, and does not make a visible impact on the environment. Because such materials are bulky, movement by barge on ocean waters makes their transport economic. The U.S. , Britain, and Japan are the chief exploiters of marine sand and gravel, using them in such large metropolitan areas as the East Coast regions of New York and Boston, and in the London vicinity. Shallow, near-shore deposits of sand and gravel, supply 16 percent of the con-struction needs of Britain, and about one-third of those of Japan.

Manganese nodules

There are various other materials on the sea floor of potential value, including geographically extensive deposits of manganese nodules that lie in the mid-Pacific between two great industrial nations, Japan and the U.S. These nodules, about the size of a golf ball, are abundant in some places as much as a pound and a quarter per square foot, and may cover many square miles. Although called manganese nodules because of the predominant metal they contain, the nodules contain other valuable metals as well. Generally, their content is about 23 percent manganese, six percent iron, as much as 1.6 percent nickel, and lesser amounts of cobalt.

If these deposits were on land, they would definitely be considered an ore deposit. However, "ore" is not a geological term but an economic one, and defines a deposit from which a metal or metals can be extracted at a profit. Whether or not manganese nodules can be mixed for their metal content at a profit is still uncertain. Economic-grade manganese nodules are generally found in the middle of the ocean in water depths exceeding 4,500 meters. Lifting tonnages from such depths is energy intensive. However, the quantity of metal in this mid-Pacific deposit is exceedingly large, running into the billions of pounds. Also, an intriguing fact is that these nodules are continually forming. So, even with extensive mining operations, it is doubtful that as many nodules could be mined as are formed in a given year. It is an interesting situation where a mineral deposit gets larger even as it is mined. There aren't many mines like that!

Some experimental equipment has been built to recover these nodules. Results have been mixed. The question also arises as to who owns these nodules, for they are beyond the claimed territorial rights of any nation. The Law of the Sea Treaty is not yet signed by all countries. Non-signers include the U.S., West Germany, Great Britain, and Japan. At present, it seems that the "law of capture" prevails — that is, whoever can get the nodules can have them.

Phosphorite nodules

There are other mineral deposits on the sea floor including phosphorite nodules. These occur in substantial amounts off both coasts of the U.S., the west coast of Central and South America, in waters adjacent to Argentina, Japan, and South Africa, and off the central and northern coasts of New South Wales, Australia. The Australian deposits are fairly thin and poorly mapped to date, but some are known to have a quality almost equal to those of onshore deposits, with a P^2O^5 content reaching 29 percent. So far they have not been mined.

Mineral-rich brines

Considerable interest has been recently shown in the brines that form around rift zones in the ocean floor. In these places, hot waters coming from the Earth's interior reach the ocean floor and precipitate a variety of metals. In the bottom of the Red Sea, there are rift zones in three distinct basins. Here metalliferous muds are relatively rich in various metals, principally manganese, lead, zinc, copper, silver, and gold. Drill cores reveal that in some areas, the muds are as thick as 300 feet. Metal concentrations are from 1,000 to 50,000 times greater than in ordinary seawater. Analysis of some of the better deposits show a content (by weight) of 0.12 percent manganese, 0.16 percent lead, 0.70 percent copper, and 2.06 percent zinc. While these deposits are still unable to compete economically with land-based ores, they may become economic in the future.

Mineral crusts are also formed by rising hot mineral-laden waters. These have been observed in a number of places where chimneys of sorts are built up by what oceanographers call "black smokers," which actually are mineral-charged vents of hot water. Such formations are known to exist along the Gorda Ridge off northern California and southern Oregon coasts, as well as in a number of other places on the ocean floors, chiefly where ocean crustal plate junctions occur.

Around some of these hot water vents, massive sulfide deposits have accumulated with mineral concentrations ten times greater than those now being mined on land. Some 250 of these deposits have been identified worldwide. If new ventures in deep sea mineral mining prove successful, renewed interest in such prospects is likely to develop, opening new frontiers for mineral exploration, mineral mining, and investment.

In the territorial waters of New Guinea at a depth of about a mile, a "site boils with volcanic hot springs whose rocky outcroppings are laced with iron, zinc, copper, silver and gold in high concentrations" (Broad, 2003). "If you found this deposit on dry land, you'd call these bonanza figures," said Dr. Ray Binns, a scientist at the Australian Commonwealth Scientific and Industrial Research Organization, who helped discover the metal-rich zone.

Some of these areas, including the California-Oregon localities, have warranted preliminary mapping. From what is now known about these formations, they probably are not large enough or economically accessible enough to justify pursuing at present. However, it appears that this is the geologic origin of some of the mineral deposits now being mined on land that were once part of the ocean floor.

Ocean water

Ocean water itself is a tremendous storehouse of elements. In fact, most of the known elements occur in seawater in greater or lesser concentrations, mostly lesser. Gold, for example, exists in seawater in the amount of about 37.5 pounds per cubic mile, but this concentration is only 0.0005 percent. The energy cost to process that much seawater to produce that little gold is inordinate. The same is true of nearly all other elements in seawater. Concentrations are so low that it does not pay to obtain them from this source. There are some exceptions. Both bromine and magnesium have been extracted commercially from seawater (Mero, 1964). About two-thirds of the magnesium used in metal alloys comes from seawater, as does most of the bromine used in pharmaceutical products, in certain types of photography, and in gasoline.

Lastly, of course, common table salt is obtained from the ocean in many areas by allowing the water to flood into shallow salt pans at high tide. The pans are then diked off from the sea and the water is allowed to evaporate. Mexico, Thailand, and a number of other countries extract salt in this fashion. One of the world's largest salt mines is at Guerrero Negro in Baja California Sur, Mexico, covering 49,000 acres; it is a vast salt water evaporation system. Mexico exports six-million tons of salt annually to Japan (Borgese, 1985). In total, about one-third of the world's supply of common salt is evaporated from seawater.

The Future

What role all these marine concentrations of phosphorite and manganese nodules, hot brine muds, mineral crusts, minerals in solution including salt, bromine, and magnesium, and placers will play in the future of various nations is difficult to assess. So far, land-based mineral deposits are far more economic to recover than similar resources in the ocean.

But as we exploit the metallic riches on land to the point of exhaustion where only lower-grade deposits remain, the concentrations of minerals in certain sections of the ocean floor around these hot water vents may become economic to recover. Over the past many years, several companies made attempts to recover some of the metallic riches from the ocean floor. However, a combination of lack of proper technology and costs put them beyond economic reach. Lockheed Aircraft Corporation built a ship designed to mine manganese nodules from the seafloor, but the project was abandoned. With better knowledge of what very high-grade deposits do lie on the ocean floor, and much higher prices for metals, new ocean-mining venture companies are being formed. One is Nautilus Minerals based in Vancouver, Canada. Since the company went public in 2006, its stock has been purchased by other mining companies, including Anglo American, Teck Cominco, and Barrick Gold. Ocean sources may indeed become economic, but must be weighed against the energy cost needed for their recovery.

Petroleum is a special situation, and even though the costs in energy and money are high for offshore development, the rewards of successful drilling can be huge. But because of higher costs, it takes a much larger field offshore compared to onshore to justify development.

Except for the richer placers now being dredged in relatively shallow waters and the sand and gravel deposits, marine mineral deposits are too costly to recover at present. In the case of seawater, as already noted, the amount of energy required to obtain various elements by processing the huge volumes of seawater that would be involved is such that except for a very few, the economic recovery of these elements from that source is quite unlikely for the foreseeable future. Until the less costly resources on land are exhausted, these marine sources will not be seriously considered. Even then they cannot be developed if energy is not cheap enough to make it economic.

For the immediate and reasonably near future, except for petroleum, the mineral resources of the sea will not be an appreciable factor in the future of nations. Consequently, there have not been any great conflicts arise over sea-floor minerals like the conflicts that now arise over the exploitation of fish stocks. However, in areas where petroleum resources exist or are believed to exist, and where there have been no clear demarcations of national boundaries, new and serious conflicts are appearing, as in the South China Sea. This is also the case for areas between Australia and East Timor, and between China and Japan. A disputed area between the U.S. and Mexico in the Gulf of Mexico recently was settled amicably.

Chapter 17

Strategic Minerals — Just How Strategic Are They?

The arrival of the industrialized world has brought with it the concept of "strategic minerals." For the non-industrial countries, no minerals are critical except perhaps fertilizers, although many non-industrial countries do not even use those. In our increasingly technologically organized societies, some minerals are absolutely essential for industry and commerce.

From time to time, especially during war or in anticipation of war, there have been concerns about supplies of "strategic minerals." Even during peacetime, a steady, reliable flow of materials, for which there are no substitutes, is needed for industry. There is unrest in South Africa, which has almost all the world's platinum. There is political instability in the Congo (formerly Zaire) where much of the world's cobalt is found. How important are these minerals to the rest of the modern world, and, how much of a power struggle may occur over these minerals (Klare, 2001)?

A considerable difference of opinion exists about the importance of strategic minerals. Some say that strategic minerals are of great and vital concern, and their free flow through international trade must be maintained at virtually any cost. Others contend there are adequate substitutes, and these, combined with government and private stockpiles of these materials, make the prospect of the cut-off of strategic minerals at any given time of little consequence.

"Strategic Mineral" Defined

To understand the issue, the term "strategic mineral" should be defined. The U.S. Bureau of Mines advises by letter dated February 1, 1988, regarding "strategic" and "critical" that:

> There have been many attempts to define each term by a large number of individuals; however, the bureau does not make a distinction between the two

> terms. The Defense Production Act of 1950 regards 'strategic' and 'critical' essentially as the same. Section 12 of the 1950 Defense Production Act states: For purposes of this act, the term 'strategic and critical materials' means materials that (A) would be needed to supply the military, industrial and essential civilian needs of the United States during a national emergency, and (B) are not found or produced in the United States in sufficient quantities to meet such a need. The act goes on to designate energy as a strategic and critical material.

Under this rather broad definition, almost all minerals are critical that are not produced in sufficient quantity to make the nation independent of foreign supplies. Nearly all mineral materials and energy minerals are needed in some fashion in industrial and military establishments. However, in a more narrow definition and a common usage of the term "strategic" (or "critical"), it would apply to certain metals that are irreplaceable in vital industrial and military applications and exist in only a few deposits in the world, and, therefore, are not readily available to most countries. Platinum is an example.

Although oil is not a metal, it is included in the discussion because the U.S. has a Strategic Petroleum Reserve stored in abandoned salt dome mines along the Gulf Coast. Japan, with essentially no domestic oil supplies, has long had a similar reserve. China is creating one, having gone from a small oil exporter 15 years ago to being the second largest major oil consumer unable to meet its needs from domestic sources.

Strategic metals in a jet engine

A common example of minerals that are strategic is a list of metals that go into a jet airplane engine, essential to both military and civilian operations of the world. There are no adequate substitutes for these metals: aluminum, chromium, columbium, cobalt, nickel, tantalum, and titanium.

Of these metals, cobalt could be regarded as the most strategic because it is produced in so few places, and it is absolutely vital in jet engine production. In 1978, there was a civil war in Zaire, and rebels invaded the Shaba Province that produces 70 percent of the world's supply of cobalt. In May of that year, the price of cobalt rose from six dollars a pound to more than $40.

Computers

Computers are essential to modern industry and commerce, as well as to military operations. The list of critical metals needed in computers for which there are apparently no substitutes includes platinum, rhenium, selenium, gold, strontium, tantalum, gallium, germanium, beryllium, yttrium, and pure silicon.

Critical minerals by nation

Which minerals are critical and which are not depends on the country. For example, the United States has no operating nickel mines, but Canada has ample sources. Nickel is critical in the United States, but not in Canada. The United States has lots of molybdenum, a key ingredient in steel, but Japan, which makes lots of steel, has no molybdenum. Molybdenum, therefore, is critical to Japan. It is not a critical metal in the United States.

Each nation has its own resources and its own needs, and thus has a particular list of what might be called critical minerals. The vulnerability of various countries and regions (e.g., the European Union) to being cut off from particular minerals differs widely with the commodity. In minerals commonly listed as strategic, Russia is by far the most self-sufficient, and the United States is intermediate.

Relative Importance of Strategic Metals

There are also wide differences in the importance of each mineral, and the degree to which substitutes exist. Gold, for example, has only a few critical uses. On the other hand, manganese is a key metal in making steel, important to many countries, and there appears to be no substitute. Tungsten is another critical material for which there are several specific uses and for which there appears to be no alternative. Bauxite, however, the chief ore of aluminum, is critical only in the sense that it is the aluminum ore from which that metal can most easily be recovered. Aluminum constitutes eight percent of the Earth's crust. There is no shortage of aluminum in the ground virtually anywhere; ordinary clay is an aluminum compound. In the case of bauxite, nature has partly done the work of breaking the tight aluminum bond with other elements, thus reducing the amount of energy needed to recover the metal. If energy were cheap enough, obtaining aluminum from common clay would be no problem.

Generally Regarded Strategic Metals

Table 17-1 is a selected list of what are generally regarded as strategic metals that are held by South Africa and Russia. This tabulation is essentially correct, but it should be noted in the case of chromium, that there are small deposits in a number of countries around the world that have not been included in the figures. Also, uranium discoveries in Canada, Australia, Niger, and Namibia, where large deposits are already known, may change these figures somewhat. However, they are broadly accurate in that South Africa and Russia are fortunate to possess some of the more critical metals.

Table 17-1. Percentage of Selected Strategic World Metal Reserves Held by South Africa and Russia

Metal	South Africa	Russia	Combined
Platinum group	86	13	99
Manganese	53	45	98
Vanadium	64	33	97
Chromium	95	1	96
Uranium	27	13	40
Titanium	5	16	21

Source: US Bureau of Mines

Iron, aluminum, zinc, lead, and copper are also exceedingly important, but their distribution is so widespread that they are unlikely to be in critical supply at any given time.

Supplies of some minor metals are important. Without manganese, chromium, platinum, and cobalt, there would be no automobiles, no airplanes, no jet engines, no satellites, no sophisticated weapons, and not even many home appliances.

Oil becomes strategic in the U.S.

In 1920, oil was not a U.S. strategic material, for in that year, the United States produced more than three-quarters of the world's oil. The Kingdom of Saudi Arabia, founded by Abdul Aziz bin Saud in 1932, was not a force in international oil markets until later.

Now, the United States accounts for less than 10 percent of world oil production. So what was a very abundant and non-strategic material in 1920, is now in domestic short supply. Oil is a strategic mineral for the United States because it is vital to all military and civilian operations. When the U.S. established the Strategic Petroleum Reserve (SPR), it was for the stated purpose of being for "national emergencies." The capacity of this reserve is about 700 million barrels, currently equal to about 33 days of U.S. oil consumption.

As gasoline prices have risen, there are occasional demands that oil be released from the SPR to reduce oil prices. However, at best this action would have a minimal short term effect on oil prices. The SPR was not established to influence world oil prices but to be available in case of major oil supply cut-off. Pleas to use the SPR to relieve higher gasoline prices have been wisely rejected so far. Cutting down on unnecessary driving and buying more mileage-efficient vehicles would do far more in both the short and long term. The world oil market is much larger than any strategic oil supply could affect significantly. Also, the United States continues to enjoy the cheapest gasoline of any industrialized nation. The oil reserve is primarily for use in national defense.

Strategic needs will increase

The definition of strategic minerals, using the criterion of adequate supply within domestic borders, changes as exploitation and depletion of these materials proceeds, and demands increase with growing world population. In the world's major industrial countries the number of strategic minerals can only increase with time. Thus the balance of power will shift toward those countries and areas that have critical raw materials. In large number, these are today's lesser-developed nations.

Uneven geographic distribution of metals

The distribution of strategic metals is the result of myriad past geologic events that have no relationship with national boundaries. Mineral resources and energy mineral resources are very unevenly distributed around the world. The great silver deposits are largely in the Western Hemisphere near the west edge of both North and South America (Peru, Mexico, and the United States). Platinum, on the other hand, is found mainly in just two places, South Africa and a relatively small area in Russia. There is a minor deposit in Montana. These diverse locations, combined with present political boundaries, cause the problems of access to minerals by the world's economies.

Rare earths — China's near monopoly

Rare earths are a recent example of strategic minerals. There are 17 rare earths. They find widespread uses in both civilian and military equipment, in such things as medical equipment, computer monitors, cathode tubes, television sets, and night vision goggles. Mixed with boron and iron, neodymium makes the world's strongest permanent magnets. Hybrid cars would not exist without lanthanum for their batteries and neodymium magnets for their electric motors. A wind turbine may contain hundreds of pounds of neodymium. Gadolinium serves as a contrast agent in magnetic resonance imaging (MRI). In many uses, rare earths have no substitute. China possesses the bulk of economically recoverable rare earths, and currently produces 97 percent of the world supply.

In 2010, China cut its export quotas by nearly 40 percent. How much China's major position in rare earth deposits increases China's leverage in developed world economies is hard to assess, but rare earths have the potential of being a significant factor. Recently, a rare earth deposit that could be comparable to China's, has been discovered in Afghanistan, but it cannot be put into commercial production for years to come.

Technology and changing societal demands

Two factors can change the problem of uneven mineral distribution. One is that an advance in technology can devise substitutes for what are now regarded as essential strategic minerals. In December, 1988, Ford Motor Company announced a substitute for platinum in automobile emission systems. However, no substitute for platinum is known yet in many other vital uses such as a catalyst in some oil refining processes. It is also used in fuel cells, and in the treatment of certain cancers.

The second possibility is that changing lifestyles, or different social and economic systems, will reduce or eliminate the need for a particular material. However, given the desire of people in rich and poor countries alike to maintain or preferably increase their standard of living, this seems unlikely. Demand will continue to grow for minerals of all kinds.

The strategic minerals each country needs today will probably continue to be of critical importance. With increasing worldwide industrialization, the number of nations for which certain minerals become strategic will increase. As demand increases against finite supplies, higher-grade ores will be depleted first, leaving the more expensive lower-grade deposits. The supply problem of strategic minerals will grow and their cost will increase.

Strategic mineral stockpiles

From time to time, nations establish strategic mineral "stockpiles." These are hard minerals, mostly metals, not oil. This mineral stockpile idea originates from experiences in World War I and World War II, and is commonly regarded as a military measure. In 1946, the United States passed the Federal Strategic and Critical Minerals Stockpiling Act to provide for adequate supplies of industrial, military, and civilian mineral needs in time of a national emergency. This Act was reviewed in 1982 and after the demise of the Soviet Union, the goals of the act were revised downward (Dorr and Paty, 2002). Subsequent legislation authorized the Defense Logistic Agency to sell the entire stock of aluminum. The stockpile of copper was liquidated by 1994. Continual decisions are made now for each mineral, depending on need and availability.

However, it is unlikely that regional conflicts would cut off strategic minerals to any appreciable extent. And, if nuclear war broke out, it would probably be over very shortly. The answer to the concerns about strategic minerals today is simply free trade. Most metallic minerals are available to any nation through international trade channels, if they are not produced domestically.

Chapter 18

Nations and Mineral Self-Sufficiency

Previous chapters have examined the relationships of minerals to nations in a variety of ways, including how minerals affect economic development, minerals in warfare, the concept of strategic minerals, minerals and health, and minerals and the money of nations. Basic to all of these considerations is the extent to which a nation is self-sufficient in minerals. A nation that does not have resources it needs must import them and find a way to pay for them. Otherwise, the country is destined to have a low standard of living.

Mineral self-sufficiency involves several variables. A largely agricultural nation with little manufacturing needs few minerals, mostly potassium and phosphorus. Thus, mineral self-sufficiency is a function of the nation's needs, at its particular level of economic and industrial development. To some extent, it is a circular situation. A country does not need many minerals because it is not industrialized, and it may not be industrialized because it does not have many minerals. A nation may be virtually self-sufficient in minerals at a given standard of living, but if it chooses to increase its living standards, or its population, it could become very short of minerals. A highly diversified, highly developed industrial economy is likely to be short of a great variety of minerals. No industrialized nation is self-sufficient in minerals, although Russia comes close. Thus there is the variable of how much and how fast a nation is becoming industrialized.

China's rapid industrialization has put a severe strain on mineral supplies and other natural resources around the world, with a commensurate rise in price for these commodities. To gain and maintain access to minerals and resources in other countries, China also has embarked on a diplomatic course to increase its influence in strategic countries. This is being done by financially supporting internal developments (roads, mining equipment, technical personnel, and investment money for a variety of enterprises). These actions have greatly enlarged China's presence on the world scene. The short- and long-term effects are as yet unknown.

Increased population cause shortages in minerals that were in sufficient supply to take care of the earlier demand from a smaller population. For example, through the middle of the twentieth century, the United States had enough oil to supply its needs, thanks to rising demand from industrialization and a growing population driving cars, and it subsequently became an oil importer. Just steady demand for a given mineral will eventually deplete a nation's domestic supplies to the point where the mineral has to be imported. Alternatively, high-grade ores may become depleted and a nation's economy may not be able to pay the higher costs of producing metals from lower-grade ores. Mineral resources from other countries with higher-grade and less-costly minerals must then be imported. In some circumstances, by paying a price for domestic supplies higher than world prices, a nation can retain, or regain self-sufficiency in a mineral.

These variables mean precise statements about the degree of national mineral self-sufficiencies are conditional. It is a continually changing situation. An analysis of mineral self-sufficiency nation by nation becomes a huge task, and once completed, it would be almost immediately out of date. However, the degree of mineral self-sufficiency can be framed in general terms for several of the larger nations.

Smaller nations, in terms of population, are not considered in this discussion. With few exceptions, such as Switzerland, a small nation will not have an industrial base of any consequence, and therefore mineral self-sufficiency is not a major consideration.

Diverse Geological Terrains Required

To have a variety of domestic mineral resources, there must be a substantial land area. The geological occurrence of various minerals, including energy minerals, is varied. Copper and oil occur in very different geological environments. Although silver and platinum are both precious metals, they exist in markedly different rock types. Therefore, only countries with fairly large areas that include diverse geological terrains can hope to have a broad spectrum of mineral resources. The country that has had the greatest variety in a relatively small area is the British Isles, and that may explain in part why it was where the Industrial Revolution began. Now its mineral resources, including oil, gas, and coal, are depleted and to meet current needs, the United Kingdom is a net importer of these resources.

Russia

The clear leader in the possession of large and diverse energy and mineral resources is Russia. It is the world's largest country in land area, and has many different geological terrains in which a large variety of minerals occur.

Russia has the world's largest known gas reserves, the world's largest coal deposits (although it may be that the United States has the largest deposits which can be economically recovered), large conventional oil reserves (nearly three times those of the U.S.), and enough undeveloped hydropower to supply the needs of 100 million more people (Central Intelligence Agency, 1985).

However, Russia is facing a problem. As the once-prolific oilfields of western Siberia and southern Russia are now in decline, Russian oil exploration is moving northward into more hostile territory. The more accessible oil deposits have already been developed, and Russia is having a difficult time expanding its oil production. In fact, it may have peaked in 2008 (Duncan and Youngquist, 1999). Whether it will increase again is uncertain. Historically, Russia's management of its oilfields has not been of high engineering quality. Recently, Russia signed agreements with British Petroleum (BP) to help develop regions that require technical expertise.

Gas wells and gas fields take considerably less engineering management than oil production. Russia has the world's largest gas reserves, and is making good use of them both domestically and as a weapon of international influence and diplomacy. Western Europe, the United Kingdom, and southern Europe are increasingly dependent on Russian gas.

Russia's very large coal deposits perversely may have been a factor in overturning the Soviet political system in the late 1980s. Soviet coal miners went on strike for improved wages, working conditions, and benefits. The official news agency, TASS, reported that the strike threatened "catastrophe" in the steel and power industries, heavily dependent on coal. To satisfy the workers, the Soviet leader at the time, Mikhail Gorbachev, promised to double the workers' pensions, increase the number of holidays, shorten the work week, and provide a variety of consumer goods previously difficult to find, or in some cases, almost unobtainable. The settlement of the strike, which threatened to paralyze the country, set a very costly precedent that tended to further upset the Soviet economy and in a sense, moved the country further towards democracy, where ordinary citizens had a greater influence than before.

Russia is in short supply of only a few minor metals. Its iron, copper, zinc, and lead deposits are large and not nearly as fully developed as those in the United States. Lack of transportation to remote areas of the Siberian Shield, a large area of potential mineral production similar to the Canadian Shield, has delayed exploitation of the deposits. Russian metal needs can probably be met from domestic sources much longer than any other nation. Russia has far more of its original mineral resources left than the United States.

Russia has large oil reserves, and these, combined with huge gas reserves and a spectrum of metal resources beyond those of any other nation, put Russia in position to become an economic powerhouse, if its internal affairs can be managed efficiently. China is embarked on an ambitious plan to become an economic titan, but it does not have the indigenous resources that Russia has. How these two countries, partly adjacent to one another, compete in industrial development over the next decade or two will be interesting to watch. Russia clearly has the potential, thanks to its natural resource base, to become the world's industrial leader.

China

China is rapidly expanding its industrial base, and has put considerable demand pressure on a variety of raw materials, including copper, bauxite (aluminum), cement, and especially oil. China is chronically short of energy. It does have a modest variety of minerals, including the world's largest deposits of tungsten, a useful industrial metal in which almost all other countries are in short supply. China has iron ore and large coal deposits. It was these latter two resources that impelled the Japanese to invade northern China (Manchuria) in 1931. China lacks oil. It currently produces only about 4million barrels a day compared with the Russian Federation production of about 10 million barrels, and the 7.5 million barrels of the United States. At best, China can expect to produce only about five million barrels a day in the next decade, with a demand of 7.9 million barrels a day and rising rapidly. China is aggressively searching worldwide for oil supplies. This is likely to continue because China is not only expanding industrial production but is getting "wheels." Beijing's streets, once crowded with bicycles, now have American-style traffic jams.

Coal is China's principal fuel, accounting for about 75 percent of its total energy supply. This is likely to continue for some time putting China in the anomalous position of being energy short in terms of oil and gas, but also the world's largest air polluter, because coal carries the load. Under the 1997 Kyoto Treaty, China was exempt from the greenhouse gas emissions limits imposed on many developed countries. Under the 2009 Copenhagen Agreement, China is aiming to lower its carbon dioxide emissions per unit of GDP (or its carbon intensity) by 40 to 45 percent by 2020 compared to the 2005 level, as well as increase its portion of non-fossil fuels in primary energy consumption to around 15 percent by 2020, and augment the area of forest by 40 million hectares (Su Wei, 2010).

China has also embarked on a program to have nuclear power meet some of its addi-tional energy needs, and it completed the huge Yangtze River dam project for electric-ity production. But China is likely to continue to be energy short for some time. It has announced plans to increase its electrical generating capacity by 50 percent within the next few years. But under this plan, coal-fired plants will remain the main generating facilities and account for two-thirds of the capacity. However, increasing coal supplies may be difficult. Even though it has abundant coal, China seems unable to develop supplies fast enough to meet demand and now imports large quantities of coal from Australia. Lack of energy has become almost a way of life in China, as power shortages are chronic.

China's biggest problem relative to minerals and all other resources is simply that its population growth has been outpacing the resources that can be found and developed. Whatever energy and mineral resources China has, they do not meet demand as China continues to industrialize, most notably with a great increase in automobile production and use. Meeting the energy demands of a further increase in population will be a Herculean task. China is reaching around the world's energy market to do this. This is having an effect on other industrial nations as competition increases for dwindling energy and mineral supplies.

United States

At the beginning of the twentieth century, the United States enjoyed an abundance of virtually all energy mineral and mineral resources required by a developing industrialized society. This was the basis for the phenomenal growth of the United States in both indus-trial production and standard of living. It continued unimpeded until the 1960s when growing demand and lower and lower grade deposits made the U.S. increasingly a net importer of nearly all metals, and oil demand exceeded domestic production. But prior to 1960, the U.S. already imported cobalt, nickel, chromium, platinum, tungsten, vanadium, aluminum ore (bauxite), and manganese because it did not have adequate domestic sources. In 1982, Chile replaced the United States as the world's largest copper producer.

The United States no longer has the endowment of minerals, oil, and gas it once did. They were consumed as the United States rose rapidly to be world economic power. That position is declining as the U.S. increasingly depends on foreign sources for both energy and mineral supplies. In the case of oil especially, this has a negative impact on the United States' international balance of payments, which is now in the vicinity of $800 billion a year. This huge transfer of wealth also erodes the value of the dollar and raises the cost of living for Americans.

Brazil

This South American industrial giant has tremendous deposits of iron ore, and some good aluminum ore, but both of these require large amounts of energy to process.

Brazil has very little coal but has made recent large offshore oil discoveries and may even become an oil exporter. It also has large relatively undeveloped hydropower.

Western Europe

This region, including Great Britain, enjoyed a fair degree of mineral self-sufficiency in the early stages of the Industrial Revolution. But it soon became apparent to Germany, for example, that it did not have the resources to enter the industrial age for the long term. This helped spur its territorial expansion plans, which led to two world wars. Great Britain, although a relatively small country, had a rather remarkable variety of mineral resources for its use, including coal. To have this in a fairly limited geographic area was fortunate, because the various resources did not have to be transported far. The geology of Great Britain is remarkably diversified for its 94,000 square miles. The many different geological terrains in a relatively small country were also probably the main reason why the science of geology first developed here. It is a splendid, compact natural geological laboratory. However, Britain's mineral deposits were not large, and the demands of the Industrial Revolution soon depleted most of them. Britain's era of mineral and energy self-sufficiency is now history.

Canada

This second largest nation in the world in terms of area now has only a modest industrial base. Perhaps that is because it has a relatively small population and still has many aspects of a frontier area, but the industrialization of Canada is growing. To support this, Canada has a fairly good variety of minerals including iron ore in great quantities. It also has large undeveloped hydropower resources, but not all of these may be developed because of environmental factors. One example is the huge James Bay project, the latter stages of which have been at least temporarily delayed by objections from First Nations (Canada's term for Native Americans).

Today, Canada is self-sufficient in conventional oil, but will lose that self-sufficiency within the next decade. However, Canada has the world's largest oil sand deposits, and oil from that source is growing as conventional oil production declines. But there are limitations on how much the daily oil production from oil sands can achieve, which seems to be about four to five million barrels. The oil sands can be a long-term supply in modest amount.

Canada has energy and mineral resources that should support it for many years. As mentioned previously, the world's largest potash deposits are in Saskatchewan. Canada's uranium deposits can only be described as huge. Large uranium mines already exist in Ontario and Saskatchewan. Even larger deposits have been discovered and not yet put into production, but remain for the future.

Historically, Canada has been an important supplier of raw materials, especially to the United States, as well as other countries. But Canada is growing both industrially and in population, and will gradually retain and process more and more of its own resources to sustain its expanding industrial base.

India

India is the world's second most populous nation, with 1.2 billion people, and is adding about 18 million more every year. It lacks energy resources, especially oil. It is unlikely to discover major oil deposits in its territory. India has a fairly wide variety of metals, but lacks things such as chromium, tungsten, platinum, and cobalt. India and China are similar in having very large populations that use virtually all their available mineral resources simply to sustain a relatively low standard of living. India is self-sufficient only in the sense that it does not import a great many minerals because it cannot afford to do so. It must live with what it has available. It does have iron and coal, and this supports a fair-sized steel industry. But the country is very short of oil, with proved reserves of nine billion barrels, and total probable additional discoveries of three billion barrels. Even with limited oil consumption in India, substantial amounts must be imported. India is one of the 20 top energy consumers in the world, but due to its huge population, the per capita energy consumption is only about one-eighth of the world average. Per capita energy consumption is a good proxy for standard of living. India illustrates how a large population can depress living standards.

Indonesia

Indonesia has the fourth largest population in the world. It is spread over several thousand islands. Indonesia is much like China and India in having modest mineral resources that are more or less adequate for current demand. But demand is probably conditioned by the availability of the minerals. That is, if more were available, more would be utilized. Indonesia does have some nickel, copper, aluminum ore, silver, gold, tin, and a little iron ore. Of these, tin and copper are the only significant exports. Indonesia's chief mineral resource is oil. The country is currently the largest oil producer in the Far East. However, it does not really have very large oil reserves, with only an estimated 5.8 billion barrels. It is now a net importer of oil. In terms of the total industrial mineral spectrum, Indonesia is not very well endowed, especially considering its large population.

South Africa

Although the Republic of South Africa occupies only a small portion of the African continent (some 471,000 square miles, about one-eighth the size of the United States), it accounts for more than half of the continent's gross industrial production. One of the reasons it can do this is because it has a remarkably wide variety of minerals, including such rare items as platinum of which it holds about 80 percent of the world reserves. Also, South Africa is one of the few countries in the Southern Hemisphere with sizable coal deposits that it uses in its steel industry. It also uses its coal to supply about half its oil needs, by converting coal to oil. This is a fairly expensive process, which South Africa has pursued because it wants to remain self-sufficient in liquid fuel as much as possible. Oil is the principal mineral resource that South Africa lacks, and this is not likely to change, except for the possibility of making some modest offshore discoveries.

Japan

Japan has an area smaller than California, and a substantial part of it is mountainous and volcanic. Among industrial nations, Japan is the most deficient in terms of minerals and energy minerals. "Japan, a highly advanced but resource-constrained economy, is the dead canary in the coal mine for the existing growth paradigm based upon resource con-sumption" (King, 2011).

Yet Japan is the third-largest industrial nation in the world. It has achieved this despite the fact it has virtually no mineral or energy mineral resources. Japan is nearly 100 percent dependent on imported oil, has very limited coal deposits, and has no metals in any substantial quantity (some minor copper).

How does Japan survive and do so well? Japan survives by importing resources, upgrading them to finished products, and then exporting them. Without large and continuous supplies of raw materials, Japan would be paralyzed industrially. To pay for these imports, Japan must have a large volume of high-value exports. Having lost its attempt to obtain needed resources by military action in World War II, Japan chose to embark on a program of rapid and high-quality industrialization. The success of this program is evident in nearly every home and office in the industrialized world, and in the many garages where Japanese automobiles are parked. Japan knows it must import and export to survive. It is simply a factory on a few islands.

Degrees of mineral dependence

From Table 18-1, it is evident that no nation is entirely self-sufficient in metals. Russia comes the closest and has the added advantage of having a vast territory still to be geologically explored in detail. In 1928, Russia was 60 percent dependent on imports for its mineral needs. But since that time, it embarked on an extensive geological exploration program, and as a result of numerous significant mineral discoveries, it is now almost entirely independent of outside supplies.

Table 18-1. Dependence of United States, Japan, European Economic Community (EEC) on Imports of Selected Metals (Russia's premier metals position evident)

Metal	USA	Japan	EEC	Russia
Niobium	100%	100%	100%	0%
Manganese	99	97	99	0
Bauxite (aluminum)	97	100	86	30
Tantalum	90	100	100	0
Chromium	88	99	100	0
Platinum	85	98	100	0
Nickel	75	100	100	0
Tin	72	96	92	24
Silver	58	93	93	18
Zinc	53	53	81	0
Tungsten	48	68	100	14
Gold	43	96	99	14
Iron Ore	36	99	90	0
Vanadium	14	78	100	0
Copper	7	99	99	0
Lead	0	73	74	0

Source: US Bureau of Mines

World Minerals and Outlook

The industrial nations, with the exception of Russia, are now, and will be increasingly dependent on foreign sources of raw materials. Thompson (2004) has illustrated (Table 18-1) the degree to which the developed world has become self-sufficient, rather than being specialists in processing resources (increasingly imported). From this graph, it is evident that the OECD countries have a long road to self-sufficiency. When that time does arrive, it implies local and regional economies based on indigenous available resources. What this would mean in terms of sustainable population size at an acceptable standard of living is a very important question.

Where minerals exist due to geological processes of the past, and where these minerals are in demand, are, in many cases, quite different places. Can free trade compensate for this? Also, as nations increase their resource demands, individual nations will face problems paying for these materials. As higher-grade deposits are depleted, lower-grade, higher-cost mineral sources must be used. This increases the cost of minerals. A continuing transfer of wealth from mineral-consuming countries to mineral-producing nations will occur. Some nations will not be able to pay the bill and both their standard of living and their industrial development may be adversely affected. It will be an ever-changing world economic scene, in which minerals and energy minerals are destined to continue to play a controlling role.

Chapter 19

International Access To Minerals — Free Trade versus the Map of Geology

No nation is completely self-sufficient in energy and mineral resources. Resources are distributed quite unevenly in the Earth. When this reality encounters the boundaries of nations, the result is frequently a substantial difference between the places where the resource is used and the source site of the resource. This causes problems. In the past, possession of some minerals has meant the difference between life and death at times. For example, copper and tin allowed the Romans to make effective use of bronze weapons against their less well-armed adversaries. That is why the Romans fought to control the tin mines of Cornwall.

Access by war

Today, possession of or access to minerals, especially energy minerals, largely determines our material standard of living. Access to minerals in the past was frequently settled by warfare, and this has continued to the present. Japan's expansionist policy in the 1930s was primarily to secure access to mineral resources, especially coal and iron ore in Manchuria. Cutting off Japan's oil supply to inhibit its expansionist plans was the immediate cause of the Pearl Harbor attack, catapulting the United States into World War II. The U.S. probably would have entered the war anyway, but cutting Japan's oil supply and the Pearl Harbor events hastened U.S. entry.

The Persian Gulf War of 1990 was a conflict over access to minerals — the threat to oil supplies for the industrial nations of the West and Japan. Saddam Hussein needed money to pay his bills for the Iran-Iraq War, and thought that tiny, oil-rich Kuwait next door might help solve his problem. But, for the most part, the unequal distribution of minerals is accommodated by peaceable trade. Whether this will be true in the future, or whether the history of conflict over mineral resources will be repeated is uncertain (Klare, 2001). There is continued unrest and intermittent conflict in the Persian Gulf region where more than half the world's remaining oil is located.

Free Trade and Cartels

From time to time, there have been attempts to disrupt international trade by means of cartels. A cartel is a combination of commercial enterprises to use some means such as control of production of an important resource to manipulate price or profit to advantage. A cartel also can be used as a political weapon to affect the foreign policies of others. An examination of the history of some resource cartels is worthwhile to see if they can, for a protracted time, limit trade (Spar, 1994).

There are two kinds of mineral cartels. One is natural and one is artificial. A natural cartel is the result of geological processes that have distributed deposits of a particular resource to a limited area. An example is platinum. South Africa is particularly well endowed with this critical metal, and the rest of the world has very little. A single nation or association of perhaps two or three nations, which enjoy such a natural cartel has the potential to control prices. This power can only be challenged by the ability of the consuming nations to discover or develop effective substitutes, or seize the resource by force.

An artificial cartel is one in which the resource is reasonably widespread but the countries holding a substantial portion of the resource agree to either limit production to bolster the price, or simply collectively agree to raise the price. The best-known modern example of this is the Organization of Petroleum Exporting Countries (OPEC).

Natural cartels may succeed, but artificial cartels almost always eventually fall into disarray. The pattern of cartel rise and fall seems to be a fairly standard one. First, the cartel raises prices beyond what the market price would be. This encourages more production by marginal producers and smaller suppliers outside the cartel. It also encourages substitution and conservation by the end users. The cartel will then try to hold down supply by agreeing among themselves on individual quotas. This invariably does not work. Because of domestic, political, or economic demands for money from the sale of the particular commodity, individual members of the cartel will tend to cheat. Ultimately, the whole cartel is in disarray. This is what happens to OPEC from time to time. At other times, it has largely controlled oil prices.

The OPEC Cartel

OPEC is the classic cartel attempt of the twentieth and now twenty-first centuries. It has had mixed results since its creation. Production quotas agreed to by OPEC members are frequently violated, as a member country needs more oil revenues to pay for basic imports such as food, or support various social programs (subsidies of various sorts to keep its citizens satisfied), or in some cases, just to line the pockets of the ruling elite.

OPEC was established in 1960 for the purpose of raising oil prices that were then in the range of $2 to $3 a barrel. Members proposed to raise prices by limiting production. In 1959, the major oil companies operating in the Middle East and Venezuela under the oil concessions of the time owned the oil in the ground. The one exception was Iran that had earlier nationalized its oil. These investor-owned companies were called the "Seven Sisters." They were Standard Oil Company, New Jersey (now ExxonMobil); Socony-Vaccuum (Mobil); Standard Oil Company of California (Chevron); Texaco; Gulf Oil; Royal Dutch/Shell; and British Petroleum (BP).

To meet rising competition from Russian oil and maintain their markets, the "Seven Sisters" twice cut the price of oil without conferring with the governments of the host countries. Since oil income in these countries was based on taxes on the value of the oil produced, this cut their income. It so infuriated the Gulf governments and Venezuela that they quickly got together and formed OPEC. Because the oil price cuts also affected Iran, it, too, joined OPEC. OPEC was formed to restore the price structure and force the companies to consult with OPEC about future price changes (Reifenberg, 1996; Yergin, 1991). Until that time, the individual OPEC countries were not in a very strong position to complain about oil price, which was chiefly a function of the amount of oil coming on the world market. With the example of the nationalized oil industry in Iran, the OPEC members moved toward their first demand, "participation in oil production." This led to nationalization of all the oil company properties. Now OPEC has control of a substantial part of conventional world oil production and can influence prices through the amount of oil produced. How much shale oil production modifies OPEC's control of world oil prices remains to be seen.

To control the price of oil, OPEC established production quotas based on its members' oil reserves. But to increase their incomes, various members cheat on their quotas at times. Another way countries increase their allowable production is to raise their claimed oil reserves. However, this does not work well, because when one country raises its claimed reserves, other OPEC countries do the same. Oil production quotas have only been partially effective.

The brief idea of a bracket range of oil price

From 2000 to 2003, OPEC said it would keep the price of oil in the $22 to $28 per barrel price range, which they thought to be fair to both producers and consumers. However, demand increased more than anticipated and prices rose. OPEC then set a new price range of $32 to $38. That "bracket" was hardly established before all OPEC members were producing to their capacity except Saudi Arabia. The price rose to $40. Then Saudi Ara-bia announced it would increase production, but demand continued to rise, and oil rose to more than $50. The idea of an OPEC-established price range for world oil is obviously very flexible. Currently (2012), OPEC seems to believe that the price range of a barrel of oil in the $80 to $110 range is fair to producers and consumers.

Other Cartels

Cartels — an old idea

The cartel idea goes back at least 3,000 years, but in almost every case, market forces prevailed. Wheat, uranium, and sugar cartels are all history. A rubber cartel bounced along for a time but no longer exists. Coffee cartels have been tried but seem less effective in controlling prices than the temperature in Brazil is. A hard freeze does far more than price agreements to bolster that market. Conversely, good weather usually creates a crop surplus which cannot be stored indefinitely, and depresses the price of coffee.

Can cartels be successful with other minerals beside oil? There has been considerable discussion about this among Third World countries, which in many cases, are vitally dependent for income on just one mineral resource. Those that have been tried so far have not met with much success (Spar, 1994). This apparently is because the resources in question are amenable to substitution more readily than oil is, and are not concentrated geographically.

International tin cartel

The International Tin Cartel, in the late 1960s and early 1970s, raised the price of tin substantially. As a result, non-members such as Brazil and China stepped up production. Even Great Britain was able to economically open some of the long-closed ancient tin mines of Cornwall, at one time worked by the Romans. Tin users found they easily could turn to substitutes including plastics, glass, cardboard, and aluminum. In 1972, about 80 percent of the beverage cans in the United States were made of tin plate. However, by 1985, almost all American beer cans and 87 percent of soft drink cans were made of aluminum. The cartel dissolved in 1985. Most "tin" cans no longer contain any tin.

Copper cartel

At one time, there was an attempt to set up a copper cartel. In 1967, four major copper producing countries, Chile, Peru, Zaire, and Zambia, formed the Intergovernmental Council of Copper Exporting Countries. This attempt hardly survived beyond the organizational meeting, and has no influence on copper prices. The market continues to control prices which, happily for the producers, are currently near historic highs.

Bauxite and iron

In 1974, seven producers of bauxite, the name of aluminum ore, set up the International Bauxite Association (IBA). The countries were Australia, Guinea, Guyana, Jamaica, Sierra Leone, Suriname, and Yugoslavia. Similarly, in 1975, seven iron-exporting countries, Algeria, Australia, Chile, India, Mauritania, Peru, and Venezuela, organized the Association of Iron Exporting Countries (AIEC). Neither of these cartels was successful.

Diamonds and De Beers

There is, however, one mineral cartel that has been effective. Even though a zircon or the synthetic gemstone, cubic zirconium, both of which closely simulate the appearance of a diamond, can be bought for a fraction of the cost of a genuine diamond of the same size, the marketing concept that "Diamonds are a girl's best friend" seems to have prevailed. The diamond cartel is essentially one company — De Beers — because it has controlled about 80 percent of world diamond production for more than 50 years.

Two other minor sources of diamonds, Zaire/Congo and Russia, have made half-hearted attempts to break the cartel, but they are such small producers that the effects of their efforts were negligible. Realizing that, these other two sources have joined De Beers in controlling production and prices. Recently, substantial diamond discoveries have been made in Canada, but there appears to be a Canadian marketing agreement with De Beers.

What has made the De Beers-run cartel successful is the fact that it is one of the best natural cartels. Gem-quality diamonds are found in only a few places in quantity, and De Beers controls the majority of these sources. Also, De Beers is virtually the only company in the business. If there were two or three major diamond producers, this might make a difference, as total agreement all the time would be unlikely. But, since there is only De Beers, it only has to agree with itself. It is not subject to production quota cheating. Because De Beers is the only significant diamond marketer (although a few are smuggled to minor outlets from time to time), and it also controls the highly technical diamond cutting facilities in The Netherlands and Israel, it is able to allow only a limited number of diamonds to enter the market, and is doing very well in maintaining its desired price. No diamond glut has disrupted the market as happened in the past with oil. Diamonds are now made synthetically by specially designed equipment, but they are small and can be distinguished from natural diamond.

Other critical minerals

There are some other minor strategic minerals such as vanadium and cobalt, which are now in natural cartels, because they are found in quantity in only a very few places. However, none of these is a major item of commerce, and, to a considerable extent, the nations owning these minerals urgently need foreign exchange, and are not likely to cut off shipments for very long. Unhampered trade in minerals is likely to prevail.

Free Trade Can Compensate

At present, free trade can erase or at least ease the effects of where geology has placed mineral and energy mineral resources. Free trade also can adjust the balance in standards of living to some extent among countries. Resource producers' standards of living are likely to rise relative to the standards of living in consuming countries. This will result in the continuing transfer of wealth from industrialized nations to major oil producing countries. Although at times going to war over access to mineral resources has been employed successfully, this cannot be regarded as the ultimate solution to the problem. In some fashion, free trade in vital minerals and energy supplies must prevail in the future. If not, war could result, which would be dangerously destabilizing.

Using the uneven distribution of mineral and energy-mineral resources as a political weapon like the oil embargo against the United States and other parts of the western world in the 1970s, is always a possibility. There may be attempts to do this again, especially if extreme militant/religious factions control major Middle East oil producing countries. But the absence of oil revenue would be a very great hardship for any oil producer, and it is probable that whoever is in charge will have to engage in commerce with the world. Economic interdependence of the resource producers and consumers will probably be the overriding factor in maintaining free trade in mineral and energy resources. Producers and consumers need each other.

Free trade and economic globalization

Free trade in energy and mineral resources that minimizes the random geological distribution of world minerals is clearly a good thing, but free trade resulting in the globalization of economies has been disastrous for some countries.

Because of huge difference in wages, clothing, once largely produced in the United States for domestic use, is now mostly manufactured abroad. This is also true of shoes and a host of other items, as anyone can observe by reading labels on many everyday prod-ucts. Textile mills in New England and the Carolinas have mostly disappeared. China in particular, and India and other countries, have taken over these and other manufacturing jobs. Free trade has mixed effects on nations.

Evolution of free trade — mixed results

As they deplete their domestic supplies of Earth resources, free trade enables industrial nations to draw upon such resources in other countries. But a number of consequences have resulted from free trade in resources and energy sources. It has given industrial nations the illusion of a sustainable, long industrial existence. At the same time, industrial nations have surrendered increasing control of their futures to countries holding vital Earth resources. Oil is a prime example.

Free trade also has resulted in the export of jobs with higher wages and standard of living to countries with much lower wages and standard of living. One large free trade agreement, named the North American Free Trade Agreement (NAFTA), was created to integrate the economies of Canada, the United States, and Mexico. But it did not address the differences in standard of living between the three.

Free trade that transfers wealth and jobs may ultimately equalize worldwide living standards. Industrial nations can adjust only downward. Free trade also tends to erase borders, and cross-border migration has never been greater. World demographics and manufacturing centers are changing.

Some negatives

Although globalization of the free trade flow in raw energy and mineral materials has benefited industrial nations as their own resource supplies have been depleted, especially the United States, some unexpected collateral effects are clearly negative. Kunstler (2005) comments: "In America, globalization meant the accelerated dismantling of the nation's manufacturing base and its reassignment to other countries where labor was dirt cheap and environmental regulation did not apply."

Globalization and the competition in cheap labor with other countries also resulted in a huge deficit in balance of payments for the United States, principally with China. Con-siderable U.S. securities (loans) are held overseas. These are denominated in dollars, and if the dollar devalues, the inclination to hold these debt obligations decreases. Clearly the dollar has lost much of its earlier world preeminence. Remaining a high-labor cost economy, increasingly dependent on imported energy and mineral resources, is a very difficult task.

Recently, there also has been "outsourcing" of technical services to engineers and sci-entists abroad at reduced wage costs, and increasing political debate about what should be done about it. This is beyond the direct matter of minerals, but affects all of us, with large economic and social implications. Both the loss of numerous manufacturing jobs and the outsourcing of more technical positions contribute to the huge and increasing deficit in balance of international payments of the United States. Eventually, some adjustment of domestic and international economics will have to be made. Although free trade may not be a good thing for everyone, it does help to even out the geological variables of the loca-tions of basic Earth resources. But it also becomes an offshoot of Gresham's law — bad money drives out good money. Lower wages in poorer countries, if freely competitive by means of free trade, drive down wages in higher-wage countries, creating unemployment and general economic uncertainty.

Chapter 20

Mineral and Energy Development, the Environment, and Global Warming

Humans, like all other organisms, are made of materials that come from the Earth, and use resources to exist. Everything we use each day to survive, except for sunlight and the air we breathe, comes from the Earth, and must be obtained someplace by someone. This applies to all human beings, whether they are lawyers, small businessmen, corporation presidents, factory workers, teachers, homemakers, conservationists, farmers, or environmentalists. We all use materials from the Earth, each of us, every day. Every human has a continuing impact on the Earth from birth to death. This is an increasing worldwide concern, as population continues to grow at the astounding rate of nearly a quarter of a million people a day

Public Involvement

Increasingly, people are expressing their views on resource development and management. It is, therefore, important in a democracy that the various aspects of resource discovery, extraction, and utilization are widely understood. The growth of the environmental movement in the past few decades has influenced regulations under which natural resource enterprises must operate in the developed countries, and these constraints are spreading to less-developed nations.

Resources for Living

At the same time that environmental rules are enacted, it is important to remember that society has been brought to its present state of affluence through the use of these resources. A higher standard of living in material terms, means the use of more energy and mineral resources. Environmental impacts of obtaining these resources can be mitigated to some extent, but to drive an automobile, holes in the Earth have to be dug somehow to obtain the iron, aluminum, copper, and glass to build the car. Energy has to be obtained to process these materials into the car (all materials listed have to be smelted which is an energy intensive process). Energy in some form, now chiefly from derivatives of petroleum, is necessary to move the car. Getting all this energy involves environmental impacts. To lead the good life, or any life, Earth resources must be used. The more people, the more is demanded from the Earth.

Resources are site-specific

Petroleum, coal, gravel, and metals have to be produced where they occur, not where one might like them to be. As population increases, more humans are living in or near places where useful mineral deposits already exist or were later discovered. As people occupy more and more land, or set it aside for wilderness areas, there is growing conflict between resource development and the population that it supports. Many areas are now designated as permanently off-limits to any resource production. The Earth is finite and there is only so much area. Decisions have to be made as to the purposes to which each area will be put. It is important to recognize logical priorities. Providing the basics of human existence presumably comes first, but can only be sustained if the environment is preserved.

Mining mineral resources uses only a very small part of the Earth's surface. Metal mines in the United States occupy less than one percent of the land surface, but are vital to our economy. The locations of these resources cannot be moved for our convenience, and civilization, as we know it today, cannot exist without these materials. Accommodating these two facts is now causing many problems as human population increases and spreads over much of the Earth's limited surface.

Human habitation and mineral development

A hundred years ago in the United States, there seemed to be ample space for mineral resource development and human habitation. The West was thinly populated. Mining, for example, did not greatly impact inhabited areas. Frequently, it was quite the other way. Mineral deposits were discovered in remote areas, and communities grew around the mining or energy mineral producing sites. Now, however, oil and gas development and mining projects meet with increased opposition. One hundred years ago there were no such things as designated wilderness areas although there were a few national parks. Now, there are many national parks and monuments. Many wilderness areas have been established, as well as numerous state and local parks and preserves.

Furthermore, many offshore ocean areas are now off limits to mineral resource exploitation, which mainly affects petroleum operations. This is particularly true off the California and Florida coasts. The reason for this, in part, is that ocean view property is extremely desirable and expensive. Tourism in both states is also important to their economies. Therefore, the value of a pristine view, unobstructed by offshore drilling rigs or petroleum production platforms — or large wind turbines for that matter — is thought to be more valuable than the resource that might be developed. Yet both states are highly dependent on imported oil and are huge oil consumers.

In world oil consumption, the United States is first, China is second, Japan is third, and considered all by itself, California is fourth. But California has large areas, chiefly offshore, where oil exploration and development is forbidden. "Dirty someone else's backyard, not ours, for the resources we use," is the prevailing view. This ethic is referred to as NIMBY, Not-In-My-Backyard.

Locking up resources

The net result of numerous environmental rules and actions is that in the United States, and increasingly in other parts of the world, more and more land is being set aside for various purposes, and cannot be used for mineral production despite the inescapable fact that materials obtained from the Earth are the basis for human existence and prosperity. More and more people are becoming dependent on less and less land. Again, we have to recognize that everything we have, including ourselves, comes from the Earth. Locking up more resource land to protect it from development cannot continue indefinitely.

Exporting environmental problems

Unfortunately, the environmental impact each of us makes is frequently either not recognized or conveniently ignored by society. Sometimes the environmental effects of producing these vital materials are simply moved to other areas out of local or national sight – "out of sight, out of mind." Because they are needed nevertheless by one and all, including the most ardent environmentalist, these resources are simply imported from other areas, which may have less restrictive laws for mineral resource production. The citizens of New York City draw resources for their support from many distant places. The same holds true for all industrialized countries. In the United States, for example, oil is produced offshore of Alaska and offshore of Louisiana in the Gulf of Mexico to be shipped to and used in California where offshore development has essentially been stopped.

This lack of awareness or concern for the impact on a distant environment is probably more evident among urban residents than among rural dwellers, as the latter live closer to the land and have a keener appreciation of the relationship of the Earth to their existence. Wackernagel and Rees (1996) write:

"With access to global resources, urban populations everywhere are seemingly immune to the consequences of locally unsustainable land and resource management practices at least for a few decades. In effect, modernization alienates us spatially and psychologically from the land. The citizens of the industrial world suffer from a collective ecological blindness that reduces their collective sense of connectedness to the ecosystems that sustain them."

Moving the environmental impact of resource extraction to regions far from where the resources are used is, in part, economic. There are mineral deposits in the United States which, if they were developed under the rules — or absence of rules — under which some foreign deposits are produced, could be economically mined here. But because of environmental restrictions, it is cheaper to obtain these materials abroad. For example, there is a large base-metal (lead, zinc) deposit that was discovered a number of years ago in northern Wisconsin, which, due to environmental lawsuit after lawsuit, may never be developed. In the meantime, the U.S. imports base metals from Peru, Chile, Bolivia, and several African nations that have fewer environmental restrictions.

Importance of gravel pits

One example of a basic resource we use that comes from nearby localities is gravel. Gravel pits are commonplace and generally not highly regarded. Yet we are greatly dependent on them. In our homes, and all the buildings of towns and cities, and in all the highways and byways all across the country, there is a very important group of materials called aggregates — sand and gravel. They are used in very large quantities and they are heavy.

Hauling them long distances is expensive because of the energy cost, so nearby sources are used. The development of gravel pits is a frequent subject of contention, but they are necessary. Gravel pits can sometimes become an asset to the community when they are no longer needed or the supply of aggregates is exhausted, as they then are often graded and landscaped into parks, or made into ponds for local recreation.

Again, to provide all these everyday materials, the Earth has to be disturbed somewhere. If wells are not drilled or mines are not dug in your backyard, they will have to be dug in someone else's backyard. This may occur where the local population urgently needs the money for jobs or for public revenues. On a global scale, smaller nations without diversified economies will export anything of value and ignore environmental problems to obtain badly needed foreign exchange to acquire essential food, medicine, and basic goods.

Environmental honesty

If the environmental movement is to be honest about these matters, it should recognize that by locking up domestic resources, the problem does not disappear. It does "go away" — to some other place where the hole has to be dug to produce the resource. One might suggest that if the environmental movement is to be absolutely "pure" in the sense of not disturbing the Earth at all, houses, hospitals, automobiles, and factories should not be allowed, and we should all go back to living in caves. Unfortunately, like other Earth resources, the supply of caves is also limited. As the world becomes more populated, and as the populations of what are regarded as undeveloped nations are becoming environmentally conscious, the issue of the environmental impact of mineral resource development is becoming a worldwide concern.

Demands of increased population

Substantially adding to the problem is that population continues to increase. Currently 80 million people are added to the world each year, a number about equal to the population of Germany. The additional resources to support all these people must come from somewhere. Also, many relatively undeveloped countries are striving to achieve a higher material standard of living. So there is not only the problem of providing material resources for 80 million more people each year, but also increasing amounts of raw materials for the many people already here who aspire to a better existence. The so-called Third World and less developed countries account for half the world's population. The resources necessary to appreciably raise their living standards are enormous, and in fact may not be available. The problem has the potential for serious conflict.

Environmental Impacts of Mineral Production

Every day, we need metals and energy supplies, but obtaining them from the Earth has a variety of environmental impacts. Many of them have come to be regarded as negative. But it may come as a surprise that some environmental impacts of mineral developments in the past, and more recently an increasing number, may actually be useful or beneficial.

Earlier impacts mostly negative

At the beginning of the Industrial Revolution, with such a great increase in demand for energy and mineral resources, the focus was simply on obtaining these resources. This was due to the fact that these resources were seen to immediately provide an increased standard of living for the general population. Increased industrialization offered not only more and better paying jobs than the earlier largely agriculturally based economy provided, but it also supplied newly invented wonders such as cars, trains, household appliances, central heating, and many other amenities for the average citizen. The rush to develop resources to produce these things did not usually consider the environment. During the initial stages of industrial development in the United States, the population was small, the land was not crowded, and there were vast, wide-open spaces.

The early days of mineral exploitation in the United States proceeded with little regard to environmental consequences, and the results are still visible in many places. This had merit in the sense that it allowed the rapid development of the United States at minimum cost and produced a large rise in the physical standard of living of the general population. So great were the volumes and quality of virgin resources available at the time, that this could have been accomplished anyway, even if environmental costs were included. But the cost would have been greater and fewer people would have benefitted. Now there is a larger demand on lesser grade resources, and increasingly we are adding in the cost of environmental impacts. To maintain our standard of living will become more expensive.

This early impact on the environment was locally severe. In places, mine dumps in Colorado and other states still leak toxic metals into streams. The smelters built to process the ores spewed destructive fumes over the landscape, killing vegetation and giving it a desolate moon-like appearance. This is evident in such places as the Bunker Hill Mining Complex, which included a silver, lead, and zinc mine; a smelter; and zinc plant near Kellogg, Idaho, and the Ducktown, Tennessee, region. Waste material dug from underground mines remains as huge piles on hillsides or in valleys, and the holes that were once open pit mines will be visible for many centuries to come.

The relatively high sulfur content characteristic of eastern U.S. coals and associated sediments has caused havoc with many streams in West Virginia, Kentucky, and Tennessee. The underground coal mines in Pennsylvania still have fires burning in them in some places. (The small town of Centralia, Pennsylvania, has been abandoned due to a fire in a coal seam that has smoldered continuously since 1962, half a century and counting.) The result of this and other mine workings, which become unstable over the years, is that cave-ins occur in unexpected areas, sometimes beneath occupied houses. Coal exists in 37 states, and is mined underground in 22 states. It is estimated that eventually underground coal mining in the United States will involve 40 million acres, eight million of which already have experienced underground mining. Ground subsidence over coal mines is already occurring on more than two million acres. The U.S. Bureau of Mines estimates that nearly 400,000 acres of land in urban areas in 18 states may be subject to subsidence, and the total costs to stabilize these lands would be about $12 billion (Johnson and Miller, 1979).

In the East, coal companies have more recently been removing the tops of mountains and mining coal by the open pit method. The overburden is dumped in adjacent valleys, and has severe adverse effects on both the landscape and the environment that will be visible far into the future. In some regions of West Virginia where mining accounts for almost all the jobs, miners and environmentalists have clashed. There seems to be no happy resolution to this problem. In whatever form and by whatever means energy is produced ("captured" would probably be more accurate) in some energy forms more than others, there is always an environmental impact.

The classic 1939 novel, *How Green Was My Valley*, by Richard Llewellyn describes the changes wrought in a Welsh coal-mining area of Britain at a time when environmental matters were not considered. Effects still exist. Landslides from unstable mine dumps have caused the destruction of buildings and the loss of lives.

Gold placer mining in California, Colorado, Idaho, Montana, Alaska, and to a lesser extent in Oregon, has left hillside erosion scars and unsightly piles of rock in stream valleys. While operations continued, placer mining had drastic adverse impacts on water quality and aquatic life in streams. Nature will eventually heal or at least modify these wounds and scars to a large extent if left alone, but may take hundreds of years to do so.

The situation now

The current world environmental scene with regard to mineral resource development is mixed. In some areas, the situation is not good; in other places, strict laws are minimizing impacts. On the negative side, one might cite the 1980s central Amazon basin gold rush (Lea, 1984). Tens of thousands of people invaded the area and set up crude mining facilities. The panning and sluicing operations put tons of sediment into local streams much to the detriment of the fish. But possibly even more destructive was that in most operations, mercury was used as an agent to recover the fine gold. This mercury is now in parts of the Amazon drainage and can be a deadly contaminant to the aquatic life, and ultimately a part of the food chain that leads to humans. Elemental mercury (Hg) is converted by bacteria into toxic methyl mercury ($HgCH_3$), a neurotoxin. Through bioaccumulation and biomagnification, methyl mercury concentrations increase to potentially dangerous levels in organisms higher on the food chain – in carnivores and predators like human beings.

Geothermal energy is relatively clean, and for the most part, has a good environmental reputation as an energy source. However, to illustrate the fact that every resource devel-opment has some environmental impact, in New Zealand's Wairakei Geothermal Field, begun in 1950, ground subsidence of up to 4.5 meters has occurred due to fluid withdrawal. Also, there have been horizontal ground displacements up to half a meter. In The Geysers geothermal field in northern California, a small subsidence of up to 0.13 meters has occurred. However, at Larderello, Italy, a geothermal field which has been producing since 1905, there have been no ground displacements, nor have any occurred at the Cerro Prieto Geothermal Field in northern Mexico.

Studies of numerous oil and gas fields, show that ground subsidence over these resource developments is generally quite slight, if at all. The oil fields in the Long Beach area of California are an exception. In some places subsidence has been as much as 28 feet, dropping the oil field surface below sea level so that dikes have had to be built to keep out the ocean. Subsidence of land from excessive groundwater withdrawal was discussed in Chapter 13.

At present in the United States, and also in Canada, Australia, and Europe, and to some extent, in the lesser-developed countries, there are increasingly stringent regulations designed to protect the environment. Many companies on their own, beyond what the laws may require, are protecting the environment as a matter of being responsible good neighbors. The cost of compliance with these regulations can be very high and time-consuming, but it is being done nonetheless. An example is a coal mine near Centralia, Washington, where re-grading the mined area and the planting of trees is making the land as fully timber productive and attractive as it was before it was mined. Native vegetation is taking over very fast.

Some beneficial environmental impacts

There have been some unexpected benefits to the environment from mining and petroleum development. In Wyoming, where strip mining for coal and uranium is the norm, the reclaimed areas where the pits have been filled now have unleached rock and soil materials at the surface, which have been re-seeded with the natural vegetation. The unleached new soil produces much better vegetation than the old leached surfaces. An unexpected result is that deer and antelope prefer to graze on the reclaimed areas.

All across the semi-arid plains and valleys of Wyoming, where oil drilling has been extensive, there are pits dug in connection with drilling operations. These pits catch moisture and provide water for birds, small animals, deer, and especially antelope, whose numbers have benefited substantially from these features.

Offshore drill rigs

Offshore drilling has been banned in many coastal areas, especially California, where memories remain of the 1969 oil platform blow-out that spilled 80,000 to 100,000 barrels of crude into the Santa Barbara Channel (and helped ignite the modern environmental movement). Where offshore drilling has been allowed, it has encountered considerable opposition. But more recently, there are people who endorse it. These are fishermen. The legs of the drilling platforms in the ocean offer a place for marine growth to accumulate, which attracts fish. Fishermen along the Gulf Coast of the United States are particularly enthusiastic about the effect of drilling rigs on fishing, and frequently fish as close to these structures as possible. Studies by the Louisiana Artificial Reef Program show that 20 to 50 times more fish live around a drilling platform's underwater legs than on the soft bottoms nearby. Some tropical fish never seen in Louisiana waters are now abundant in the reef-like habitats beneath some of the state's 3,600 offshore drilling rigs and production platforms.

When an oil or gas field is depleted and the drilling and production platforms are no longer needed, the cost for oil companies to remove them is about $2 million each. But legislation now exists whereby Louisiana can take title to the equipment and relieve the oil companies of further obligations. It is a happy solution whereby everyone benefits, includ-ing the fish (*The Futurist*, 1995). Generally, the structures are dynamited and dropped into the ocean, where they attract and afford a home for a variety of marine organisms. Thanks to greatly increased marine life around these artificial reefs, recreational scuba diving has become popular. Other coastal states — Texas, Mississippi, Alabama, and California — are considering this concept.

The former U.S. Minerals Management Service (reorganized into the Bureau of Ocean Energy Management, Regulation and Enforcement in 2011) predicted that about 2,500 offshore drilling rigs and production platforms will be abandoned by 2014, and stated that these structures will be "a great opportunity to construct artificial reefs that we will never have again." Thus the oil industry will leave a positive legacy in this way, which will last for many hundreds if not thousands of years.

Dams: Mixed Gains and Losses

In the case of dams, environmental impacts have been very mixed. Originally, dams were thought to be environmentally benign, producing no noxious fumes like fossil fuel power plants do. Used for irrigation, dams would enable arid lands to produce crops.

In the United States, more than 85,000 dams block normal stream flow. About 5,500 of them are more than 50 feet high. But dams have proved to produce diverse, and in some instances, quite unexpected effects on the environment.

The positives

Dams have provided cheap, non-polluting electric power and flood control, although nature can overwhelm dams, as happened on the Mississippi during the great Midwest floods of 1993. Dams have brought water to previously unproductive arid areas, which now produce a variety of crops. Dams, with their reservoirs, also provide water recreation of various sorts, and often afford good fishing and hunting.

The U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service have collaborated in the creation of national wildlife refuges at a number of dams and reservoirs around the country, for example, Eufaula National Wildlife Refuge astride the Chattahoochee River alongside the Walter F. George Reservoir in Alabama and Georgia; Cross Creeks and Tennessee National Wildlife Refuges on Lake Barkley and Kentucky Lake, reservoirs on the Cumberland and Tennessee Rivers, respectively; and Choctaw National Wildlife Refuge on the Tombigbee River and the Coffeeville Lock and Dam project in Alabama. All of these refuges protect and manage habitats for migratory birds and other wildlife, as well as providing recreational opportunities for the public.

The elongated arms of reservoirs reaching back into the hills supply water for wildlife that would otherwise not be there, or at least not in such abundance. Dams and the impoundments they create, particularly in their early life, have meant big economic gains for adjacent areas.

The negatives

As communities and regions live with dams over the long term, more negative effects may become apparent. Some examples are described here.

Columbia River/Snake River

No river system has been dammed more than the Columbia/Snake system, with 30 major dams. The renowned Columbia River with its Bonneville Power System is one of the world's largest hydroelectric power producers. It is the pride of the Pacific Northwest, giving that area the nation's cheapest electric power, and luring electric-intensive industries, particularly aluminum refining, to the region. The Columbia River system also has a world-famous and highly productive salmon and steelhead (a sea-run rainbow trout) fishery. But power and fish have come into sharp conflict.

Salmon versus dams

The Columbia drainage salmon fishery, long important to the Pacific Northwest, is under stress, and many individual salmon runs up particular streams tributary to the Columbia are now extinct. In 1884, 42.2 million pounds of salmon and steelhead were caught in the Columbia River by commercial fishermen. By 1994, only 1.2 million pounds were caught. There are other causes besides dams for the decline of the salmon, but the evidence is strong that the dams are a major problem. Redfish Lake and the very small streams that drain into it in central Idaho are the ultimate destination of some of the salmon of the Columbia drainage. The lake was so named because of the great number of sockeye salmon in their red spawning colors as they return from the sea to the lake and its tributary streams to complete their life cycle. But the dams have taken their toll. To get to Redfish Lake, the salmon now have to pass four dams on the Columbia River and four dams on the Snake River.

Declining salmon runs have been apparent for some years and various attempts have been made to mitigate the problem. The dams are problems for the salmon in both their upstream migration, and also in the downstream migration to the sea of the smolts — the young salmon that have been hatched in the far upstream spawning areas and grow there to fingerling size. They must get back to the ocean to start their life cycle. But to do this, some have to pass through the turbines which turn the electric generators in the dams. This often results in homogenized salmon smolts.

To remedy this situation, turbines are shut down at times, and water is simply spilled through the dam when the smolts are migrating seaward. This results in a loss of electric power generation. A relevant cartoon once appeared in regional newspapers. It showed salmon in a fish market with a sign which read "Salmon, 700 kilowatts a pound."

This procedure for spilling water is only partially effective, however, as the turbulence of the water spilled over the dams creates a high nitrogen content that kills young salmon. An alternative is to truck salmon around the dams, and indeed, a whole fleet of trucks have been doing so. The fish also have been barged around the dams. At Lower Granite Dam on the Snake River, a tributary to the Columbia, the U.S. Army Corps of Engineers funnels from six to nine million salmon smolts into barges each year and then hauls them past seven other dams, eventually dumping them into the lower Columbia River beyond the last dam. Many scientists think that barging kills more smolts than it saves.

In 1997, there was serious discussion about removing some of the dams that lie across the historic salmon spawning routes. But the cost of doing so, together with the lost power, makes this option unattractive. Recently, however, a dam on the Rogue River in Oregon was removed. Demolition and removal of two dams that blocked salmon runs for more than a century on the Elwha River in Olympic National Park of Washington's Olympic Peninsula began in 2011 (*The Seattle Times*, September 21, 2011).

Salmon and California

To a large extent, the salmon in the streams of central California have suffered a fate similar to those in the Columbia River. The Friant Dam on the San Joaquin River eliminated a salmon spawning run of 150,000 fish. In the Sacramento River basin, the huge Shasta Dam, along with dams on the Sacramento River tributaries, reduced the 130,000 salmon winter run to about 2,000 by 1987. The salmon run remains very low. The situation in California is grim not just for the salmon, but for those who fish them. By 2008, the salmon harvest in the state had shrunk so much that the Pacific Fishery Management Council closed California's entire coastal salmon fishery, casting many commercial fishermen into unemployment.

Altered hydrology downstream of dams

Of course, dams and reservoirs impact streams and rivers at the site of the dam itself and within the "footprint" of the reservoir. This is where the shallower, moving waters of a watercourse with a current are converted into deeper, cooler, stiller waters with no current and lower dissolved oxygen levels. But the impact of dams and reservoirs is not restricted to the portion of a formerly free-flowing river they have converted into a lake. Rather, the hydrology and geomorphology of the river downstream of the impoundment is altered permanently as well. The water released from the dam is virtually free of suspended sediments, which have been deposited in the still waters of the reservoir. Thus, the released water downstream of a dam is "hungry" and tends to pick up sediments from the bed and banks of the river downstream; this erosion may or may not be problematic, depending on how the river is used and whether or not structures or resources of values line its banks.

Additionally, dams and reservoirs tend to reduce overall downstream flows (lower annual discharge of water) and to blunt or moderate the peaks of higher flows during the rainy season and floods (which is one of their benefits). For species of fish that depend on environmental cues such as higher water, stronger current velocities, or lower temperatures, these changes can disrupt critical phases of their life cycle, such as spawning.

Power and population

The problem, of course, is to supply power to the West. And more, not less, power will be needed, because the population in the area of the Bonneville Power System is expected to continue to grow. Until 1993, the Bonneville Power System had an electricity surplus, but in that year, the surplus disappeared, and all the generators were needed to harness the available water. The carrying capacity of the region's river system in terms of hydroelectricity has been reached. In the process, the salmon fishery has been severely reduced.

Bonneville used to sell their surplus power to other electrical utilities outside their service area, but when the surplus disappeared, those utilities had to make their own arrangements to provide electrical power to their own growing customer base. In at least one case, this led to the proposed construction of a coal-fired power plant on the Missouri River in Montana to replace the power Bonneville formerly supplied (USDA Rural Utilities Service and Montana Department of Environmental Quality, 2006).

Loss of fertile lowlands

In both mountainous areas and plains regions, dams may flood what were once the most fertile parts of the region, the lowlands adjacent to the rivers. In parts of Kansas, the upland areas have little topsoil. The bedrock is close to or at the surface, whereas the adjacent broad river floodplains have rich alluvial soil. These areas are flooded and lost to agriculture when dams are built. In some cases, the government had to expropriate private farmland to put in the dams, and feelings ran high in this regard. Along one highway bor-dering a flooded river valley in Kansas, local citizens erected a series of billboards which read: "Stop This Big Dam Foolishness."

Flooded water wildlife range

Another negative effect of dams may be the loss of valuable bottomland wildlife habitat. In some places, the various extended arms of a reservoir may promote growth of emergent marsh plants, bottomland or riparian woodlands, and other vegetation, and in turn, encourage wildlife. Reservoirs can also provide habitat for waterfowl (swans, geese, ducks), shorebirds, and wading birds such as herons and egrets. This is true primarily in relatively flat and fairly arid regions such as the Great Plains. However, in more mountainous regions of high uplands and deep canyons, the flooding of the canyon areas destroys the vital wintering grounds of big game animals.

At the upper end of the Columbia River System in the United States, the rising waters behind the Libby and Hungry Horse dams have flooded more than 90 miles of tributary streams, destroying more than 50,000 acres of wildlife habitat. The related need to relocate railroad tracks also destroyed 2,100 acres of wetland and riverbank habitat.

Dams and the Colorado River

The life-giving artery of the arid southwestern United States is the Colorado River. Once flowing strongly to the Gulf of Lower California, it reaches the gulf now only as an occasional trickle and sometimes not at all. Today there are more demands on the Colorado River than there is water to meet them. To control the Colorado and to allow for irrigation and city water supplies, a series of dams have been built. The two most famous are Hoover Dam and its reservoir, Lake Mead, the first one below the Grand Canyon, and Glen Canyon Dam and its reservoir, Lake Powell, just above the Grand Canyon. Both dams and their reservoirs are exceedingly important to the Southwest as sources of power, irrigation water, and municipal water supply. They also provide a variety of recreational activities. But these benefits are not without cost.

Raising and lowering reservoir levels at various times of the year has created unstable water conditions for animal and plant life. There have been significant changes in shoreline vegetation. In particular, the growth of an exotic bush, the tamarisk (also called salt cedar) has been encouraged. This plant forms dense thickets, accumulates litter, attracts obnoxious flies, and produces large amounts of hay fever-causing pollen (Potter and Drake, 1989). Also, sediment that the Colorado River once carried through to the sea is now accumulating behind the dams. In several miles of the lower Grand Canyon, large banks and terraces of mud are forming due to low flows of water. Major flood control releases of water from the dams scour out river bottom vegetation vital to fish life, and also remove the natural sandy beaches, but may bury other areas in mud.

Water levels in the Colorado River fluctuate as much as 13 feet in a day. As a result, about half the beach areas of the original pre-dam river have been destroyed. The dams have changed the entire regimen of the river and the process has altered the environment. Nevertheless, at the present time, it seems clear that the beneficial effects of the dams outweigh the negative environmental impacts. The Southwest United States could not exist as it does today without having harnessed the Colorado River for both water and power.

To provide the benefits dams in the U.S. produce, they have flooded an area equal to the size of New Hampshire and Vermont. Today, the only major river (defined as 600 miles or longer) still entirely free flowing in the 48-adjacent states, is the Yellowstone River.

Aswan High Dam — Saad el Aali

One of the most famous dam projects in recent times is the great Aswan High Dam across the upper Nile in Egypt. There is a narrow zone of greenery bordering both sides of the Nile. Beyond this lies almost total desert. Planned for three purposes, a power source, a way to irrigate a million acres of desert, and to control the flooding of the lower Nile, the Aswan High Dam was built with the aid of the (then) Soviet Union. The dam did these things, but the environmental effects have been profound, and largely negative.

With the completion of the dam in 1970, the annual flood of the lower Nile Valley was eliminated. These flood waters had been very useful because they left behind layers of new, fertile soil each year in the most important agricultural area of Egypt. Now the land must be fertilized artificially, and the approximately one million tons of synthetic fertilizer applied annually cannot replace the 100 million tons of silt previously deposited by the floods each year (Stross, 1995). And no synthetic fertilizer can equal the nutrient balance of materials, particularly the very important organic constituents, in the sediment brought by the Nile. Now, farmers who previously got fertilizer free each year in the form of nutrient-rich sediment from the Nile must buy artificial fertilizers. Many do not have the money. Also the annual floods used to wash away salts from the soil along the Nile, which would otherwise injure plant life. Now the salts are accumulating.

Because the silt load of the Nile is trapped behind the dam, the Nile delta in the Mediterranean, formerly stable and growing outward in places, is now being eroded. Before the Aswan High Dam, the Nile annually carried 42 billion cubic yards of water, with its sediments, to the delta area. Now the flow has been reduced to 7.9 billion cubic yards (Postel, 1995). The sediments carried by this much smaller amount of water are insufficient to maintain the delta against erosion by the sea. This is an exceedingly productive agricultural area, but now about one-third of the delta edge is being cut back at a rate of as much as two meters a year. Before the dam, there was a balance between building the delta and its erosion by wind and water, which was favorable to the sustenance and ecology of the region. That balance has now been lost (Stanley and Warne, 1993; Stross, 1995).

The Nile floods also brought nutrients into the eastern Mediterranean, feeding a rich plankton population. Because the dam cuts off so much of the nutrient supply, the plankton base of the marine food chain has greatly diminished. The end result is that crustacean, mackerel, and sardine populations have shrunk. The sardine catch in the eastern Mediterranean dropped by 83 percent. Some 30,000 Egyptian fishermen lost their livelihood, and the Egyptian food supply has decreased correspondingly. The dam also had a negative effect on the freshwater fishery. "Out of 47 commercial fish species thriving in the Nile prior to the dam's construction, only 17 are being harvested a decade after the dam's completion" (Postel, 1995).

The Aswan High Dam does provide canal irrigation to 2,800-square kilometers of formerly desert land. But there has been an enormous build up of the infamous water hyacinth that is choking the canals, causing greatly increased water loss through evaporation by plant transpiration. The stagnation of the waters caused by this weed, and the lack of the floods' scouring effect has resulted in a great rise of the *Bilharzia* larvae which causes schistosomiasis, a very debilitating and often fatal blood fluke infection in humans. It had been brought under control before the dam, largely through the efforts of the Rock-efeller Institute after World War II, but the disease now has acquired a new virulence and is spreading.

Analyzing all factors involved, some observers conclude that the dam and reservoir, in total, are an ecological disaster. Perhaps the observation by the Greek historian Herodotus, who traveled through the Nile region about 450 B.C., may be the last word. He wrote, " … especially in the part called the Delta, it seems to me that if … the Nile no longer floods it, then, for all time to come, the Egyptians will suffer." There is, however, another view of the dam expressed by African expert Robert Collins who says that: " … the high dam would free Egypt from being the historic hostage to upstream riparian states by providing over-year storage within the boundaries of Egypt. Whatever the demerits of the High Dam, they were rendered insignificant by that fact" (Ward, 2002).

Population growth absorbs dam's benefits

It is significant to note that Egypt's population is now increasing at a rate of about one million a year. The additional food supply provided by land irrigated by the Aswan High Dam was totally absorbed by the population increase that occurred in just the period of time during which the dam was being built.

The Aswan High Dam and Egyptian population growth is an excellent example of the race between resource development and a continually growing population. Egypt continues to grow at a far faster rate than most other countries. There are no more Niles to dam and only so much water in the Nile to irrigate desert lands. The resource base is the ultimate control, and Egypt's destiny is tied to the waters of the Nile. Obtaining money from other governments to import food supplies simply allows Egypt to ignore this basic fact, but it is not a long-term solution. Egypt's carrying capacity cannot support its population. It already relies on outside support, but its population of 83 million is projected to be 123 million in 2050.

Brazil and China

In Brazil, the largest nation in South America, large dams have been constructed to meet demand for electricity. But in the process, a number of native cultures were displaced, and large areas of rainforest were flooded. As the population grows, more dams are contemplated.

China, with 1.3 billion people and great economic aspirations, urgently needs more electric power. To meet demand for electricity, and also for irrigation water, China implemented a huge dam construction program over the past 50 years. In 1950, there were just two large dams higher than 50 feet in China. By 1985, there were 18,820. China has completed what may be the world's largest water impoundment project by building a dam across the Yangtze River, named the Three Gorges Dam. It displaced more than a million people, inundated 13 cities and 140 towns, and flooded large areas of fertile river lowlands. It also flooded the spectacular scenery of the Yangtze River gorges, and numerous archeological sites. Six hundred feet high, one and a half miles wide, and with a 400-mile long reservoir, Three Gorges is the world's largest single hydroelectric generating dam.

Dams and their reservoirs have a lifespan

When one looks at the recently built huge dams with their reservoirs, it is not apparent that they are not the permanent features they appear to be. We do not see this, because the life of huge dams with their reservoirs is longer than the lifespan of one or perhaps several human generations.

However, in the U.S. and abroad, many smaller impoundments are now simply concrete waterfalls, filled to the brim with mud. At least 2,000 irrigation dams in the United States are now useless, having been filled with sediment (Jackson, 1971). A dam built in India with high hopes of supplying long-term electricity and irrigation water saw its reservoir half filled with sediment in 30 years, and its power producing facilities rendered almost useless. In India, in eight large reservoirs, the actual rates of sedimentation were up to 16 times the projected rates. The lives of the reservoirs were reduced accordingly. A study of 132 dams built 30 to 50 years ago in Zimbabwe found that over half are more than 50 percent filled with sediment (Elwell, 1985).

Eventually, all dams and reservoirs will suffer the same fate. In the epilogue to Potter and Drake's book (1989) on Lake Powell and the Glen Canyon Dam, Professor Orson Anderson considered the future and writes:

> Will Lake Powell still be a sparkling blue lake winding among the spectacular red Triassic rock canyons, or will it be a meandering segmented river coursing through sediment-filled marshes of tamarisk? Will there still be a functioning

> dam, controlling and distributing the flow of the Colorado River, or will there be a cascade of water over a crumbling concrete ledge, a broken dam whose penstocks have long since been filled with mud?

The silting of reservoirs is a major short-term and long-term problem. It is estimated that Lake Mead, the reservoir behind Hoover Dam on the Colorado, will be filled with sediment in about 400 years. Hoover Dam will be a concrete waterfall. A raft trip through the Grand Canyon reveals benches of sediment already built up in the lower end of the canyon. In pursuing this matter of reservoir life with the governmental agencies concerned, the gist of the reply to my question of what happens when the reservoirs are filled with mud is, in effect, "Let the future generations worry about that."

The impoundment of sediment behind dams not only eventually fills reservoirs, making them useless, but it also stops sediment from going downstream as it normally would to maintain and build out deltas and marshlands, home to myriad forms of wildlife. Instead, the absence of these stream-borne sediments results in deltas being cut back by wave and current action and diminished in size. Marshlands are invaded by the sea and destroyed.

In the United States, the era of building big dams is largely over, mostly because there are very few sites left, such as the Grand Canyon and the lower Hells Canyon on the Snake River, both highly sensitive environmental areas. But in other parts of the world, South America, Africa, Asia, and even in Europe, large dam construction projects are either underway or contemplated. Canada seems to be on hold at the moment, giving the matter of large dam construction more thought.

The United States government, and the world as a whole, began building large dams (those over 50 feet high) in the 1930s. There were 5,000 such dams in 1950. Now there are 38,000, and many more are either in the planning stage or already under construction.

We now enjoy the most useful part of the lives of these relatively recently constructed big dams. We enjoy the short-term benefits, some of which, however, are already costly in terms of things such as lost salmon runs. The long-term results, when reservoirs are filled with silt, may not be so beneficial.

Global Warming, Industrialization, and Natural Climate Systems

Industrialization in some countries, largely based on fossil fuels, has made affluence and high living standards possible, which other countries would like to achieve by their own industrialization. China and India are prime examples. Their industrialization also is largely dependent on fossil fuels, principally oil and coal, and recently natural gas to a lesser extent.

There was little notice of the effects all this might have on the environment until concerns arose about global warming related to burning fossil fuels. Although these fuels eventually will be depleted and renewable energy sources will be used, fossil fuels are the current basis for industrialization around the world. By burning fossil fuels, we are putting the accumulated hydrocarbons from about a half billion years into the atmosphere. This has become a very large topic for worldwide discussion.

The "greenhouse effect"

The "greenhouse effect" is presumed by some to be the cause of global warming. The visible (shorter) light rays from the Sun go through the Earth's atmosphere with no trouble, but when they hit something and warm it, the energy is radiated out in the form of longer infrared waves not visible to the naked eye. These cannot penetrate various gases in the air very well including carbon dioxide (now over 390 parts per million), methane (now only 2 parts per million), and water vapor mostly in the form of clouds. Water vapor is the chief and most important gas in the atmosphere in terms of trapping the infrared heat waves that warm the air. The source of much of the recent increase of carbon dioxide in the atmosphere is from burning of fossil fuels, with coal, oil (and its derivatives including gasoline and diesel), and natural gas, contributing in that diminishing order. Industrial civilization has been built on fossil fuels. How significantly carbon dioxide from human burning of fossil fuels contributes to global warming is an unresolved question. Some say it is negligible; others say it is the chief factor and more important than natural climate change.

Global warming is discussed in dozens of books and hundreds of articles in current circulation. These cover a host of considerations, such as the use of coal to fire power plants for the world's growing electric power demand; China's and India's coal plant expansion plans; carbon dioxide in exhausts from conventional internal combustion engines; melting of glaciers and permafrost; submerging islands and coastlines; drought and floods; the Kyoto treaty; and many other issues. Reviewing much of this body of work, these are what seem to be the salient facts:

1. The Earth is in a long-term gradual warming trend, as we emerge from the most recent ice age.

2. Within this long-term trend, there are oscillations with both warmer and colder climates than at present.

3. The Medieval Warm Period (900-1300) was warmer than the present, among other things, luring Vikings to Greenland. It was a time when there was virtually no industrialization, fewer than a billion people on Earth, and the carbon dioxide content of the atmosphere was lower than at present. The "Little Ice Age," beginning about 1300 and lasting into the 1800s caused the demise of Viking settlements in Greenland and had no apparent relationship to atmospheric carbon dioxide content.

4. Carbon dioxide is only one of several gases affecting climate. Water vapor is the single most important and abundant atmospheric gas with more total effect on the atmosphere than carbon dioxide.

5. Sea level and ocean shorelines are among the most unstable features of the Earth's surface. Large fluctuations are known from recent geologic times, apparently not related to the amount of carbon dioxide in the atmosphere.

6. We have established civilizations (locations of cities on coasts and agricultural zones) based on the idea that the present climate and sea level will not change. They will. It is very doubtful that humans can do much about this, except to accept and adjust to changes as they have done in the past. Climate has always changed and always will. Nevertheless, in 2009, the U. S. House of Representatives passed HR 2454, legislation designed to prevent the Earth climate from changing, which, if achieved, would be the first time in four billion years it has happened.

7. Significant changes in climate are evident in relatively recent times. The Sahara Desert, stretching across all of northern Africa, was grassland where nomads grazed livestock and rivers and lakes existed not long ago. In the Libyan part of the Sahara, I have seen dried lake beds and the bones of large grazing animals nearby. At the height of the Roman Empire, Romans built revetments, now abandoned for lack of water, to direct the then-available water to irrigate crops. North Africa was an important granary for Rome,

and the harbor, now filled with sand at the once-great Roman city of Leptis Magna on the Libyan coast, is lined with the ruins of warehouses for storing grain for shipment.

> What really caught the attention of climate scientists was the observation that many of these events, including regional average-temperature increases of more than 15° F, happened over mere decades or even years …. Rather than shifting smoothly from one set of conditions to another, the world climate systems tend to change abruptly — flip-flopping between stable states and spending little time in between. Climate surprises appear to be the rule, rather than the exception of climate change (Overpeck, 2000).

8. "Climate change" has become politicized, giving rise to strong emotions on both sides.

9. Climate is a complex system resulting from the interaction of many forces ranging from solar variations to ocean currents. Trying to model such interactions is exceedingly difficult, perhaps impossible given the present state of records and knowledge.

10. The logical response is to adjust to climate changes as they occur. Over a human lifetime, a trend in changes may actually be temporary, and actions taken at one time may not be appropriate just decades later.

> Many social and economic decisions are based on the assumption that the climate of the next year, next decade, and even next century will be much the same as that of the last 30 to 50 years. But continuing this way could become a costly mistake, particularly as we enter the new millennium, because we now know that climates are always changing. 'Normal climates' are just snapshots along the way (Overpeck, 2000).

Natural systems may well dominate human efforts or effects. "Human forces are orders of magnitude lower than the natural forces that drive climate" (Plimer, 2009). Human activities may only be enhancing a natural trend toward a warmer climate.

11. The current heated debate over climate change will be ongoing for decades, while climate continues to change as it always has. The recent increase in carbon dioxide content of the atmosphere is well documented. Its effect on climate is uncertain, but cannot be ignored.

The population factor

If population growth promotes more industrialization with more power plants, more cars and trucks on the road, and is a significant factor in global warming, then those concerned with global warming should also be concerned with population matters. Professor Tim Dyson of the London School of Economics argues that the positive effects of a 40 percent cut in per capita carbon emissions in the developed world would be completely canceled out by global population growth by 2050.

India and China

India, with a population now 1.22 billion and projected to be 1.75 billion by 2050, has stated flatly it will not accept any emission restrictions interfering with planned economic growth to support its population. In 1951, there were an estimated 3,000 cars in India. By

2005, there were 85 million, all burning either gasoline or diesel fuel. The recent introduction of the "people's car" will put additional millions of cars burning gasoline on India's roads over the next decade. A greatly enlarged highway system is being built to accom-modate this growth.

China is putting one coal-fired power plant on line each week, generally lacking significant pollution controls. The United States has no ready means to determine what levels of emissions come from either China or India. There is little reason to think that much can be done about this.

Huge and rapid changes

Included among the plethora of articles and books on climate, expressing varied views, Richard Alley, Professor of Geosciences at Pennsylvania State University (2000), describes a study of two continuous miles of ice core from the Greenland ice cap. In regard to the changes of climate that occurred after the end of the Younger Dryas cold period, about 11,000 years ago, he finds there were huge climate changes. He says:

> …how huge were the changes, and how rapidly did they happen? The answer is: Really huge and really fast…. The Greenland ice cores and other records show that climate changes large enough and rapid enough to scare civilized peoples have occurred repeatedly in the past, and that our civilization has risen during an anomalously stable time…. Greenland ice cap cores and many other records show that the climate of the last few thousand years is about as good as it gets…. Will nature, or humans, return the climate to the 'normal' condition of wild jumps rather than 'anomalous' stability we now enjoy? And if such a return seems likely, is there anything we can do about it?..The stable-isotopic record is that the surface of Greenland warmed by about 15° F in a decade or less. And this phenomenal change is supported by a completely independent thermometer…. What are the odds that natural or human activities will trigger abrupt climate change big enough, fast enough, and soon enough to enter into economic discussions? The simple answer, again, is that we do not know…. The study of abrupt climate changes really is in its infancy…. We do know that abrupt climate changes could happen and that human activities make large, abrupt changes more likely.

Alley concludes: "Change is the only unchangeable reality, and change will continue."

Climate will change, gradual warming probable

This said, then perhaps the conclusion reached by Richard Lindzen , Professor of Meteorology at Massachusetts Institute of Technology (2009), who writes, "the climate science isn't settled," is the proper answer regarding human effect on climate warming. Looking at climate more broadly, it appears that, with modest interruptions of colder intervals in the trend, we are coming out of an ice age, and that previous interglacial times were warmer than now. Climate, whether dominated by the effluents of our industrial civilization and increased population or by natural trends, is likely to gradually warm over the next several centuries at least. Adjustments are inevitable. Henry Pollock , a member of the United Nations-sponsored Intergovernmental Panel on Climate Change (IPCC), and professor of geophysics at the University of Michigan for more than 40 years (2009), says: "Unfortunately there is no course of action that will freeze today's status quo and forestall any further changes. Change is under way and is certain to continue because of inertia in both the climate system and the global industrial economy. It is impossible to stop these systems. They each have momentum analogous to that of an aircraft carrier trying to change course …." Recognizing inevitable climate change, he suggests some "strategies for adaptation."

Methane release

Given the roughly twenty times greater influence that methane has on atmospheric warming over carbon dioxide, global warming's release of methane from the methane-rich frozen tundra in high latitudes of the Northern Hemisphere may exacerbate atmospheric warming. As oceans warm, some of the methane locked in gas hydrates occurring in many areas of the ocean floor also may be released. Methane releases from thawing permafrost and from gas hydrates in the ocean already have been observed.

Sea level will rise — and fall — and rise — and …

Sea level is probably the most variable of the major features of the Earth's surface. The likelihood is that the long-term worldwide warming, from whatever source, will continue to melt glaciers holding most of the fresh water on the Earth. Sea level seems certain to rise. Terraces, including some as high as 17 feet above current sea level along the Oregon coast, and wave-cut benches around the world testify to such events many times in the past. All communities located near or along ocean shorelines are at risk.

Human habitation on low-lying oceanic islands or in cities or other developments near sea level is based on erroneous assumptions that sea level remains constant. Even a casual geologic inspection of ocean coastlines shows that sea level is always changing.

With half or more of the population of Bangladesh living on a delta, anticipating a sea level rise displacing that population, India is building a fence on its eastern border with Bangladesh to prevent the anticipated flood of refugees that would compound its already large population problems. Probably the place most immediately threatened is the Maldives, a small group of islands barely above sea level, about 300 miles southwest of the southern tip of India. A Maldives representative at the United Nations Climate Change Conference in Copenhagen in December, 2009, pleaded with participants to save his country from the ocean. However, it is doubtful any action by other countries can halt rising sea levels.

In the past, people rarely understood the geologic facts of ever-changing sea levels, and they built in areas we now know to be at-risk areas. But, now that we have knowledge of the risk, further development in these areas should be carefully weighed against what seems certain to be a rise in sea level in the foreseeable future. Various estimates have been made for how soon and how much sea level will rise from the melting of various portions of existing ice sheets. One meter by 2100 is a common estimate. All estimates indicate further shoreline and near-sea level development should not proceed. Some low-lying sites may have to be abandoned. Earth's processes and rhythms will inevitably prevail.

A geological perspective on global temperatures is treated extensively in a volume edited by Gerhard and others (2001). Gerhard, in other publications, has expressed reasoned doubts on various aspects of the warming causation controversy (Gerhard, 2004).

Mitigating climate change

If some part of climate change is anthropogenic (human caused), then mitigating efforts may be of some help (e.g., drastic cuts on atmospheric emissions). *The Economist* (Special Report, December 5, 2009) entered this discussion:

> The trouble with mitigating climate change is that the benefits are uncertain and distant. Compared with investments that deliver clear benefits in the near future — such as education in developing countries, for instance, which commonly produces returns around 10 percent a year — they do not look worthwhile. Conventional analysis would, therefore, suggest that those who want to make the planet a better place should invest in schools in Malawi rather than in clean energy.

Unfortunately, for those hopeful of seeing early results from efforts to modify climate change, "Nothing can be done to reduce the global warming effects expected in the next several decades. They are already locked into climate change" (Kerr, 2011).

Whatever proportional role human actions or natural causes have on the warming trend, it seems inevitable that the result will include sea level rise and agricultural production shifts. In various regions, rainfall will either increase or decrease.

All emissions reduction laudable — transition to post carbon future inevitable

Regardless of what effect atmospheric carbon dioxide may or may not have on cli-mate, reduction of all emissions seems a worthwhile course to pursue. The "killer" smog that afflicted London some years ago, the persistent Los Angeles basin smog (detectable far inland), and the notoriously bad air quality in Beijing are human-caused and related to burning fossil fuels. As the eventual transition to a post-carbon fuel economy is inevitable, pursuing an early start will surely do no harm and probably do considerable good. Although there will be an economic cost to transition to more expensive and less convenient alternative energies, sooner or later it must be faced. An incremental and early tran-sition will be less stressful than a rapid shift.

More obvious problems are population growth, resource depletion, environmental destruction, and the degradation of fertile soil and freshwater resources, while nearly half the world's population is malnourished. Soil and freshwater are essential to food production for our seven-billion human population that is expected to be 9.2 billion or more by 2050, when worldwide food supply problems are likely. Concern over climate change, now the center of much of the world's political attention, may be displaced by more immediate problems. Food supply will surely be one of them.

Oil Spills in Perspective

Much of the world's oil moves by ship. Until the U.S.'s self-sufficiency in oil ended in the 1960s, most oil used in the U.S. was transported within the country by pipeline. Imported oil requires sea transport, and spills at sea occur as a result. The Exxon Valdez spill in Prince William Sound, Alaska, is one of the more infamous of such disasters. Numerous other spills have occurred. In 1996, the tanker Sea Empress ran aground off the coast of Devon in southwest England. Twenty-million gallons of oil were spilled, about twice the amount of the Exxon Valdez spill. The spill encircled Lundy Island, a marine nature preserve, and ranked as one of the 10 worst oil spills in the world.

Accidents are an unfortunate fact of life. Vehicle accidents happen on highways simply because people drive. Marine accidents, like accidents on land, can be caused by storms, fogs, or other weather problems. They are largely unavoidable and unpredictable. Mechanical failures also cause accidents. As long as people drive gasoline-powered cars, and oil is transported by sea, spills will occur. Efforts can be made to minimize them, but they are not likely to go away. The only way to avoid oil spills is not to transport or use any oil.

Weber and Gradwohl (1995) report:

> Although estimates vary, tankers and freighters are the source for 42 percent of the estimated 25 million barrels of oil entering the oceans every year — about 100 times the entire spill from the Exxon Valdez in 1989. Two thirds of the oil from marine transportation comes from routine operation of vessels including the discharge of oil in ballast water, of oil washed from tanks for storing oil, and of the sludge from fuel oil used to power these vessels. On average, spills from tanker accidents release nearly 3 million barrels of oil into the oceans each year.

"Citizen oil spills"

It is important to understand that whereas the Exxon Valdez spill was about 10 million gallons, and created worldwide outrage, the United States dumps 20 to 30 times as much oil onto the ground and into storm drains each year through do-it-yourself oil changers. Estimates are that less than 25 percent of the oil from this source is collected and recycled. The rest is believed to be disposed of improperly.

Natural oil seeps

In petroleum regions, oil seeps out of the ground naturally. Locally, seeps may exude large amounts of oil for many years. Nearly all major oil fields including those lying beneath the sea, exhibit some surface seeps. Around the world, it is estimated that about 1.8 million barrels of oil are discharged into the sea annually by natural oil seeps. At Coal Point west of Santa Barbara, California, a large shallow underwater oil seep continually leaks as much as 150 barrels of oil a day. A recent study showed that the western part of the Santa Barbara channel is not well-suited for oil production because of the high tar content of the oil, and that much of the oil and tar on the beaches as well as releases of gas and air pollution result from the enormous volume of natural seepages in the area. If the area was drilled and oil produced, these naturally caused polluting effects would be lessened.

Alaska Pipeline and the Environment

One of the most bitterly fought battles concerning perceived danger to the environment from a mineral resource development, involved the construction of the 800-mile pipeline from the Prudhoe Bay Oil Field on Alaska's North Slope to the shipping terminal at Valdez on the southern Alaskan coast. The Prudhoe Bay Oil Field was discovered in 1967. Subsequent drilling proved it to be the largest single oil field ever found in the United States. The only feasible way to get the oil out of Prudhoe Bay was to build an 800-mile pipeline across large areas of permafrost, and over three major mountain ranges, including the Alaskan Range, with the highest mountain in North America. It was one of the largest engineering projects ever undertaken anywhere.

Perceived environmental impact

Opposition to the pipeline construction was intense. Articles and books predicted numerous catastrophes from earthquake rupture of the line to the prevention of the caribou from migrating. Pipeline opponents said the warm oil pumped through the pipeline would cause all sorts of damage by thawing the permafrost. There were fears that wildlife all along the pipeline route would be adversely affected. Environmental protests and related legal proceedings delayed the building of the line for several years.

Actual impact

Despite vocal opposition, the pipeline was built. To see what actual impact the pipeline made, I visited Prudhoe Bay in 1992, and followed the pipeline from Prudhoe Bay to its terminal at Valdez. None of the predicted negative environmental impacts was apparent. Where the pipeline crosses the permanently frozen ground (permafrost) from Prudhoe Bay to a short distance south of Fairbanks, it is elevated nine feet above the ground. The support structures have miniature self-circulating refrigeration systems in them, which prevent the steel supports from conducting heat to the ground and thawing it. This is necessary to keep the pipeline stable. South of Fairbanks, where there is no permafrost, the pipeline is buried.

Caribou and Prudhoe Bay oil

In the Prudhoe Bay Oil Field, where the greatest oil-related activity is, the caribou herd has grown from approximately 3,000 when the field was discovered to more than 15,000 today. The caribou graze extensively over the field and move beneath the pipeline unconcernedly, and there is no barrier whatsoever to their movement.

All along the elevated pipeline, animals including moose, caribou, bear, and wolves pass freely beneath it. A major highway follows the general route of the pipeline south of Fair-banks to Valdez. Traveling the highway, it is hard to see where the pipeline is buried. The only readily visible facilities are the several pumping stations built along the route. Helicopters and ground personnel maintain a 24-hour watch the entire length of the line.

Importance of Alaska Pipeline to U. S.

If the pipeline had not been built, it would have negatively affected the U.S. balance of payments, and further exacerbated U.S. currency problems. Although it did not solve the ultimate problem of U.S. dependency on foreign oil, it mitigated the problem for a time.

Area involved in oil production

The North Slope of Alaska is the area between the foothills of the Brooks Range to the south, and the Arctic Ocean on the north. It is an area of approximately 69,000 square miles. Oil development, including Prudhoe Bay and some nearby smaller fields, occupies about 400 square miles or slightly less than six-tenths of one percent of the total area of the North Slope. The actual area involved in various installations is, of course, much less than that. Wells are drilled directionally from gravel drill pads, with 16 to 40 wells per pad. The drill pad occupies an area of 20 acres or less, but the wells drilled from this pad produce from an underground area of up to six square miles. Using a drill pad and directional drilling greatly reduces the need for roads connecting well sites. All together, in the 400 square miles of the oil field less than 15 percent has any road or installation on it. This is less than one-tenth of one percent of the North Slope.

Arctic National Wildlife Refuge (ANWR)

This area is of great environmental concern. About 92 percent of ANWR is already designated a wilderness area by Congress, and is off-limits to any kind of development, oil or other. The rest of the refuge was specifically set aside by Congress for possible oil exploration. But the environmental debate over even this eight percent continues. With the U.S. now importing more oil than it produces, resulting in a negative effect on the balance of international payments and the dollar, the matter of ANWR and its potential oil is a relevant topic. The commonly held impression, fostered by environmental interests, is that oil exploration would take place over the entire refuge. This is not true. It is important in any discussion to know the facts.

The facts of ANWR and oil

The entire refuge covers about 19 million acres. The coastal plain, which is the only area of oil interest, is 1.5 million acres, and is that part set aside by Congress for oil exploration. Oil company estimates are that at full development of what are believed to be the petroleum resources there, no more than one percent of the coastal plain would be involved. In terms of the entire refuge, this means that oil development would involve 15,000 acres. Current permafrost transport technology, combined with directional drill-ing, probably would reduce the area affected to 2,000 acres. Therefore, out of the total 19 million acres in ANWR, oil development would use less than eight one-hundredths of one percent (<0.08%). The U.S. Office of Technology estimated that the "footprint" of human activity on ANWR, if oil is discovered, would actually cover only about 7,000 acres, which is less than the area of Dulles International Airport in Washington, D.C.

The coastal plain of ANWR is now the best prospective area for a major oil discovery in the United States. It has been rather thoroughly studied by oil company geologists and the U.S. Geological Survey (Bird and Magoon, 1987). No threatened or endangered species call it home.

A suggestion and a view

There is debate about how much oil is recoverable in ANWR. Why not allow the U. S. Geological Survey to drill a very few test holes and see what is there? This would clarify the situation. The area may or may not be worth developing. There is a broader view which might be taken of ANWR. Assuming there is a modest amount of oil there, its production would simply allow the United States to continue a bit further along its unsustainable path of oil use. It would only delay the ultimate and inevitable decision to move to other fuels.

Some Positive Environmental Trends

Recent assessments of environmental trends contain some encouraging facts. Acid rain from burning coal is declining. The 23 million tons of sulfur dioxide put into the atmosphere in 1970 by U.S. power plants is now more than cut in half. Recently introduced reformulated gasolines have the ability to substantially cut automobile emissions. Improved jet airplane engines burn about 30 percent less fuel than previous generation of planes. Greatly improved water treatment facilities have made the use of water supplies much more efficient. A very important positive trend is increased access to safe drinking water. Between 1980 and 1990, Mexico increased such supplies from 73 to 89 percent, Zimbabwe from 52 to 84 percent, India from 42 to 73 percent, Myanmar (Burma) from 21 to 74 percent, and Nepal from 11 to 37 percent. Similar large gains were made in a number of other countries. Because water is the chief carrier of disease in many countries, the increase in safe water supplies is a major step in improving the health of these areas.

Excess optimism

Gains have been made, but some environmental pessimists frequently see only the dark side of a situation, and so too may environmental optimism become excessive. For example, suggesting that the arid Southwest United States may be among the most appropriate places for large populations of people to live because solar technology will make it all possible, ignores reality. Solar energy cannot create water. Even if solar power could operate the pumps for groundwater sources, such sources in the arid Southwest are simply not adequate to sustain large populations.

One recurring statement of environmental optimism holds that if the majority of U.S. automobiles were pushed to a 45 mpg standard, petroleum imports could end. It is altogether unrealistic, because it ignores the increasing number of cars on the road, and our increasing population. It is unfortunate that such misleading statements appear. The general public has little ability to evaluate them and is given a false sense of security by them. On both sides of the environmental debate, facts and realism are in order.

Solar and wind

These electric power sources are often cited as free of environmental impacts. Although they each have low impacts, the development of their equipment and sites must be considered. The area beneath solar panels cannot be farmed. Many solar energy areas, however, would be deserts, so the inability to farm beneath solar panels would not be a consideration. Agriculture often is compatible with wind mills. In both cases, however, the equipment has a limited life span. Things wear out. In the case of solar cells, they are increasingly made of relatively rare Earth materials. To manufacture, replace, and repair both wind and solar equipment, resources must be taken from the earth.

Biofuels

These are also promoted as having little or no impact on the environment. It is true that burning them may be less objectionable than using gasoline, but biofuels are vegetable crops of various sorts and the environmental impact of growing them and using them may be considerable. Growing corn is a source of much soil erosion, and, as noted previously, if cellulose is used and not returned to the soil, the soil is depleted of humus, the single most important ingredient in a healthy fertile soil.

Society's Choices and Priorities

There is no question that development of mineral and energy mineral resources has an impact on the environment. Mitigating these impacts can be done in various degrees, but the question becomes two-fold. One is the cost of completely repairing or reclaiming the landscape. Currently some jurisdictions require that open pit mining operations restore the land to its approximate original contour. This can be done more easily in some mining operations than in others. In the case of coal mines, the thickness of the coal bed is generally less than 50 feet and, therefore, the amount of material taken from the ground is not large. It is possible to restore the landscape quite easily. The strip-mine operation moves along, and the overburden of the coal seam, as it is removed, can simply, conveniently, and economically be thrown over the previously mined area. When the mining operation is completed, the land can usually be graded into relatively smooth contours at modest cost. In some areas, leaving the pits as they are has provided ponds and recreational facilities, and valuable wildlife habitat.

However, in open pit metal mining operations, the entire rock material containing the metal is removed. In the case of copper ores in the United States, as little as four-tenths of one percent copper or less exists in the ore. Although this is a very small part of the ore, the entire mass has to be transported to the mill usually some distance away where it is crushed, and the copper is removed. Moving all the waste material back to the mine is very costly, but it could be done. But to do so might make the operation unprofitable.

Although mining may create a huge local landscape such as the copper mine at Bingham Canyon, Utah, metal mining operations actually occupy only 0.02 percent of the land in the United States. This is 0.02 percent of land that is vital to our economy (Dorr and Paty, 2002). Non-metal mining occupies a larger area. Coal production and sand and gravel operations account for most.

Do people want to use the materials?

In considering environmental impacts of mineral resource production, the first question is simply: Does society want to have use of the materials that mining metals, non-metals (e.g. sand and gravel), and coal, or oil and gas that drilling provides, even if such activities in some cases scar the local landscape? Or, to put it another way, do you want to live in houses, keep warm in the winter, cool in the summer, and drive automobiles made of steel and powered by gasoline? Do you want to have electricity in your home and office? It is produced by coal-fired, oil-fired, natural-gas fired, or uranium-fired power plants, or by dams. Producing the things that people demand has an environmental impact. Obviously people need to use Earth resources. There is no alternative.

Environmental economics — who will pay?

The second question is whether society is willing to pay all the added costs that may be involved to mitigate the environmental impact of mineral production. In some cases, such as some coal mining operations, the answer has been yes. But in many metal mining operations, restoring the landscape would be so costly as to make the project uneconomic. Then it is a choice of leaving the open pit as it is, and having the economic advantage of having the domestic production of a useful metal, together with employment, or not producing the metal, and having to import it with an increased balance of payments problem, and not providing employment.

Environmental concerns over such local impacts should also be weighed against exporting a problem to areas where local citizens have little or no say in the ethical use of resource lands. "If not here, where?" should be part of every environmental review that would simply export the extractive activity to parts of the world where there is much less concern for human or natural environments. Exporting environmental problems does not help the world environment. In some places, this already has had a very negative effect.

Land-use priorities

The amount of land involved in new mineral production each year in the United States is less than 50,000 acres. The majority of this is for coal mining. In comparison, to accommodate what is generally called "economic development," basically a reflection of population growth, about one million acres of land in the United States is paved over annually or used in various developments and cannot easily be reclaimed. This includes housing projects, shopping malls, factories, stadiums, golf courses and other recreational facilities, and roads. All these are required by a growing population. Yet none of these things could be built without the use of minerals and energy supplies that use up far smaller land areas in their production, many of which are reclaimed essentially almost to their original form.

Mining has disturbed less than one percent of the land area of the United States to produce all the minerals consumed since 1776. About one-third of that area has been reclaimed. This includes all the iron, copper, lead, zinc, molybdenum, and other metals, and coal, all of which have been absolutely indispensable to building the U.S. economy.

Also, land used for houses, factories, shopping malls, and golf courses is relatively flat, commonly fairly good land that could be used for agriculture. This contrasts with many mining areas in mountainous areas not generally suited for crops. Many oil fields are also in fairly rugged terrain, desert regions, or offshore — hardly farming country.

Yet, the hue and cry over mining and drilling operations essential to economic development tends to be much greater than complaints about housing projects and shopping malls (although there are some voices raised about that also). The proliferation of golf courses seems to be popular. An expanding population needs more space on which to live, increased recreational facilities and areas set aside for recreation, and correspondingly increasing energy and mineral resources. Inevitably, this has an environmental impact, beyond what would be needed simply to maintain a stable-sized population. People must recognize the choices they are making.

Individual lifetime environmental impact

If one is concerned about the environment, the place to start is with birth control. Hall, et al.(1994) cited some interesting facts about the lifetime environmental impact of one baby born today in the United States. From birth to death, the child will generate 13 tons of waste paper, 10,355 tons of waste water, 2.5 tons of waste oil and solvents, 3 tons of waste metals, and 3 tons of waste glass. From the manufacturing processes, mining, and agriculture used to support this individual, there will be 83 tons of hazardous waste, 419 tons from mining (not including coal mining), 197 tons from manufacturing in general, 1,418 tons of carbon dioxide, and 19 tons of carbon monoxide. During a lifetime, there will be 1,870 barrels of oil and 260 pounds of pesticides used to produce the food to sustain the individual. Given present concerns about the environmental impacts of various endeavors, it has been suggested, only partially in jest, that before a child is conceived, an environmental impact statement should be required.

Treat the cause not the symptoms

Organizations concerned with protecting the environment would do well to allocate more funds toward birth control rather than using their money to fight the symptoms of the problem, which are the increased resource development demanded by an ever-growing population. Treating just the symptoms of a problem rather than its basic cause is ultimately futile. Preserving natural regions is a worthy objective, but if the pressure of increased population is not stopped, wilderness and other such set-aside areas will inevitably be invaded. In 1993, and again in 1995, entry to Yosemite National Park had to be closed for a time because of the huge press of cars and people wanting to come in. In Africa, the pressure of population impinges on designated wildlife preserves, and hungry people poach animals to survive.

It is becoming more widely recognized that population growth and preservation of the environment are in direct conflict. Thanks to increasing numbers of hungry people, the problem is growing. The 2004 Nobel Peace Prize winner, the late Wangari Maathai, founder of the Green Belt Movement in Kenya, said, "People living in poverty and desperation will not hesitate to destroy the environment if they believe that in doing so their needs will be met." Presentation may be a panacea for the moment, but in the longer term, it cannot succeed.

In the final analysis, two things combine to degrade the environment: high individual resource consumption, and population growth. These are described by Tobias (1994): "Today, countries are divided into two types: those exploiting their domestic environs in order to meet the survival needs of their expanding populations, such as India, and those impacting their environment strictly to meet their increasing expectations, such as the United States." One could argue that the impact on the environment in the past in the United States has been largely for the purpose of meeting rising expectations. Now, to a considerable extent, it has changed to trying to provide a growing population with the current standard of living.

Brown and Kane (1994) provide ample evidence that as far as the world as a whole is concerned, we now have a "full house." Pimentel and Giampietro (1994) arrive at the same conclusion: "This brings us to the present situation in which the world is full. The exponential increase in the demand for natural resources, due to demographic and economic growth, is rapidly eroding resource stocks and national food surpluses all over the world. As a result, the assumptions typical of the 'empty-world development paradigm' are no longer valid."

Everyone an environmentalist

To say that some people are environmentalists and imply that others are not, is not a fair statement. Surely everyone wants a clean environment in which to live. Geologists and others concerned with the production of energy minerals such as coal, oil, and uranium, and various metals are commonly drawn to their professions by an early interest in and affection for the out-of-doors. They find employment in the out-of-doors where these resources exist. They dig mines and drill holes in the Earth to produce materials that society demands. It would be nice if all mineral and energy resources could be obtained in some fashion without disturbing the Earth, but that is not possible. The controversy arises about how and where the Earth shall be disturbed, and how much can be restored to its original form and at what cost. The debate must recognize the fact that the resources we use come from the Earth, and as we each use these every day, we each have an environmental impact on the Earth. It is unavoidable, and the more of us there are, the greater the total impact. At present, 219,000 more of us arrive each day.

Summary

Employing today's technology, we are in a geological instant, using the mineral and energy resources accumulated over hundreds of millions of years by countless geological processes. This has enabled the world's population to greatly increase. But because each person has an environmental impact every day from birth to death, the total environmental stress on the Earth is increasing rapidly. The more people, the greater the impact is. Treating the problems of the environment can only buy time to develop a sustainable economy based on renewable resources, and to adjust population to a stable size to fit the resources available in that kind of an economy, at a reasonable standard of living.

At present, we are living on a great mineral resource inheritance. We must begin to live on our current income, and recognize that the world is probably beyond the population size that can be maintained on a day by day renewable resource availability. Wackernagel and Rees (1996) conclude:

> We have shown that current human consumption of agricultural products, wood fiber, and fossil fuel have an Ecological Footprint that exceeds ecologically productive land by close to 30 percent. In other words, we would need an Earth 30 percent larger (or more ecologically productive) to accommodate present consumption without depleting corresponding ecosystems.

The Reality of the Future

People use resources. We look toward a "renewable natural resource sustainable economy." In pure form, it cannot exist. For even if we use renewable energy resources, such as wind, solar, and waves, equipment deteriorates and the materials from which these energy conversion devices are made must come from the Earth. They must be mined. The human race will continue to draw on and impact the Earth. The challenge is to minimize the impact, and at the same time, maintain an acceptable standard of living.

It is futile to try to solve environmental impact problems without also addressing the underlying issue of excess population. All of society, and especially organizations with a primary concern for the environment, must recognize this.

Chapter 21

Mineral Economics

Economics of mineral and energy exploration and production are exceedingly complex. They are treated here only in broad generalities, emphasizing a few factors common to most activities.

It is important to understand and appreciate some facts of mineral economics so the public, especially in a democracy, can give appropriate concern to the organizations that produce the resources we need and use. Individuals must be knowledgeable consumers and informed policy makers with respect to the resources supporting our modern civilization. Lack of knowledge and appreciation of mineral economics and the general importance of minerals to the public welfare has led and continues to lead to antagonisms and misdirected hard feelings at times between the consuming public and the resource producers. This is not in the best interests of either group.

Cameron (1986) wrote about the public perception of mineral resources:

> The result of changing social attitudes is a new set of priorities for the use of natural resources. Development of mineral resources has a much lower priority than in the past and often fares poorly in competition with use of land for wildlife refuges, wilderness areas, wild and scenic rivers, and other scenic and historical attractions. Perhaps the new set of priorities has found its ultimate expression in the massive withdrawals of lands in Alaska, the last great wilderness frontier but also the last great frontier of mineral exploration in America. To those who are concerned over the deteriorating mineral position of the United States, the new priorities are difficult to reconcile with the continuing large-scale use of minerals in the national economy, with our growing dependence on mineral supplies from abroad, with our growing deficits in international trade, with the loss of some of our mineral-based industries, with the related weakening of American power and influence in international affairs…. In the early part of this century, development of mineral resources was consid-

> ered essential to the economic welfare of the United States. In the 1980s, the development of mineral resources seems to be viewed by the general public (with the active encouragement of environmental groups) primarily as a source of quick profits to large mining companies, as a source of disturbance of the environment, and as an activity in conflict with more attractive pursuits. The fact that mining industry is basic to the American economy (and the world economy) is not widely perceived. The lessons of the mineral shortages of two world wars are long since forgotten. The energy shocks of the 1970s have not even led to design of a national energy policy.
> This is not a healthy situation. Agriculture, energy and mineral raw materials are still the pillars of the economic structure of a nation.

As world population continues to increase and large segments of it aspire to a better standard of living, the demand for raw materials grows even faster than population. Rising resource-based consumer expectations and the increasing economic influence of China, India, and Southeast Asia are examples.

The growing focus on environmental considerations makes it even more important for the general public and national policy makers to know something of mineral economics. What are the monetary and inevitable environmental costs (mitigated though they might be) in supplying the world with its basic materials?

To some extent, each mineral resource has its own set of economics. Some are natural in origin, and some are the result of various governmental regulations and tax policies. However, some economic factors apply to all.

Seven Factors in Common

Seven factors in common to all mineral exploitation are:

1. The economics of location — easy or difficult physical access. In general, the more easily accessed, less-costly supplies are already developed — some nearly exhausted.
2. Political risks — the instability of many governments in which agreements made by one regime can be repudiated by another regime, and the economic treatment of resource companies that can change with political winds.
3. Costs are rising in real terms.
4. Risk of unsuccessful exploration.
5. The large amount of time involved in searching for and developing the resource before any income can be generated.
6. Mineral deposits are nonrenewable. If new discoveries are not made, the company gradually goes out of business.
7. Taxes

Location economics

Mineral resources must be developed where they are located. Writing about the United States, Lovering (1943), already seeing the increasing problem of access to mineral deposits in the first half of the last century, made the point:

> The mineral resources of a country are fixed as to location; they must be

> exploited where they occur or left to the future. Even such abundant and widespread deposits as coal and oil underlie only a very small fraction of our land. Although they are relatively common in some sections of the country, they are entirely lacking in great areas. The proportion of the earth's surface that is underlain by many other important minerals is infinitesimal. The molybdenum deposit at Climax, Colorado, is included within less than a square mile, but for many years approximately 85 percent of the world's molybdenum came from the Climax mine.

Some mineral deposits are in convenient locations. Others are remote, and have difficult access. Most convenient, low-cost, readily accessible mineral deposits are already developed. Some have been depleted. Some lie under areas that already have seen human development. As exploration proceeded in the Los Angeles Basin, it was belatedly discovered that parts of Los Angeles overlay substantial oil deposits. Putting together a viable lease city block by city block, or in some cases city lot by city lot, was a huge and expensive problem, but it was done. Now some of the buildings you walk by in Los Angeles are not offices but house oil pumping units. In the Beverly Hills field, there are some 40 to 50 wells pumping oil, but you cannot hear nor see any of them.

Recently a large gas field was found in the Barnett Shale, which lies in part, beneath Fort Worth, Texas, and surrounding developments, which is a metropolitan area of 1.6 million people. Putting together a usable lease situation with a multitude of landowners, and then finding places to move in and operate drill rigs, is a difficult task to say the least. But if homes are to continue to be warm in the winter, and there is to be electricity provided by natural gas turbine/generators to run air conditioners in the summer, and Texas's petrochemical plants with their associated payrolls are to exist, we must provide the basic resource that is natural gas.

Disregarding the different geological conditions that cause significant differences in initial production costs, the cost of bringing a barrel of crude oil to a distant refinery from a well at Prudhoe Bay is considerably different than bringing a barrel of oil from a well a few miles offshore in Galveston Bay to a refinery in Houston less than 20 miles away.

At Prudhoe Bay, the ground is permanently frozen, and temperatures drop to -60° F and the wind chill can approach -100° F. There is little or no daylight for six months of the year and it is 800 miles to the shipping terminal through a pipeline that has to be constantly patrolled and maintained. From the shipping terminal at Valdez, it is another thousand miles to a refinery. Supplies for Prudhoe Bay operations must be barged in through the Bering Strait during the few months of open water, or hauled several thousand miles by truck from the lower 48 states. On-site housing must be provided with electric power and other utilities.

The well in Galveston Bay enjoys a mild climate, supplies are close at hand, a remote, isolated community does not have to be built, and many of the oil field workers can go home every evening. The oil's journey to the refinery just a few miles away is relatively inexpensive.

Each mineral deposit, depending on its location relative to where it will be processed and used is subject to a unique framework of economics. When mineral and energy resources are to be developed, the governmental entities involved need to understand the framework and treat the projects accordingly, particularly in terms of taxation.

Political risks

As countries such as Great Britain and the United States industrialized, initially most raw materials needed were available within the country. But gradually, these resources were depleted and the companies producing these resources had to go abroad to lesser-developed countries for raw materials. Many of these governments were, and remain, to be unstable. The degree of risk depends on the relative stability of governments and the politics within these countries. A continuing civil war is not helpful to oil or mining operations: examples being Angola, Colombia, and Nigeria. The risks can be enormous, and range from the destruction of the resource producer's equipment, kidnapping or murder of company workers, and the expropriation of company assets without compensation. Contracts made by one political regime may be invalidated by a succeeding political regime. Or the same governing group may simply change its mind and not honor a contract.

High costs

Another factor is cost. Any mineral development of consequence is expensive. The property must be obtained in some way. In the case of many petroleum projects, this is done by competitive bidding, just to win the right to look for oil. For mining, once again the land must be explored and then obtained. In some cases, the land must be obtained before it can be explored. Increasingly, this requires dealing with foreign governments of various degrees of stability.

Prior to petroleum or mining development, an initial study of the geology of the areas must be done. Before a single area of interest is located, many areas must be evaluated, almost all of which will prove to be of no value. Many under-financed companies have never survived beyond paying the cost of doing geological studies. They went broke before they found anything.

Once an area of interest is located, the leases must be obtained, sometimes by competitive bidding wherein some companies may lose out despite the money they have spent already for exploration. Then the prospect must be evaluated to determine if an economically recoverable resource exists. This is done by further geological exploration, usually aided by drilling. Drilling, whether for metals or oil, is expensive.

The easy oil and other minerals have been found. Most of the surface of the Earth has been mapped geologically. Mineral resources that are readily apparent have been developed for the most part. The early prospectors quickly found the rich mineral deposits exposed at the surface. In many cases, these were small operations, but the quality of ore was such that relatively little work could yield great wealth. And so the easily found, rich mineral deposits were soon exploited.

In the case of petroleum, oil and gas seeps originally indicated the presence of easily discovered and inexpensively drilled shallow oil and gas fields. Now the oil industry must find anticlinal oil traps at great depth, or find much more subtle oil traps such as a lens of sand of a delta finger at a depth of 10,000 to 15,000 feet, or locate a buried ancient coral reef with no surface expression.

The same circumstances apply to metals and other hard minerals. Native copper (that is, pure) discovered in the Upper Peninsula of Michigan was the beginning of the great copper industry of the United States. Anyone could see this copper in large quantities in the "Great Conglomerate." In prehistoric times, native Americans dug more than 10,000 pits to produce this copper, which became a major trade item up and down the entire Mississippi River Valley. It took no skill to find the copper, and, because it was pure copper, it was easy to use.

United States copper is now produced from a tough, fine-grained igneous rock (quartz monzonite) containing only specks of a copper mineral, not pure copper. The quality (tenor) of the ore is as low as four-tenths of one percent. This means that a ton of rock has to be blasted out, crushed, milled (upgraded by various processes), smelted, and eventually put through an electrolytic process to obtain just eight pounds of copper. It takes a huge and expensive facility to do this.

If the mineral deposit occurs in veins and is too deep to mine by the open pit method, shafts must be sunk. Underground operations must be pumped free of water that continually floods in, huge fans must be installed to ventilate the mine, and the mine must be electrified. A variety of mine safety devices must be installed. Trying to follow veins of ore through the various complex rock structures that control the ore is difficult and expensive. Because of all these factors, estimates are that it takes the work of seven men underground to produce the same amount of ore as one man working a surface mine. Today there are mines two miles deep in operation. At such depths, the natural heat gradient of the Earth necessitates that the mine be air-conditioned. Also, because of the great pressure of the overlying rocks, violent rock bursts may occur. Rocks simply burst out of the sides of the mine. They are unpredictable, smashing ore cars and killing miners.

So mining is hazardous and insurance and other costs are high. In the case of underground mines, fluctuating metal prices are a special economic hazard. Unlike surface mining operations, which simply can be shut down if the price of a metal temporarily drops below its production cost, an underground mine must be constantly maintained. The main problem is groundwater, which must be continually pumped out. The mine also has to be kept reasonably dry to prevent the hoisting and other equipment from being damaged, and to provide proper working conditions for the miners.

Risks of unsuccessful exploration

With the obvious, easily reached deposits of minerals already discovered and developed, the search for minerals today involves looking beneath the ocean floor to find an oil or gas trap many thousands of feet below. Or it could be exploring for deposits beneath the muskeg swamps of Canada or under thick jungle cover in Brazil or New Guinea. If a mineral exploration company is formed, there is no assurance whatever that anything of value will be ever found. Too many consecutive dry holes have put many a fledgling oil company out of business. Imperial Oil of Canada, a partially owned subsidiary of ExxonMobil Corporation, drilled 131 dry holes before striking the buried coral reef where their Leduc No. 1 was a major oil discovery. The story is told that when the discovery was made, the geologist at the well in Alberta wired the Imperial home office in Toronto, Ontario, saying, "Leduc No. 1 flowing 640 barrels." The return wire from Toronto asked, "Six hundred and forty barrels of what?" They had almost given up the thought that their efforts would result in an oil discovery. It takes courage and large amounts of money to get into the mineral development business. And, once in it, more companies fail than survive.

A friend told of drilling in the Denver-Julesburg Basin of eastern Colorado. It is a deltaic complex where winding channel sands are the productive structures. The first well drilled was moderately successful. So he drilled an offset well — which was dry, then another offset, also dry, and then two more offset wells, all dry. The amount of oil produced from the first well did not pay the cost of drilling the offset wells. He said if he had drilled one of the dry holes first and given up, he would have been better off financially. Fortunately, he had other resources and survived, but many others in similar situations do not. Drilling is now going deeper and is more expensive. Metal deposits are also far more difficult to find and develop. The time of the small wildcat driller and the lone prospector is largely gone. It takes major company resources to survive repeated failed exploration experiences, some of which cost many millions of dollars. A Scottish firm, Cairn Energy, recently spent $600 million on exploratory drilling in the Arctic and found no oil.

Length of time to begin to get return on investment

Another factor common to all mineral ventures is that it takes a good deal of time to realize any income even from a successful project. Time is almost always measured in years. In the case of the Prudhoe Bay Oil Field, it was twenty years from the time when the first exploration money was spent just to the time of drilling the discovery well in 1967. On June 20, 1977, *The Anchorage Times* carried the headline, "First Oil Flows (After 8 years, 4 months, 10 days)." Actually, after the discovery, it was nearly 10 years before oil was sent down the pipeline and income could begin to be generated from the wells.

The huge Hibernia oil field project off the east coast of Canada took almost two decades to develop. One problem was to build a big enough and strong enough drilling platform to resist the icebergs that frequently float down iceberg alley where the offshore Hibernia field is located. By the time the platform was in place and production began, the various project participants had invested a total of more than six billion dollars (U.S.), which had not earned a penny in interest for a period of about 20 years.

Individuals do not have such large sums of money to invest, nor can they wait many years for a return on their investment. It requires large corporations to take on such long-term risk ventures, carry them to completion, and put gasoline in the world's automobiles.

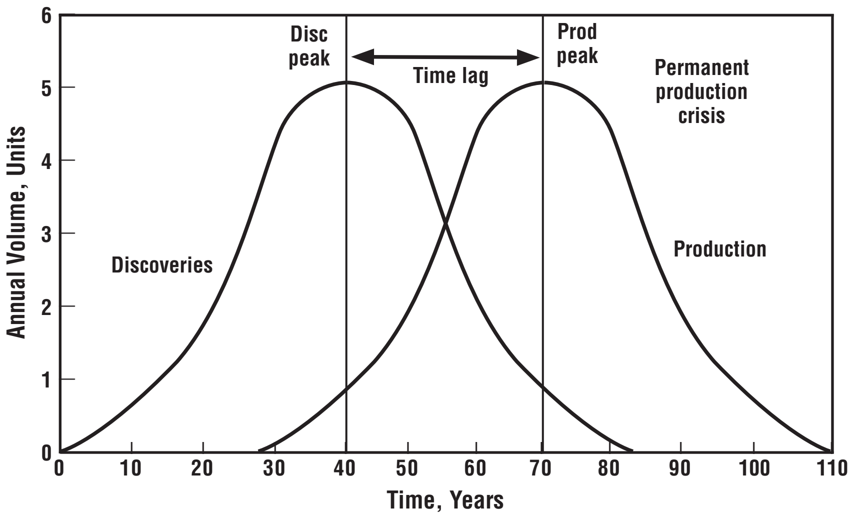
For mining operations, the average time from discovery of the prospect to production is about seven years. Previously there were costs of exploration. It may have taken many years just to find the prospect. Then add seven years cost of drilling; building the mills to crush the ore; building other facilities, including roads and housing for the workers; supply lines to support continuing operations; and arrange for transportation of the product. There are increasing financial and time costs for environmental studies, compliance, regulations, and mitigations. These are important and necessary, and their absence in earlier times is still reflected in major scars on the landscape and in streams still polluted from long-abandoned operations. But, complying with regulations is a cost that must be paid to obtain the mineral product.

Time is a factor in mineral economics, because until production starts, all the money invested earns nothing. Money has a time value. For example, if all costs from the beginning of exploration to bringing the mine to production means that $100 million has to be invested for a total of ten years, that $100 million must either be borrowed for ten years at the going rate of interest, provided by earnings from other projects, or supplied by stockholders who buy the stock in hopes of eventually getting a reasonable return for their risk investment. And they may lose it all if the project fails.

The time lag from discovery to full development and the beginning of getting a return on capital investment in a mineral deposit (including petroleum) differs widely depending on a variety of factors, such as accessibility to the resource and the infrastructure needed for profitable production (such as pipelines onshore or undersea and plants for milling and smelting metal ores). See Figure 21-1.

Bringing an oil field into full development may take as long as 40 years. Metal deposits usually take less time, but in all cases, the return on invested capital is substantially slower than in other industrial enterprises. One of the problems is predicting the price of the product over the life of the project. Price changes beyond those anticipated may make the venture uneconomic or in some cases, very profitable.

Figure 21-1. Idealized Curves of Discovery and Production and Time Lag to Bring Oil Basin to Production Peak



Source: After Hubbert, 1956

Note: Time lag between peaks may differ in different oil basins. Figures shows 30 years; average time lag is about 40-45 years for oil. For gas it is usually much shorter.

Investors who buy the stock, or the company itself, could have invested their money in some income-producing instrument such as a bank deposit or a bond and earned an immediate income. Instead, their money was spent trying to develop a mineral prospect that not only has to earn a current return, but also make up for the years when the money earned nothing.

Cameron (1986) puts the situation in perspective:

> Part of the current American attitude toward mining is a carryover from the 19th century, when there were spectacular successes in some districts of the West. Mining became identified as a quick source of easy profits. Those days are long since gone, although there was a brief revival during the uranium boom in the late 1940s and 1950s. Mining today is a highly competitive industry, in which profit margins are low. It is capital-intensive, yet the profit margins and the long lead times between discovery and first production make it difficult to attract capital funds in competition with other industries in which returns on investment are higher and can be realized in much shorter periods of time.

Mineral resources are nonrenewable

The mineral industry differs from other basic wealth-producing activities such as farming, fishing, hunting, and forestry in that minerals are non-renewable. The average metal mine life is seven to ten years. Oil may first flow from a well from its own pressure.

Then it has to be pumped. During production, the field usually has to be repressured by water-flooding or gas injection. Finally, all oil fields are abandoned. Each pound of copper produced and each barrel of oil produced puts the company involved a bit closer to being out of business, unless some of the money earned from current production is set aside to pay exploration costs to find more resources. A new crop of corn may be grown each year to replace the crop produced the year before, but fossil fuels and minerals are one-crop situations.

Taxes

The seventh but very important factor in mineral development, and one completely under the control of people, is taxes. Since money has time value, it is to the advantage of any company to write off expenses in the year in which they occur. Oil and mining companies are no different. But some tax jurisdictions do not allow this, instead requiring that it be done over a period of several years.

Another aspect of taxes is that companies are commonly taxed on plants and equipment, and also on proved reserves. This means that the tax bill increases if exploration to prove up reserves gets very far ahead of production needs. Taxing reserves discourages exploration.

At one time, Britain levied taxes as high as 90 percent on the income oil companies received from British North Sea oil production. This left very little for companies to reinvest in further exploration in this high-cost area, and firms began to reduce operations. Recognizing this, the British government has since reduced its taxes on North Sea oil companies but still taxes them very heavily. There are some smaller fields that could be found and developed if taxes were lower. At present, only large fields with relatively few wells are economic to develop. As these fields are depleted, Britain will have to make a decision to reduce taxes or import even more oil. To date, North Sea oil fields have been milked very heavily by British taxes.

Metal mining also tends to be a cash cow for both federal and local governments, with total taxes commonly taking 50 percent or more of gross income. Local governments frequently expand their political boundaries to include mining and oil properties into their tax base.

In less politically stable countries, taxes can and infrequently are changed on a moment's notice by the action of the person in charge. In 2005, President Hugo Chavez of Venezuela raised royalty payments (taxes) by 16 times on the crude oil from the heavy oil Orinoco region. The same year the Russians charged back taxes on a joint oil operation between British Petroleum (BP) and a Russian company, TNK. The assessment was $936 million.

Price estimations and hazards

Increasingly, companies in industrialized countries have to search abroad for natural resources. Political volatility in many countries makes the work of the producers of our basic mineral and energy needs rather difficult. Some understanding of the long-range planning that goes into resource development, and the need for a stable economic environment in which to do this is frequently absent among both the public and the politicians in the countries in which the companies operate.

Mining and public lands in the United States

There has been considerable controversy over the 1872 Mining Law, which allows public lands to be claimed and become private property for the production of minerals. In earlier times, obtaining public lands this way was easy and no doubt abused. Recently, however, requirements for claiming lands have become much stricter, and it has become much more difficult to patent public lands. In 1989, for example, only 43 claims were granted and most of them went to Native American tribes through land settlements in Alaska. At present, it is necessary to prove within reasonable doubt that a mineral deposit of value exists before the land can be claimed. To do this an expenditure of between half a million and a million dollars must ordinarily be spent on each claim. A claim is 600 feet by 1500 feet. A placer claim, one on sand and gravel deposits, is 660 by 1320 feet. Subsequent to obtaining a deed, many millions must be spent in developing the property. Also, no other industry in the U.S. is covered by more stringent federal, state, and local permitting, safety, reclamation, and environmental laws.

By way of example, a recently proposed underground uranium mine on the Cibola National Forest in western New Mexico needed the following studies, reviews, permits, and approvals: 1) several million dollars spent on baseline environmental studies, including surface water, groundwater, cultural resources, vegetation, wildlife, soils, geology, and air quality; 2) a million dollar Environmental Impact Statement; 3) approval of its Plan of Operations by the U.S. Forest Service; 4) consultation with five American Indian tribes and other "consulting parties" under provisions of the National Historic Preservation Act; 5) ethnographic studies prepared by the tribes but funded by the mining company; 6) application for a Discharge Permit by the New Mexico Environment Department; 7) application for a Mine Dewatering Permit from the New Mexico Office of the State Engineer; 8) application for a New Mine Permit from the New Mexico Mining and Minerals Division; and 9) application for a National Pollutant Discharge Elimination System (NPDES) permit from the U.S. Environmental Protection Agency.

In the past twenty years, the American mining industry has spent more than $15 billion to comply with environmental procedures and regulations.

From these operations come the materials for making the things used by everyone: cars, trucks, roads, houses, factories, office buildings, home appliances, and myriad other products in everyday use. The bottom line is that mining is an important part of the U.S. economy, but even when public lands are claimed and owned by mining companies, the industry remains one of relatively low profitability. If public lands require payment of a royalty to the government on minerals produced, that cost ultimately will be borne by the consumer, the general public.

The oil industry and land

Initially, in the United States, most oil drilling took place on private lands where the mineral rights were held by the land owner. This is in contrast to the rest of the world where these rights are usually owned by the respective governments. Now in the United States, oil development increasingly is going offshore where mineral rights are owned either by the federal or state governments.

Competitive bidding

Oil leases, which are merely the right to explore for oil with no assurance that any will be found, are put up for competitive bidding by governments. The cost of buying these leases routinely runs into many millions of dollars. Very often leases are bought at high prices that ultimately prove to have no commercial oil. If a company is to survive, these costs have to be recovered from exploration projects that are successful.

Oil: a highly complex, expensive enterprise

The oil industry plays an important part in countless ways in the lives of nearly all of us. The oil industry in its entirety, including exploration, drilling, production, transportation, refining, petrochemical production, and marketing uses more varied technology than any other industry in the world. These range from space satellites, to the highly complex science of organic chemistry. In between, seismology, directional drilling, drilling in waters a mile or more deep, and putting vast quantities of steam into the ground may be involved, among many other activities. The oil industry invests far more money than any other industry in the world to conduct its operations.

Resource development: open to everyone

The Western World, and increasingly the rest of the world, are open economies. Anyone has an opportunity to raise capital and invest it in mineral development. If anyone believes that searching for and developing oil, copper, gold, silver, or any other mineral resource is the easy and quick road to riches, they are free to try. We need exploration people with an entrepreneurial spirit like those in the past who provided the raw materials needed to build our present civilization, and the high standard of living we enjoy. But those who try should know they must have a lot of time and money to spend before they can expect to get anything back. And they may get nothing.

It is not necessary to form one's own company to participate in these enterprises. Almost all metal resource and energy resource companies (iron mining, copper mining, oil companies, coal companies, etc.) are public corporations, with stock traded on various financial exchanges. Individuals can buy into these enterprises with only small amounts of money. There are also mutual funds specializing in owning mineral and energy min-eral resource companies in which individuals can easily invest. In general, however, returns from natural resource companies are modest compared to investments in many other enterprises. But they are attractive investments because they produce vitally needed resources that will always be in demand, and because they own tangible things, which are a hedge against inflation. Precious metal stocks are particularly attractive in that regard.

Basic and useful

A lot of the strident opposition to resource developments fails to consider that if these were shut down and did not exist, the human race would still be close to living in caves, and heating only with wood. Even solar energy devices require metal to produce. Bicycles are made of metal, as are knives and forks. It is critical that companies that produce these raw materials be allowed to continue to do so. It is also important that there are economic rewards for those willing to supply the risk capital to do these things. Communist societ-ies, even if they have huge natural resources, have not provided a high standard of living for their citizens, as the history of the Soviet Union so amply demonstrated. With the greatest energy and mineral resources of any nation, Russians should enjoy a very high standard of living. But until recently, politics stood in their way.

Printed capital and natural capital

In considering the economics of natural resource supplies, mention should be made of an economic concept sometimes heard: that an increase in capital investment, that is, spending more money to obtain a commodity, will solve any shortage. It is true that money can bring more marginal resources on stream. More investment combined with better technology has made it possible to produce copper from deposits with less than half of one percent copper. This approach has worked for other mineral resources as well. And it may work for a time but not indefinitely. There are geological limits to the problems that money will solve. Theoretical economic arguments tend to blur the capital fact that Earth resources are finite, and if a given industry such as oil begins to disappear without an apparent substitute, huge problems will arise that economics may not be able to solve, particularly with the ever-growing population demands on Earth resources.

Recently, a few economists have demurred regarding more investment capital and price as the solution to any scarcity problem (Zachary, 1996). They suggest there are two kinds of capital, that represented by money and that in the form of natural resources, termed natural capital. We are using this natural capital at a tremendous rate, and simply printing money will not create more natural resources than nature provides. The idea that a higher price is all that is needed to maintain or increase the supply of a commodity, taken further, would suggest that as long as more money is printed, there would be no lack of oil or any other resource. Or, suggesting that if the price gets too high, the use of a given commodity will simply fade away ignores the fact that the commodity may be essential to the economy and have no adequate substitute. Losing it could be a disaster economics cannot solve.

Oil is a particularly good example to illustrate the fallacy of the economic argument that price is the determining factor. The economic argument ignores the reality that if energy takes more energy to produce the energy obtained, then it becomes a net-energy loss, which cannot be continued. The amount of oil that can be extracted does not simply depend on price. If a given form of energy cannot be produced at a net-energy profit, then all the things which that energy source enables to be produced, such as metals, are lost.

Summary

The economics of the mineral industry are frequently misunderstood by the general public, the people who need and use the products the industry produces.

The most important and obvious fact is that minerals must be developed where they have been located by geological processes. This reality must be reconciled with environmental restrictions if the resource is to be developed. Additional costs of complying with environmental regulations must be added to the final price of the resource to the consumer.

Large sums of money are required to find and then bring a substantial metal deposit or oil field into production. There is also a large time interval between the date of discovery and the time the discovery can begin that must be accounted for in the return on the investment.

Explorations for metals and petroleum are high-risk ventures. Many projects fail. Once a resource is found and development begins, more resources must be discovered to replace the deposit when it is depleted. Depletion allowances in tax laws must allow the company to accumulate money for this purpose. If not, then the company eventually will go out of business, no additional resources will be discovered, and the consumer will not have those resources to use.

The mining and petroleum industries are commonly perceived to be major sources of wealth. They do produce great quantities of valuable resources benefitting nearly everyone. But for the producing companies and their investors, returns on these high-risk investments are modest. Because most major natural resource companies are publicly held, it is possible for anyone to become a part owner of mineral resources and to begin to understand firsthand the problems and risks and rewards of mineral resource exploration and production.

If a company is to remain an oil company, some profits must go either to finding more oil or to alternative energy resources. One hundred years from now, there will be no oil companies as we know them today. Today's profits must be invested wisely for the great changes coming in the field of energy sources and production. These are the decisions facing oil companies. Some companies are seeking to diversify to survive, not as oil companies, but as "energy" companies. BP identifies itself with a sunflower logo and the phrase, "Beyond Petroleum."

One cannot simply print money to create more and more resources. Economic capital cannot increase the natural capital represented by the amount of water that falls on Israel, now in increasingly difficult straits in regard to water supply. Nor will higher prices cause more water to flow in the already overdrawn Colorado, Jordan, or Nile rivers. No amount of money can produce more soil. There are limits to natural resource capital that printed capital cannot solve. Geology, not economics, ultimately controls the availability of Earth resources.

Chapter 22

Population, Environment, and Basic Life Support

Although the interdependent relationship between humans and the Earth was understood in most earlier cultures, in many parts of the world today, this vital point is unrecognized or ignored in the current ideology of growth. We live in the shallow zone of a friendly environment. Relative to the size of the Earth, it is thinner than a coat of shellac on a large schoolroom globe. The topsoil on which all land life depends averages less than a foot deep, and above about 30,000 feet, the air is too thin for humans to exist. It is within these two limits where we must live. This delicately balanced zone vital to our existence needs great care.

In a classic and comprehensive study of past civilizations, Ponting (2007) writes:

> The most important task in all human history has been to find a way of extracting from the different ecosystems in which people have lived enough resources for maintaining life — food, clothing, shelter, energy and other material goods. Invariably this has meant intervening in natural ecosystems. The problem for human societies has been to balance these various demands against the ability of the ecosystems to withstand the resulting pressures.

Between the rising resource demands of industrial societies, and the continued growth (with few exceptions) of national populations worldwide, we clearly have gone beyond a sustainable situation. The only question is how soon this becomes evident. It is already evident in many places. But for the more fortunate countries, which still have some "environmental padding" available, it is not so obvious. Unless checked, however, environmental degradation will proceed worldwide and will ultimately destroy the basis of any reasonable standard of living.

Modern humans change the Earth

During most of the time that humans have lived on Earth, they were relatively few.

They lived and died leaving Earth very much as they found it. That is no longer true.

> … advances in health and agriculture in the 18th century largely eliminated the checks and balances that kept people and the environment in a rough balance. But the arrival of the Industrial Revolution brought prospects of a much better life to many people, and has since been an increasing rush to extract resources from the Earth to provide the 'good life.' The good life, in turn, brought more food, and better health facilities including safe water supplies. That in turn increased the population demanding even more of the Earth's resources, and so it has continued to the present. The machines that the Industrial Revolution brought us have given us the means by which to exploit the Earth's resources beyond anything seen before. Since then people … have become a major force in transforming the environment, not just locally but globally as well, on land, in the air, and in the oceans (Weber and Gradwohl, 1995).

Several comprehensive studies of the huge impact humans have had on the Earth have been made. These include *The Human Volcano: Population Growth as Geologic Force* (Erickson, 1995), *The Human Impact on the Natural Environment* (Goudie, 2000), and *Humans as Geologic Agents* (Ehlen et al., 2005). Human impact on the Earth has been acknowledged with the new term Anthropocene (the Age of Man) to name this time interval.

With the enormous growth in population and fossil-fuel powered machinery to alter the landscape, humans have been blasting and cutting through mountains, digging immense pits to recover minerals, and plowing up millions of acres of virgin land. The human impact on the Earth is immense, modifying all land areas (except what lies under ice) across the globe. In contrast to early humans, the past two or three generations and the present one, and perhaps the next, will leave the Earth much different than they found it. With the extraction of minerals and fossil fuels, the irreversible collapse of groundwater aquifers in some places, and the extinction of organisms, the Earth will be left considerably poorer. What will people in 2099 think of these times?

In Chapter 20, we examined the environmental impact of the extraction of mineral and energy resources. In this chapter, we examine some broader aspects of human activities and their effects on the environment. One example is the globalization of trade and the inadvertent altering of ecosystems by the introduction of alien species of animals and plants, and the spread of diseases, such as the West Nile virus and AIDS. The destruction of the most diverse biological realm in the world, the tropical rainforests, and the introduction of toxic materials in the environment are other examples of the human impact on the Earth. With numerous articles and books now pointing out these trends, perhaps there soon will be much needed changes. Knowledge is the start.

"Humanity's proud illusion"

> In the ancient world localized civilizations such as Mesopotamia surged, receded and collapsed as their ecological fortunes waxed and waned. Today, however, ecological imbalance is emerging for the first time at a global level, as we put unprecedented strains on the carrying capacity of this small planet (McMichael, 1993).

It has been said that civilization is a wholly owned subsidiary of the environment, but many do not realize it. In the modern industrialized world, more and more people live in urban areas where asphalt, not fertile soil, is the Earth's surface. Removed from the soil, the illusion has arisen that humans are above and beyond nature, rather than a part of the environment and dependent on its myriad inter-related complexities. A farmer realizes how much we depend on and are a part of nature, but in the United States, only two percent of the population is directly involved in agriculture. The movement of agricultural commodities and other resources within countries, across international boundaries, and even across oceans, allows access to global resources, so that we may not immediately feel the impact of unsustainable resource management practices and depletion of nonrenewable resources. "In effect, modernization alienates us spatially and psychologically from the land. The citizens of the industrial world suffer from a collective ecological blindness that reduces their collective sense of 'connectedness' to the ecosystems that sustain them" (Wackernagel and Rees, 1996). This is "humanity's proud illusion" (Morrison, 1999).

As more and more people move to cities, their awareness of their connection to the land as a source of vital resources diminishes. Water comes from the faucet, food comes from the supermarket, and electricity comes from the switch. Gasoline comes from the service station. I live in a state known in the oil industry as "oil-less Oregon." I doubt that one percent of the Oregon population has seen an oil drilling rig in operation. Many city dwellers do not realize how far the "ecological footprint" of an urban area reaches. It has become global, reaching not only across the continent, where cities exist, but across the seas to many other lands.

Biological globalization

Thanks to cheap energy fueling transport by ship, train, truck, and plane, we have a globalized economy. Both people and materials are moved around the world. But humans are only one of a great many organisms transported daily around the globe. Previously, biological communities had evolved into balance within their various environments. But these biological balances are now being altered. The globalization of transportation has meant the introduction of numerous alien (also called exotic, non-native, or invasive) species into new areas, some introduced intentionally by humans and many others as "hitchhikers." Some arrive as microorganisms in humans, and may be pathogenic. Both micro- and macro-organisms have been transported thousands of miles to new habitats with mixed results. The arrival of the European corn borer, the English starling, scotch broom, gorse, tansy ragwort (poisonous to cattle), the West Nile virus, fire ant, gypsy moth, chestnut blight, zebra mussel, and water hyacinth (choking southern waterways) in North America are examples of how human activities have negatively altered the native biota of many regions. One method by which marine organisms are readily transported is through the ballast water of ships that is carried thousands of miles and then discharged into different marine environments. Others simply attach themselves to the hulls of ships. More than 45,000 cargo ships transport 12 to15 billion tons of water from port to port around the world each year carrying thousands of species into new environments. For the most part, this has had a negative impact.

Infectious diseases can be spread within days across a country by travelers crossing land borders. In 2006, a disease called the mumps, largely unknown for many years in the United States, suddenly reappeared again in Iowa and then in four other states. It eventually was traced to the travels of one air passenger. Air travel has the potential of globalizing a plague in a matter of days. The spread of the Asian "bird flu" is a special concern. Now transmitted only from birds to humans, the fear is that it may mutate so it can spread from human to human. In 2009, the H1N1 virus, misnamed the "swine flu," spread rapidly from continent to continent.

We now witness Burmese pythons crossing Florida roads. Their former owners found them too big to handle and released them into the Everglades. The spread of exotic species to new environments is becoming, as one biologist described it, "an ecological cancer, taking a staggering toll on the world economy. They cost the U.S. alone 140 billion dollars a year." An estimated 7,000 alien species are now at home in the United States. Elsewhere, from New Zealand to the Hawaiian Islands to the Black Sea, invasive species are creating huge, costly problems. Native Hawaiian flora and fauna, especially birds, have suffered greatly from alien species invasions. The Eurasian zebra mussel, transported to North America by ship, is crowding out native clams and mussels and creating havoc in the U.S. Great Lakes and major river systems. In places it grows to densities that clog intake utility cooling water pipes. This alien alone causes an estimated $7 billion dollars damage yearly.

Invasives, unfortunately, don't stop spreading. Thus the problem will expand, and when or how some sort of ecological balance is achieved between native species and the invaders, no one knows. The ultimate environmental result cannot be predicted, but the impact already is very large in many areas. There is an extensive literature on the topic, which is a huge concern, particularly in agriculture. One comprehensive study of the worldwide problem is the 377-page volume with the apt title: *Nature Out of Place: Biological Invasions in the Global Age* (Van Driesche and Van Driesche, 2000).

Habitat loss

In their study, *The Sixth Extinction*, Leakey and Lewin (1995) conclude:

> [By] far the most important mode of human-driven extinction is the destruction and fragmentation of habitat…. The continued growth of human populations in all parts of the world daily encroaches on wild habitats, whether through the expansion of agricultural land, the building of towns and cities, or the transport infrastructure [roads, airports, railways] that joins them. As habitats shrink, so too does the Earth's capacity to sustain its biological heritage.

Extinctions due to loss of habitat are estimated to be 10 to 100 times faster than would otherwise be normal — the baseline or background rate — except for the human factor. Multiply our huge population numbers by the many advances in technology with which huge areas are altered through plowing or deforestation, and cities and factories are built, and the result is an impact on the environment much beyond the extraction of energy and mineral resources. Mining and oil and gas operations occupy very little land compared to the sustenance needs of burgeoning populations. Farming great areas for a single plant such as wheat (a monoculture) reduces the variety of organisms. Many organisms are dependent on a specific plant or on a very few plants for their survival. Butterflies are particularly restricted in this regard. The monarch butterfly and its relation to the milkweed plant is an example. The panda and the koala are examples of animals dependent on a very few plant species for survival. Biologists call this "obligate dependence."

Coal miners used canaries to detect dangerous methane gas in mines that could and did explode and kill. If one uses birds as an environmental indicator around the world, indications are not good. There are now some 9,000 species of birds on Earth, but bird populations and the number of species are declining, as are the size of bird migrations. The populations of most "neotropical migrants" — birds which migrate between breeding areas in North America and wintering areas in the Caribbean, Central and South America — are in decline. Among these species are virtually all of America's beloved and colorful warblers and vireos. Declining bird numbers represent a worldwide "canary" indication that the diversity of habitats is being destroyed by human invasion and incursions. Humans have adapted to a great variety of environments, helped in many cases by resources and technology. But, in turn, humans are now modifying and degrading a great many environments as we have spread in massive numbers over nearly all the land area of the Earth, and affected the oceans as well. Our impact as a species is huge and growing every day, and eroding the basis of our own existence, perhaps committing "genocide." When we are unable to draw on the environments of the past that produced the resources we now so depend on, the damage we have caused will become all too clear. If we are to be adequately fed in the future, fertile soil and the freshwater base of food production must be preserved. Half the topsoil of Iowa is already lost downstream into the Mississippi River delta, and beyond, into the Gulf of Mexico.

Diversity of life

We are critically dependent on a very complex interrelated organic web. If humans were the first organisms to arrive on the Earth, they would promptly starve to death. Over eons, organisms developed that now provide us with the means to exist. But our sheer expanding numbers are invading and destroying the habitats of myriad organisms that evolved by complex processes over millions of years, and on which we depend. We do not yet fully understand how basic this intricate web of life is to our existence. But if not checked, our expansion will surely be fatal. In just the past century world population tripled.

Humans first developed on the Earth when biological diversity was probably near its all-time high. But we are now causing one of the greatest extinctions the Earth has ever seen (Leakey and Lewin, 1995). A grim example is what is happening to one of the most biologically diverse areas in the world, the Amazon Jungle and rainforests. They are being reduced daily by expanding human populations. Biological diversity is under siege with negative effects on the entire ecosystem. "Everything is connected to everything else." The marvelous diversity of life is an intricate interrelated network.

The value of nature

> Biodiversity is our most valuable but least appreciated resource (Wilson, 1992).

Countless organisms support our life systems by diverse processes, which, collectively have been aptly termed "nature's engineering," the value of which can hardly be overstated. Eldridge (1998) states, "Scientists estimate that humans utilize over 40,000 species every day." He lists 400 (just one percent of the 40,000), which help to support us. The substances these organisms give us, and the tasks they do, include antibiotics, food, pest control, pollination, nitrogen fixation, anti-inflammatory medicine, laxatives, skeletal muscle relaxation, antiseptic, carbon cycle, anti-hemorrhagic, anesthetic, fermentation, cellulose metabolism, and anti-malarial drugs.

Nearly half of humanity's medicines are drawn from, or based on, natural ingredients, extracted from the very few species with which we are passably acquainted. Of the world's higher plants, for example, scientists have screened only 0.5 percent, and these now provide the bases of forty-seven of the world's major pharmaceutical drugs. Yet, according to a recent survey … tropical forests contain about half the world's 125,000 species of flowering plants, and each plant will yield an average of six compounds that have medicinal potential…. Nevertheless, the world's tropical forest, already reduced to half its preindustrial size, is disappearing faster than ever (Morrison, 1999).

In just one year, 2005, 10,400 square miles of the Brazilian rainforest were destroyed. At that rate, it will all be gone within less than 30 years. This great diversity of plant life, already the source of many useful drugs, has been called "the green pharmacy." To destroy it before we have studied the other 99.5 percent of plants for their medicinal potential has been described as burning down a library before we read any of the books. Yet, the destruction continues.

Rainforests are the world's greatest repository of naturally occurring drugs, with a greater percentage of alkaloid-bearing plants than in any other region. Fourteen-hundred plant species may offer a degree of protection against cancer. One example is that someone suffering from leukemia in 1960 faced a one-in-five chance of remission. But, two drugs developed from a tropical plant raised the chances of survival four times. Worldwide sale of these two drugs in one year totaled more than $100 million.

Figure 22-1. Losing the Rainforest

Sidney Harris: ScienceCartoonistPlus.com, by permission

As they do now, plants in the past used carbon dioxide in the process of photosynthesis. This entered the oxygen/carbon cycle and fixed the carbon now found in our oil, natural gas, and coal. The value of plants is incalculable, and we need to preserve their abundance and diversity as a storehouse of wealth. When we degrade the environment, we reduce organic diversity at the peril of our survival.

Robert Costanza of the Institute for Ecological Economics has calculated an economic value for our natural biological systems. Studying forests, wetlands, and other ecological systems, he concludes that the value of nature's services comes to "…about $33 trillion a year." A freshwater marsh in Canada was worth 58% more intact due to hunting, angling, and trapping, than when farmed....A Thai mangrove swamp was worth 72 percent more when left intact to provide timber, charcoal, fish, and storm protection than after being converted to a shrimp farm" (Begley, 2002). A study by biologist Andrew Balmford at Cambridge University concluded, "In every case we looked at, the loss of nature's services outweighed the benefits of development, often by a large amount." A simple example of the value of natural services is the pollination of fruit trees by bees. It cannot be done by humans, but the bees' work results in millions of dollars worth of produce just in the United States. Unfortunately, through the indiscriminate use of pesticides, the loss of honey bees has become a severe problem. In 2011, the traveling beehives available to orchardists needing their services were substantially fewer than the needs. Every act of destruction of part of the environment costs money, and adds to the perils of our survival.

How is the environment doing? Nelson (2002) writes:

> There is, at long last, a growing sense of recognition that human activity on the planet is dangerously compromising the world resource base — that we are, in fact, seriously degrading those ecosystems that sustain all species — including us…. The reality is that no war, revolution, or peril of any other kind, measures up in importance to the threat of environmental deterioration.

World population growth and its negative impact on our future are rarely discussed publicly in political circles. The topic wins few votes and may not be popular with segments of society that benefit from population growth such as the retail business (more people mean more sales) and homebuilding (more people need more houses as well as more furniture, home appliances, and carpets; in addition, homebuilders like a large and growing population to supply cheap labor). Urban sprawl raises land values for real estate speculators. There is broad-based support for population growth in the lobby halls of Congress. In a departure from that view, then-Senator Al Gore (1992) wrote:

> No goal is more critical to healing the environment than stabilizing human population. The rapid explosion in the number of people since the beginning of the scientific revolution — and especially since the latter half of this century — is the clearest example of the dramatic change in the overall relationship between the human species and the earth's ecological systems. Moreover, the speed with which this change has occurred has itself been a major cause of ecological disruption, as societies that learned over the course of hundreds of generations to eke out a living within fragile ecosystems are suddenly confronted — in a single generation — with the necessity of feeding, clothing, and sheltering two or three times as many individually within those same ecosystems.

The impact that population growth is having on the environment was clearly summarized in 1992 by the *World Scientists' Warning to Humanity*. Signers of this appeal included 1,700 of the world's leading scientists, among them 102 Nobel laureates. These were a majority of Nobel Prize winners in the sciences living at that time (Union of Concerned Scientists, 2012). "Human beings," they said, "and the natural world are on a collision course." This important document, spearheaded by Massachusetts Institute of Technology Professor Henry W. Kendall, who is a Nobel Physics Laureate, and Union of Concerned Scientists cofounder, went on to say about population:

> The earth is finite. Its ability to absorb wastes and destructive effluent is finite. Its ability to provide food and energy is finite. Its ability to provide for growing numbers of people is finite. And we are fast approaching many of the earth's limits…. Pressures resulting from unrestrained population growth put demands on the natural world that can overwhelm any efforts to achieve a sustainable future. If we are to halt the destruction of our environment, we must

> accept limits to that growth.... No more than one or a few decades remain before the chance to avert the threats we now confront will be lost and the prospects for humanity immeasurably diminished.

Van Der Ryn and Cowan (1996) have put the beginning of our industrial civilization in ecological perspective, writing:

> We live in two interpenetrating worlds. The first is the living world, which has been forged in an evolutionary crucible over a period of four billion years. The second is the world of roads and cities, farms, and artifacts that people have been designing for themselves over the last few millennia. The condition that threatens both worlds — unsustainability — results from lack of integration between them.

The environment is not constant. Like all things, it changes over time. This is part of the evolutionary process. Nature shoots in many directions through mutation, and only rarely produces the organisms that fit and succeed in the new environment. Stephen Jay Gould, describing punctuated evolution, believes this occurs actively for rather brief times, followed by longer periods of stability. Others view the process as ongoing. Either way, the result is the same. Extinction is the order of the ages. Nearly all organism lineages have proved to be dead ends. So the "balance in nature" we now observe may be, like climate, a snapshot of only the very recent past and present. Nevertheless, as geneticist David Suzuki stresses, it is important for humans to preserve the life-supporting elements of the environment we use and need now, and not unduly upset or change the balance beyond the limits of its natural rate of change.

We have impacted and continue to impact the environment much beyond the normal natural scale of change. This does not bode well for our future. Most of the existing "balance of nature" is what must support us. But we continue to upset this balance, as the intricately complex and interwoven natural biological heritage is degraded. It is the incipient erosion of the prospects for a sustainable future.

Nature, objectively and without favor, will continue to combine what successfully adapted organisms and environmental niches are available to carry life into the distant reaches of time. We hope to be part of this process, but nature makes no such guarantee. So we have to preserve what enables us to survive, recognizing that we are subject to both the biological and physical limits of what the Earth can provide, and limit our demands on these Earth resources to a sustainable rate.

Humanity is creating an ecological imbalance, which is unsustainable. This overriding fact is recognized by some, but not yet by the majority of policymakers in politics and industry who continue to promote growth, applauding "economic stimuli" in all its forms. They urge us to consume our way to prosperity on a flat Earth that has no end and, therefore, no limits. An example of this economic perversion occurred in the United States in 2008, when $160 billion was sent directly to citizens with the admonition to "go out and spend it to benefit the economy."

A few illustrations of what is happening

Encroaching growing human populations are reducing or destroying natural habitats worldwide. Biological diversity is steadily being reduced. The effects, some very subtle and some very obvious, are gradually decreasing the carrying capacity of our planet.

Fish populations are diminishing around the world. The dramatic decline of codfish off the coast of Newfoundland and the decimation of fisheries in the China Sea are two of many examples. Sharks, swordfish, and other game fish are being greatly overfished, with some populations reduced by 90 percent. Off the West Coast of the United States, bottom fish (rockfish) found in markets, have been greatly reduced and fishing is greatly restricted. A contributing factor is the use of bottom trawlers, which scrape the seafloor, catching everything, and in the process tearing up the seafloor's delicate balance of organisms. Another factor is the slow growth of many bottom fish. Some take 5 to 20 years to reach reproductive maturity. The yelloweye rockfish begins to bear young at 16 years, and may live to 114 years. Overfishing off the Oregon coast resulted in a drop in yelloweye landings from 364,458 pounds in 1992 to 9,564 pounds in 2000. An extreme example of overfishing a particular species is the bocaccio. It is estimated that even if it is not fished again, it will take 92 years to rebuild the population to earlier levels. One fisherman said, "We have the technology to catch all the fish in the sea." This is the problem. Off the Oregon coast, fish landings dropped 61 percent from 81 million pounds in 1993 to 39 million pounds in 2001.

In my native state of Minnesota, lakes historically have produced good fishing. I enjoyed some of it. The tourist industry is very dependent on fishing, but a recent fishing experience back at some of my old haunts was very disappointing. Minnesota's vehicle license plates proudly proclaim it to be "Land of 10,000 Lakes." But many fishermen now describe Minnesota as "Land of 10,000 lakes and 5,000 fish." Lakes once reached only by portage now are accessed easily by road, and cabins line the shorelines. During my lifetime, United States' population has more than tripled, and it continues to grow. But nature is not making any more lakes, and the pressure on fishing has grown tremendously.

Water habitats also are being destroyed by sedimentation, contamination from waste water, and toxic runoff from the streets of cities and towns. This is the story of streams and estuaries across the United States. Coastal marshes, the nurseries for many fish and other organisms, are in decline because of human encroachment. California has lost about 90 percent of its valuable wetlands. In the states of Oregon and Washington, wetlands are under assault from both development and pollution, degrading their life supporting systems.

The state of Louisiana contains 40 percent of the wetlands of the United States. The value of these lands is huge, with 95 percent of all marine species in the Gulf of Mexico spending all or part of their lifecycles there. They supply the source of more than 30 percent of the nation's fisheries' catch. It also is one of the largest habitats in the world for migratory waterfowl. It provides protection from storm-generated ocean surges for the more than two million people living in the coastal zone, including New Orleans. Yet, about one million acres of these wetlands have vanished since 1900; many square miles are lost each year.

In part, the loss is due to the natural sinking of the land. But in nature, this is compensated largely by the inflow of sediments from river distributaries. However, levees have been built to keep the Mississippi River in a single channel away from where it would naturally spread out and distribute the load of sediment laterally through marsh areas. There is a program under way to restore the wetlands as much as possible by river water introduction, sediment and nutrient trapping, vegetative planting, marsh creation and other measures. This is projected to be a 20- or 30-year project costing $14 billion or more. At best, it can only be partially successful in replicating the natural system.

Interfering in natural systems such as deltas and river courses has been disastrous in many areas. This is now widely recognized. One project was undertaken in Florida, in which streams were "channelized" by straightening the meandering streams that entered the Everglades region. This practice proved to be destructive to the Everglades environment, so now more money is being spent to restore the streams to their previous natural meandering courses. The once lush four million acres of wetland Everglades wilderness has been reduced to less than half that size. It is finally apparent to the six million residents of southern Florida that they depend on the Everglades for their drinking water. They are now directly interested in preserving what is left, and have launched the Comprehensive Everglades Restoration Plan. Human habitation, however, continues to expand. The Commission for a Sustainable South Florida warned that, "rapid growth and sprawling development patterns are leading South Florida down a path toward wall-to-wall suburbanization." Population growth is the problem. Land and water resources cannot expand accordingly.

The U.S. Fish and Wildlife Service states that the U.S. loses 60,000 acres or more of wetlands annually. In the ten years from 1986 to1997, the loss was 644,000 acres. During that decade, the United States added 30 million people to its population.

The coastal marshes and shallow waters of the continental shelves are far more biologically productive than deeper open ocean areas. They are the nurseries of many marine species. But these are the areas subject to increasing contamination from the polluted run-off of the continents.

In a study of United States coastal areas, Brinckman (2001) makes a number of significant observations:

> Half the U.S. population lives in a 50-mile-wide ribbon along the coasts. Projections for the next 25 years show that half the nation's population growth will occur within that ribbon adding 39 million people to 17 percent of the U.S. land area…. The construction of roads, buildings and parking lots along U.S. coastlines has become one of the most serious dangers to the oceans, joining the better-known threats of overfishing, industrial pollution, and invasion of non-native species. The primary reason: Development and roads near ocean shores send toxic chemicals and other pollutants directly into fragile ocean marshes, estuaries and lagoons…. Findings released this month in Portland show that when paved areas near ocean shores exceed 10 percent of the land area, coastal ecosystems degenerate rapidly. Rainwater flows off impervious surfaces quickly, instead of seeping into the ground. Stream banks erode, the water gets warmer, and pollution from cars and homes washes into estuaries and marshes…. Population growth in coastal regions is increasingly recognized as a major cause of harm to fish, birds, and ecosystems along the shore.

The Mississippi River system drains parts or all of 31 states, a total of 1.2 million square miles. All the pollutants drained from this large area eventually become concentrated in this one river. Water runoff from streets and farms create huge amounts of chemical runoff. In places, raw sewage sometimes discharges into the river. This huge volume of chemicals, much of which is agricultural fertilizer and feedlot runoff, becomes nutrients breeding widespread algal blooms at the mouth of the Mississippi.

> These blooms grow and multiply until all available nutrients are consumed by the algae at which time the algae dies and sinks to the sea floor. Bacterial decomposition of the algae then uses up all the oxygen available in the water column, killing all marine species that require oxygen and can't rapidly leave the area. Oysters, worms, and other similarly immobile species perish. This dead zone moves around in the northern Gulf of Mexico with the prevailing currents and can even trap and kill mobile crustacean and finfish species (Phillips, 2005).

This "dead zone" is now about 8,000 square miles in area. Coastal flooding was the natural way the river formerly cleaned itself as the water filtered through the coastal marsh areas, but dikes and levees now block much of the river's former course.

Loss of soil

Overall, one-third of the topsoil of U.S. cropland has been lost over the past 200 years. Worldwide, degradation of agricultural land is causing irreversible loss of an estimated area of six million hectares (nearly 15 million acres) annually.

All across the United States, to some extent in Canada, and even in Europe, agricultural lands are being paved over for shopping malls, residential areas, and "industrial parks." This use of the term "parks" is something of an oxymoron. Cropland loss is a serious problem because the World Health Organization reports that more than 3.7 billion people in the world are malnourished. Soil is being lost from land areas 10 to 40 times faster than the rate of soil renewal, endangering future human food security.

Growth — the modern icon

"Growth" is the icon of industrial civilization. If a corporation does not increase its volume of products and profits each year, it is shunned by investors. The financial community and business journals discuss and endorse "growth companies." Sales of cars, and all other products must grow in numbers for companies to be regarded as successful. And the increase in car sales and almost everything else is based largely on population growth. But population growth and growth in affluence (increased individual consumption) has a price. Professor Albert Bartlett says, "Every increment of added population and every added increment of affluence invariably destroys an increment of the remaining environment." The non-profit organization, Population-Environment Balance, has a logo (Figure 22-2) that illustrates Professor Bartlett's statement.

Figure 22-2. Population Growth and the Environment

Source: Population-Environment Balance, Washington, D.C. By Permission

Growth is the religion of our industrial society. As Bartlett (2002b), pointed out, if a city or a state does not grow in population, it is said to be "stagnant." Instead, Bartlett suggests, it should be regarded as "stable." To stop the destruction of adjacent farmland, cities sometimes establish "urban growth boundaries." Portland, Oregon, is perhaps the best-known example of this. But when more land is needed to accommodate growing population, the "growth" boundaries are simply expanded, and in effect, are meaningless. Population historically settled on the most fertile agricultural lands because that is where people gained their livelihood and flatlands are the easiest to build on. The great migrations of rural people to urban areas, have had an adverse effect.

One can look at one of the most fertile valleys in the world, the Central Valley of California, and see how cities such as Modesto, Fresno, and Sacramento are invading rich farmland. In Oregon, most growth is taking place in the most fertile area of the state, the Willamette Valley. During my 50-year residence, I have seen the city of Eugene more than quadruple in size from fewer than 35,000 people to more than 156,000 (not including several satellite communities that bring the total to more than 200,000). There is no end of this growth in sight. The hazelnut groves and apple and cherry orchards that fringed the town are gone. Eugene is now a full-blown city, complete with traffic jams, and at times, poor air quality. The richest valley soil next to the river is now producing its last crop, asphalt.

"Smart growth"

Some communities appreciate that farmland must be preserved. To meet these situations, the concept of "smart growth," or it's sometimes suggested alternative "managed growth," are invoked. This may take the form of building closer together and constructing communities vertically rather than expanding horizontally. The terms "smart growth" or "managed growth" seems to make people feel better, and they believe the problem of growth is being solved. But growth is growth by whatever name it is called. Smart or managed growth is analogous to moving the deck chairs on the *Titanic* closer together, and finally stacking them on top of one another. This simply results in the ship going down in a more organized manner than it would otherwise. My good friend and neighbor, Eben Fodor, is a city planner engaged in organizing growth in better form, for which I chide him occasionally. However, he is doing the best he can in the face of what he cannot control — continually growing population. He has written a book expressing his thoughts with the title *Better Not Bigger* (2001) — surely THE goal to be pursued.

Bartlett (2006) has offered these *Thoughts to Remember*:

> Every increment of added population, and every added increment of affluence invariably destroys an increment of the remaining environment.
> Population growth and increases in affluence make it impossible for reasonable increments of improved efficiency in use of resources to enhance or even to preserve the environment.
> You cannot preserve the environment by accepting the population growth and the increased affluence.
> Whether 'smart' or 'dumb,' growth ruins the environment.

Herman Daly is one of few economists who understands the limits of a finite Earth. As early as 1987, in "The Steady-State Economy: Alternative to Growthmania" he related his concerns about "growthmania" and the ecosystem with the observations:

> The economy grows in physical scale but the ecosystem does not…. Standard economics does not ask how large the economy should be relative to the eco-

> system, but this is the main question posed by steady-state economics…. Standard economics…is indifferent to the scale of aggregate resource use. In fact, it promotes an ever-expanding scale of resource use in appealing to growth as the cure for all economic and social ills…steady-state economics stresses the optimum scale of resource use relative to the ecosystem.

"Growthmania" (In growth we trust) is the current guiding creed of both industry and government and of both main political parties in the U.S. Chambers of commerce enthusiastically and unanimously promote it. This century will show it to be a false pursuit, even a delusion.

As communities grow and problems of growth develop, various remedies are tried. Roads are widened and outer belt-line road systems are built. Light rail lines are built to facilitate commuting. But continued growth overwhelms everything.

California and population

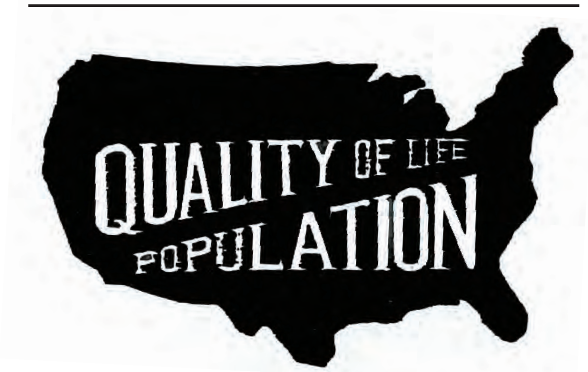
It is said that wherever the United States is going, California will get there first. California does showcase problems that occur elsewhere later or currently in lesser degree.

California has been the fastest growing state in population for many years. It had 38 million residents in 2011, an 80 percent increase since 1970. Estimates are that the state will add a population equivalent to that of Texas by 2040, swelling to 64 million people. One observer quotes California residents saying, "It's a lovely state, but there's too many people here. It's not good for the environment. It's not good for wildlife. It's not good for the farming community…. It's a time to look at what our capacities are, how big of a place we should be — what's environmentally and economically sustainable…. All you have to do is look at the traffic to know there are too many people here" (Smail, 1997b).

Population and quality of life

Bartlett asks, "What qualities of life will be improved with increased population?" This is a provocative question. There are no good answers yet. Beyond stabilizing population, we might visualize a smaller population; fewer traffic jams, less air and water pollution, uncrowded recreation areas, and no pressure to put more wild areas or marginal lands under cultivation. There would be many benefits.

Figure 22-3. Quality of Life vs. Population Growth



Source: Population-Environment Balance, Washington, D.C. By Permission

Population, present and future

How has population grown? It took from the origins of humankind until 1825 to reach one billion. It took 100 years more to reach 2 billion. Three billion was reached in 1960; 4 billion by 1975; 5 billion by 1987; 6.2 billion by 2000, and 7 billion in 2011. There are numerous estimates of the eventual maximum size of world population ranging from about 8 billion up to 12 billion by the end of this century. The latest United Nations' projection of world population for 2050 is 10.5 billion. If population size is not stable by then, an increase to 12 billion by the end of the century is plausible. Such a huge number of humans can hardly be supported above bare subsistence, and population growth may stop well before then due to natural unpleasant interventions such as famine and disease.

Without predicting when population will stabilize, the "World Population Data Sheet" issued by the Population Reference Bureau (a non-profit organization based in Washington, D.C.) estimates that global population will rise from 7 billion now to 9 billion in 2050, a level also predicted by other groups. Africa is expected to add one billion people despite its AIDS epidemic. Even now, Africa is struggling to provide a basic existence for many of its people, and in some countries fails to do so. Starvation takes an annual toll.

India's population is projected to grow from 1.2 billion in 2011 to 1.7 billion in 2050, when it will surpass China as the world's most populous country. Nepal, Iraq, Saudi Arabia, the United Arab Emirates, and most African countries are projected to more than double their population by 2050. Afghanistan, where the United States currently hopes to establish democracy and improve living standards, is expected to grow from the current 32 million people to 76 million by 2050. In the already over-populated Israel-Palestine region of continued unrest and short water supplies, Israel is projected to grow from eight million people in 2011 to 11 million by 2050, and Palestine from four million people to 10 million. Where people are already fighting over land and water, how can lasting peace be achieved against such population stress?

Worldwide, it is hard to see how living standards can be maintained, much less raised, against a continually rising tide of humanity. Preserving the environment against this human onslaught will also be difficult, if not impossible. The United Nations, the United States, and other government and non-government entities talk about eliminating poverty and raising living standards for the more than half the world's population that now lives on less than $2 a day. The number of people at this standard of living account for 75 percent of the population in Sub-Saharan Africa; 75 percent in South-Central Asia; 47 percent in China; 29 percent in North Africa; 26 percent in Latin America; and 14 percent in Eastern Europe.

From travels around the world "in search of our environmental future," Hertsgaard (1998) observed:

> It is hard to find a plausible scenario in which the world's population will stabilize at much less than eight billion people, and an eventual total of ten or twelve billion is quite possible. Global, regional, and local ecosystems are already crumbling beneath the weight of today's six billion (2008 — 6.7 billion), yet many of those six billion are living in indescribable squalor and billions more are on the way. Under the circumstances, the future looks troubling ahead.

Harvard biologist E.O. Wilson has called population growth, "the raging monster upon the land."

According to the U.S. Census Bureau, U.S. population is expected to grow from its current 315 million (2012) to over 439 million by 2050, based on a stable birth-rate and high levels of immigration. Without immigration, the U.S. population would not have reached 315 million, and would have been expected to level off at 236 million by 2040. In the mid-2000s, illegal immigration into the United States exceeded legal immigration according to a study released in 2005 by the Pew Hispanic Center, a nonpartisan research group.

World population still growing

The Population Reference Bureau (2005) writes: "Some stories in the popular media suggest that world population growth has stopped — but world population is still increasing at 1.2 percent per year, resulting in an additional 80 million people annually." All estimates are for world population to increase for the next several decades at least. Riley and McLaughlin (2001) conclude: "Population growth the next two or three decades is possibly the world's most serious problem, reducing our chances for a successful transition to sustainability while maintaining quality of life."

In 1966, Martin Luther King, Jr. recognized the serious problem of a growing population related to Earth resources and urged family planning as a solution. He said:

> There is no human experience more tragic than the persisting existence of a harmful condition for which a remedy is easily available. Family planning, to relate population to world resources is possible, practical and necessary. Unlike plagues of the dark ages or contemporary diseases we do not yet understand, the modern plague of overpopulation is solvable by means we have discovered and with resources we possess.

Human environmental impact: population, affluence, technology (I=PAT)

This simple summary statement was presented by physicist John Holdren and biologist Paul Ehrlich. It explains how the developed world with its current **P** = Population size, its high degree of **A** = Affluence, and its **T** = Technology has so rapidly and negatively **I =** Impacted the environment (Ehrlich and Holdren, 1971). Of these three factors, population may be the most important. Between 1950 and 1987, the global population doubled from 2.5 billion to 5 billion – an increase in just 37 years equal to the total increase in world population from the time the human species first emerged to the middle of the twentieth century. This rate of growth is unsustainable. We face the limits and controls of a finite Earth in both renewable and nonrenewable resources.

Population — a locally based problem

In an article titled "There Is No Global Population Problem," Hardin (1989) points out that unlike air pollution, which can be a global problem, population problems are within countries. He writes:

> We will make no progress with population problems, which are the root cause of both hunger and poverty, until we deglobalize them. Populations, like potholes, are produced locally, and, unlike atmospheric pollution, remain local unless some people are so unwise as to globalize them by permitting population excesses to migrate into the better endowed countries … . We are not faced with a *single* global population problem but, rather, with about 180 separate national problems.

One has only to look at Haiti to realize the truth of the foregoing statement. Overpopulation is Haiti's basic problem. It must be resolved at home. The bumper sticker I saw recently, "Control Your Local Stork," makes the point that population control is a local and personal issue. Globalizing the population problem by allowing the free migration of excess populations is no solution. If we follow that road, eventually we will have perfect equality. Poverty and hunger will be equally distributed. If individual countries match their populations to the resources they can secure on an environmentally sustainable basis, then a reasonable standard of living can be achieved. But at present, this does not seem to be on the world's agenda.

There have been attempts to limit population. China tried it, but in rural areas, especially, it has not been very successful. China's population continues to grow, although at a slower pace. If overpopulation is not to be corrected by the cruel limits of nature — famine and disease — education and universally available family planning must be available and used. Education must be available for both men and women on an equal basis.

Education will help solve the population problem, but it must include the total emancipation of women to control their own destinies. Education should also teach the fact that quality of life for all is a function of population size. Only when this is understood and acted upon, can a nation preserve and hope to improve its living standards. Its borders must be protected against nations that do not recognize and observe that elementary fact.

Subsidizing families larger than two children with tax incentives is a highly questionable policy. It does not improve the environment nor make it easier to obtain the resources to sustain a high standard of living. Governments should aid in family planning. This is probably the single most important thing that governments can do through the United Nations or individually for the future of the Earth's inhabitants. Just a small fraction of the money spent on armaments would be a great asset for such a cause. Excess population in some areas is a cause of war, and continued population growth in other regions is the sole factor in environmental degradation. Environmental quality is a major part of any standard of living. If religious factors enter in, respect for the quality of life surely can be invoked. Quality, not quantity of life should be the goal.

Population and the value of life

I have observed from worldwide travel that the greater the population density, the less valuable life becomes. India, with bodies lying in its streets and floating down rivers, and Haiti, where children are given away, are prime examples of how population pressure devalues human life. In regions afflicted by famine, some children are simply abandoned to survive on their own, or more likely, to starve to death. "Street children" are a common sight in many cities with large, poor populations.

Degraded environments and related difficulties in maintaining a decent standard of living degrade life itself. High population densities and environmental stress force people to think of themselves and their own survival. To have one's life valued by a community is important to self-respect and esteem, which in turn relates to the productivity of the individual and to the productivity and living standards of community and country. We should live in a world where every child is wanted, cherished, and adequately supported and where every human being at any age is valued and respected.

As population increases, traffic jams increase, there is more crowding and impatience, tempers flare, there is less compassion for one another, and life is cheapened.

Isaac Asimov, the renowned science and science fiction writer, once said:

> Democracy cannot survive overpopulation. Human dignity cannot survive

> [overpopulation]. Convenience and decency cannot survive [overpopulation]. As you put more and more people into the world, the value of life not only declines, it disappears. (Interview with Bill Moyers on *Bill Moyers' World of Ideas*, October 17, 1988.)

Population growth and its impact on Earth resources are now the largest problems we face in achieving a reasonably happy future for humanity. It is as Smail (1997b) says, "Population growth seems to affect everything but is seldom held responsible for anything." He has written an excellent article making the case for dramatically reducing global human numbers (Smail, 1997a). He also makes the point that, "Ultimately, both individually and collectively, the people of each sovereign state must come to terms with, and subsequently resolve, their own local and unique demographic problems, hopefully motivated not only by an increasing awareness of global realities but even more by their local consequences."

Decision time is at hand. Several African countries are at the brink of the Malthusian precipice. Rwanda, with the highest population density of any country in Africa, already had a near-societal collapse with the genocidal killing of some 800,000 Tutsis by Hutus in the 1990s. Shipping food to already overcrowded countries is not the answer if there is no internal effort to control population growth. It simply serves to increase the population and makes the situation worse. Hard facts and compassion collide at that point.

Lifeboat ethics and the immigration dilemma

Immigration can be viewed from the concept of lifeboat ethics as described by Hardin. A ship is sinking. There is only one lifeboat with a capacity of 10 people. There are 50 people on the ship. Do the 10 people already in the lifeboat fend off the other 40 in the water, and make it safely to the far shore? Or do they "humanely" take the other 40 people into the boat, whereupon the boat sinks and everyone drowns — perfect equality, and complete disaster. How much this analogy will apply to the future remains to be seen. With population restraint, it may not apply. Overpopulation and open immigration will eventually achieve perfect equality. But at what standard of living? If some nations conscientiously hold their numbers in check, but other nations do not, then immigration, if not checked, will equalize everyone. Nations that practice population restraint should have the right, indeed the obligation, to protect themselves from nations that do not.

Optimum population size — and "overshoot"

Bouvier and Grant (1995), surveying the American scene, observed: " … our natural resources and the demands of our infrastructure will not permit the population to stay at the present level for very long without dramatic deterioration of the quality of life. The country needs not stabilization, but a rollback." The United States is now adding nearly 3 million people a year, and 82 percent of projected growth to 2050 will be due to immigration (Passel and Cohn, 2008). Worldwide, Pimentel and Giampietro (1994a) concluded, "At present and projected world population levels, the current pattern of human development is not ecologically sustainable."

In a study for the National Academy of Sciences, Wackernagel et al. (2002) issued a comprehensive report stating that economic expansion has boosted demand for resources and has overshot the Earth's ability to regenerate goods and services by 20 percent. They state: "Our accounts indicate that human demand may well have exceeded the biosphere's regenerative capacity since the 1980s. According to this preliminary and exploratory assessment, humanity's load corresponded to 70 percent of the capacity of the global biosphere in 1961 and grew to 120 percent in 1999." What this means is that we would need an Earth 20 percent larger than the one we have to accommodate present consumption without depleting our natural capital — the Earth's ecosystems. This path is unsustainable.

The book *Overshoot* (Catton, 1982) was perceptive ahead of its time, and still well worth reading. In it, William Catton said, "Human society is inextricably part of a global biotic community, and in that community human dominance has had and is having self-destructive consequences."

Abernethy (1993) makes the important observation that the carrying capacity of a region is not constant:

> Life support systems deteriorate from overuse and are less able to support life. This means that overpopulation in one period decreases the future number of people who can be maintained without aggravating the damage. The carrying capacity does not remain constant. It shrinks.

But world population continues to grow and all our economic systems are based on growth. What politician or business is against growth? "Growth is the Santa Claus," which presumably is used to solve economic problems (Laherrere, 2004). But growth is the creed of the cancer cell, which eventually destroys its host, and ultimately itself. As Albert Bartlett has told us repeatedly, "sustainable growth is an oxymoron." A brief note in *Science*, April 7, 2006, reports that about 95 million hectares of arable land in Africa have been degraded to the point where they are virtually nonproductive. Population destroyed the environment, and imported food supplies cannot solve the problem indefinitely. Populations there must not only stop growing, but must shrink if that environment is ever to be restored to productivity.

Optimum population size: less

The most important variable for determining future quality of life will be population size. Optimum size depends to some extent on culture. What one culture regards as a good quality of life may be considerably different from another culture. But comprehensive studies indicate optimum population size is significantly less than the more than seven billion on Earth today. Smail (1997a) says: " …the Earth's long-term carrying capacity, at what most would define as an 'adequate' standard of living is probably not much greater than 2 to 3 billion people." Other studies indicate less. Brown and Kane (1994), in a book with the very clear title, *Full House*, provide compelling evidence the environment now contains all the humanity it can handle. Pimentel and Giampietro (1994a) arrived at the same conclusion: "This brings us to the present situation where the world is full. The exponential increase in the demand for natural resources, due to demographic and economic growth, is rapidly eroding resource stocks and national food surpluses all over the world."

Numerous other studies support the need to decrease population to ensure a decent future for all, but this vital fact is not yet part of any political platform. Politicians avoid discussion of population like the plague.

Lack of media recognition of the basic population factor

An example of how population and population growth are being ignored by a major newspaper is found in an article by a *New York Times* columnist. Returning from Niger, which he identifies as "the most wretched country in the world") he writes:

> I stopped in village after village where peasants told me of young children dying of starvation in the last few months. One man named Haroun Mani had just buried three of his eight children…. We need a new international initiative to extend the Green Revolution to Africa…. Momom Burhary, a 63-year-old man, stated: 'And this land used to be far more productive than it is now. When I was a young man, the annual harvest would last a full year. Now it only lasts three months and then we run out of food.' We are not even using our aid money wisely. Unless we help start a Green Revolution in Africa, we'll be back in Niger year after year — and every village will be surrounded by more tiny graves.

What the columnist advocates is simply making more food available so more people can survive to produce more children, and on and on. Producing more food would be good — only if population is stabilized at the level where the food supply can support the population at a decent standard of living.

The columnist avoids any mention of population or population control. One would think when the man told him he had just buried three of his *eight* children, it would have dawned on the writer that population is a large part of the problem, and until it is recog-nized as such, all other efforts are doomed to fail. Niger's population, now 16 million, is projected to reach 55 million by 2050. But, the word "population" does not appear in the article.

It is always the children who do most of the starving. Emaciated bodies are carried in the arms of people still at least able to get around to some degree. If we don't want to see starving children, we must first acknowledge they are long-term responsibilities. People must assume responsibility for each life they create and not pass their child on to others for care. This most personal aspect of public policy must be confronted the world over in undeveloped areas, as well as in industrialized societies. Global lack of responsibility on population growth will assure that, as resources become more and more limited, social chaos will grow. If it could be arranged that whenever more children are brought into the world than parents can support, the parents would be the ones to starve and the children be allowed to survive, the problem might be solved rather quickly. Children who are totally innocent in creating the problem have to suffer the ultimate consequences.

Birth control methods are relatively simple and are widely used, but not widely enough. The problem is human nature and ignorance. That is where the social sciences and education can do more than technology. And it would help to have the widely read and influential *New York Times*, as well as other media, find the courage to recognize and publicize the problem — and solutions. Legislative bodies must also confront population growth in the allocation of their resources. Funding family planning would probably do more for world peace than any other dollar spent. A letter to the editor in the *Oregonian* (Stevens, 2003) made this point in commenting on government spending priorities: "I would rather my tax money go to birth control and education on environmental degradation. I realize that children are a gift from the Lord, but so is rain, and when we have too much, we wear rubbers."

Liebig's Law of the Minimum

Justus Liebig was a German chemist (1803-1873), who, working with the chemical elements as they are applied in agriculture, determined that regardless of how many other nutrients were put on plants, if one essential element was below the minimum required, the plants would not grow. His law can be stated: "The growth of a species is limited by whatever required nutrient is least available. An organism is no stronger than the weakest link in its ecological chain of requirements."

Liebig's Law can be applied to inanimate natural resources as well. For example, the ultimate limiting factor on the rate of production of oil from the Athabasca oil sands is likely to be either water supply or energy available for the recovery process. In the Great Plains of the United States, the limiting factor for agricultural production is water supply from the underlying Ogallala aquifer. The general tenet of Liebig's Law has widespread validity throughout the environment. The point is that there are limiting factors in the survival and growth of anything.

In determining what level of population is optimum, Liebig's Law also applies. It means that the sustainable carrying capacity of a region is determined by the minimum environmental circumstances, not by the maximum. A simple example is in the populations of big game animals in northern latitudes. It is not the lush summer range that determines the survival rate, but the much more limited and harsh winter range environment. By the same token, human populations tend to expand for a time under favorable climatic conditions, as in parts of Africa for example. But periodically prolonged drought conditions arrive, and we see pictures of emaciated and dying children when famines occur. In the harsher minimum conditions, the population is beyond sustainable size. Sending food into such a situation is logical and humanitarian, but it ensures that when the next drought arrives, even more will starve.

A reverse of that — flood, not drought — is the limiting factor in Bangladesh. A considerable part of Bangladesh is a low-lying plain, the combined delta region of two rivers, the Ganges and the Brahmaputra. The land is an alluvial marsh slightly above sea level, with hills only in the extreme northeast and southeast parts of the country. As a result of the country's large population, most people live close to sea level. The region is subject to monsoons that bring huge amounts of water down the rivers and flooding the lowlands. At times, typhoons in the Indian Ocean drive ocean waters across the deltaic areas. The result is that many people drown. Yet the population has grown from 70 million in 1975 to 162 million at present. With a natural increase of 1.9 percent per year, the population is projected to be 183 million by 2025 and 227 million by 2050. It is unlikely these growth figures can materialize. Either personal responsibility or nature (famines, floods, and disease) will meet the task of population limitation. Sadly, natural controls seem the more likely.

Family planning materials and related information should accompany all the Cooperative for Assistance and Relief Everywhere (CARE) disaster relief packages. The minimum conditions of the environment, not the occasional better conditions, are the limiting factors in determining long term sustainable population size.

Population and Immigration

The most important element in a possible change of course from the present unsustainable direction, is population size. Haiti and parts of Africa such as Niger and Ethiopia are examples in which environmental degradation and resulting stress from overpopulation have already resulted in chaos and misery. In 1986, Haiti produced 80 percent of its food. By 2009, the loss of topsoil so decreased agricultural production that Haiti depended on imports for 80 percent of its food. Seventy-one percent of the aid came from the United States. Robert D. Kaplan, in his book, *The Coming Anarchy* (2000), foresees spreading chaos. It is up to the human species to prove him wrong. We have the knowledge and intellect to do so, but there must be action.

World population has grown beyond what the environment can accommodate, with the result that more and more people are increasingly put at risk of natural disasters. Some of the disasters are sudden, such as tsunamis, landslides, floods, and earthquakes. But the disaster of environmental degradation is an incipient one. It arrives slowly but steadily, and ultimately is much more disastrous and permanent than the immediate spectacular catastrophes.

The late Gaylord Nelson, founder of Earth Day in 1970 and former U.S. Senator, was a person of high ethical standards. Regarding overpopulation as our most compelling environmental issue, Nelson wrote (2002):

> But any ecologist will tell you that the growing human population is the greatest single stressor, endangering the planet's carrying capacity, and that most environmental issues today stem from overpopulation.

As the sixth century B.C. Chinese philosopher, Lao Tzu, said, "If you do not change direction, you will end up where you are heading."

Herschel Elliott (2005) in his book, *Ethics for a Finite World: An Essay Concerning a Sustainable Future*, writes:

> It is important to stress that to prevent the citizens of overcrowded nations from becoming permanent residents of less-populated countries is not racism or imperialism. Rather it is a logical consequence of the finitude of every nation's boundaries. Inevitably, the land and resources of every nation have a maximum support capacity at any given standard of living…this is not a cultural racial prejudice; rather, a logical consequence of the fact that people live in a finite world — a world in which citizens become desperate when their rapidly rising numbers exceed the capacity of their environments to sustain them.

Beyond whatever other matters relate to immigration, the problem should be viewed in the larger, more fundamental context of how many people a country can adequately support at a desired standard of living in both the immediate and long-term future. In the case of the United States, people continue to migrate to it because it is, among other things, a "rich" country. However, that view may be increasingly an illusion. With an annual deficit in international payments of more than $600 billion, the rest of the world is loaning the U.S. nearly $2 billion a day to support the American lifestyle. It is like a giant credit card and, like all credit cards, it has limits, and must eventually be paid. Historically, the U.S. economy has generated employment and that is the "pull" of many immigrants to the United States. During recent street demonstrations by Hispanics, one who was interviewed simply said, "I can't make a decent living for my family in Mexico." To a considerable extent, this reflects a failed Mexican economy. It also reflects a population growing beyond what the environment can support. In 1960, Mexico's population was 34 million. By 2011, the population had more than tripled to 115 million. This trend ensures strong and continual pressure to migrate.

In direct contrast to its actions at its northern border, where Mexico has provided maps and instructions on how to cross into the United States, Mexico is actively trying to protect its southern border with Guatemala. Guatemalans and Hondurans, with annual population growth rates of 2.5 percent and 2 percent, respectively (doubling times of 28 and 35 years, substantially higher than Mexico's at 1.3 percent), seek to enter Mexico. In Mexico, illegal entry is a felony that is subject to a two-year imprisonment and a $28,000 fine. Mexico is very cognizant of its population problem, and, indeed, has done much more to address it than all of the Central American countries except Costa Rica.

Based on indigenous resource sustainability and its ecological footprint, the U.S. is already overpopulated. The U.S. standard of living has been declining for several years. Costs of food and energy, both vital elements of everyday living, are rising faster than incomes, and 46 million people now receive a food stamp subsidy. The U.S. has no population policy. The size of a nation's population, and on a personal basis, the number of children and standard of living are almost always in an inverse relationship. The only substantial meal some children in the United States now receive is at school.

Some migrants are fleeing from war or despotic governments, but the great mass of immigration is to search for a better life in a more materially favorable environment. One cannot fault people for pursuing that goal. On the other hand, the people on the more affluent side of the border can hardly be faulted for trying to preserve the standard they have. Unrestricted migration will eventually lower the higher living standard to the level from which economic migrants flee. The situation is analogous to two pools of water at different levels connected by a channel. If there is not a dam between them, eventually both pools will have the same water level. The pool with the initially higher water level will be lower and the lower one will rise.

Material standard of living is largely a function of natural resources available to each person. The problem is simply the question of how many people will divide available resources.

Migration is likely to continue, but it adds to the environmental impact on the destinations. Unrestricted, it will eventually result in an equalization of both environmental and economic conditions. Maintaining "islands" of above-average affluence will be difficult. It demonstrates Garrett Hardin's concept of "lifeboat ethics." As population pressures increase on diminishing resources, the clash between regional degrees of affluence is likely to become increasingly severe. This is largely what immigration conflict is about. It illustrates again the control Earth resources exerts over nations and individuals.

Environmental stress, population growth, and demographic changes

The continued flow of immigrants from environmentally stressed areas to those regions not yet under such pressures will markedly change the demographics of the world in this century. It is doing so in Europe, and it is doing so in North America. Environmental conditions and resource limitations and overexploitation by populations expanding beyond sustainability in a region, will continue to move people for decades to come. The ultimate outcome is difficult to predict, but it must be hoped that the result will be a reasonable standard of living for all. But this is unlikely as long as world population continues to grow.

"Full house"

The United States continues to add more people, but we are almost certainly already beyond a sustainable population size. Pimentel (2006) estimates that a sustainable U.S. population may be between 100 and 200 million, with the smaller figure more likely unless unexpected technological advances are made in energy sources. The U.S. population is now 315 million and counting. For the world as a whole, "Our suggested 2 billion population carrying capacity for the Earth is based on a European standard of living and sustainable use of natural resources" (Pimentel and Pimentel, 2006).

Experiment in self-support

Eventually, some nations will try to balance population with indigenous renewable resources. This cannot be achieved with unrestricted immigration. Elliott (2005) writes:

"Autonomous nations must be allowed to carry out their own cultural experiments without incurring the moral obligation to rescue the nations whose misguided experiments have failed. The autonomy of nations requires them to be self-reliant and self-supporting … the citizens of all nations have to experience the destructive consequences of their own experiments in order to learn how to correct them and better to fulfill the goals of moral life.

Any nation that does not limit immigration loses its ability to make its own cultural/moral experiment. Its failure to curtail immigration would prevent it from choosing to use its lands and natural resources to support a minimal population at a high standard of living, and maximum quality of life. In effect, uncontrolled immigration allows the nations whose experiments have failed to overload the world lifeboat and cause it to founder."

When the world is forced to rely chiefly on renewable resources, the challenge will be for each nation to live on its indigenous resources. This was the world condition prior to the industrial revolution.

In discussing critical transitions in nature and society, the Dutch scientist, Marten Scheffer (2009) states: "Perhaps the best-known class of failures is the collapse of many advanced ancient civilizations facing resource crisis." Not available then, the current worldwide trade in commodities has temporarily mitigated many supply problems. But it has also converted the Earth into a global commons that is not sustainable, for there is then no "elsewhere" from which to obtain more resources on a finite Earth.

About 1800, the world contained barely a billion people. Demographics are now leading it toward nine billion or more by mid-century. As problems of basic survival emerge, concepts of equality and justice — the ideals of all great religions and human compassion to relieve suffering — will no doubt increase in response. But these worthy moral principles cannot alleviate problems when necessary resources do not physically exist. Humanity must recognize the hard fact that good, humane intentions cannot create the basic materials needed to alleviate the suffering resulting from too many people and too few resources.

Global economic developments — global problems

Jeffrey Sachs, Director of the Earth Institute at Columbia University and of the United Nations Millennium Project, says: "Economic development has become a generalized global phenomenon, except in sub-Saharan Africa and a few other poverty hot spots." He explains that there are mixed consequences for many people:

> Every major ecosystem, whether marine or terrestrial, is under stress. The world economy is depleting the earth's biological diversity, ocean fisheries, grasslands, tropical forests, and oil and gas reserves…. Our global politics is not yet adapted to the challenges of sustainability. The superpowers spend far more time angling for short-term military and economic advantage than they do honoring international agreements on biodiversity, climate, oceans, desertification, and other fundamental issues that will count much more for our well-being in the decades to come…war, terror, corruption — more and more frequently have an ecological underpinning.

Environmental refugees — the United Nations

In 2004, a United Nations report said that Ethiopia was on the "brink of disaster because it is failing to deal with soaring population growth and environmental problems." But people there, with few exceptions, are unable to flee their conditions. No doubt they would if they could. Recognizing this growing problem, in 2005, the United Nations Refugee Agency proposed a new class of refugees, who, like political refugees, would be legally able to move to other countries and claim asylum. These would be "environmental refugees." On this basis, nearly all of Haiti could move. Many other people, mainly from Africa (especially Ethiopia, Gabon, Niger, and Rwanda) would qualify. The shores of southern Europe are already feeling the impact of environmental refugees fleeing Africa. The Canary Islands, Spanish possessions a short distance west of impoverished northwest Africa, are experiencing a flood of refugees. In 2006, the European Parliament held meetings to determine what could be done. In the European Union (EU), of which Spain is a member, there is no internal passport or other travel controls. Once inside the EU, immigrants are free to move at will.

Moving masses of population on the pretext of their environmental refugee status would result in bringing the environmental degradation problem with them. Exporting the problem of overpopulation is not a true solution. The United Nations did not state to which countries these refugees should be admitted. Given the already overpopulated world, with diminishing basic resources, it is unlikely any country would open its door to receiving environmental refugees, especially as the numbers would be in the many millions.

Noting the broader environmental-immigration problem, Gaylord Nelson (1997) observed that:

> Many immigrants to the United States are refugees because environmental problems are not being dealt with in their native countries…many of the world's violent conflicts are heavily influenced by — if not caused by — over-population and environmental mismanagement of agriculture, water, and forestry resources.

Immigrants from Central America, Haiti, and other places to the United States are, in many instances, environmental refugees. Nelson adds: "the economy is a wholly owned subsidiary of the environment, not the other way around…don't think most people understand where we are headed."

The world's ecological systems can get along fine without us. In fact, they would do much better without us (Weisman, 2007). But we cannot get along without the diverse and interrelated environmental complexities that support us. Some of them we still know little about. We need to modify our consumption habits and reduce our numbers. The overriding factor in this imperative is population. The motto of one environmental organization says this clearly: "Whatever your cause is, it is lost without population control." The organization, Negative Population Growth, declares on its letterhead: "Fewer people for a better world."

In his last book, *The Ostrich Factor: Our Population Myopia*, Garrett Hardin (1999) wrote:

> …perpetual growth in a world of infinite and available resources has been treated as an immemorial truth. Painful experiences will be required to banish this illusion from the intellectual armamentarium of humanity's leaders. Our ostriches will have to have their heads yanked out of the comforting sands of illusion…. If the dream of perpetual growth is now near its end, then it is time to explore the possibilities of living in a non-growing but sustainable world….

The concept of sustainable growth is analogous to the concept of perpetual motion — both happy illusions that are detached from reality. The former ignores limitations of a finite Earth, and the latter ignores the second law of thermodynamics.

Jacques Cousteau observed: "Population growth is the primary source of environmental damage." Any organization dedicated to environmental protection must recognize that and devote at least part of its efforts towards population control. Treating only the symptoms of the problem while ignoring the cause is no solution.

Humanity must recognize the environmental limits of the Earth and adapt its demands accordingly to survive. The major adaptation is achieving a global population size that can be sustained at an acceptable standard of living on an annual increment of resource growth that can be harvested from Earth's resources. Brown (2011b) notes that although we live in a technically advanced society, we are dependent on the Earth's natural support systems. No amount of technology can replace fertile soil — it is nature's domain. Brown states:

> If we continue with business as usual, civilizational collapse is no longer a matter of *whether* but *when*. We now have an economy that is destroying its natural support systems and has put us on a decline and collapse path … . We need an economy in sync with the earth and its natural support systems, not one that destroys them. The fossil fuel-based automobile-centered throwaway economy that evolved in Western industrial societies is no longer a viable model — not for the countries that shaped it or for the countries that emulate them.

Our natural support systems must be preserved, and in many places, they must be restored if we are to survive very far into the future. These include fertile soils, forests, surface and groundwater supplies, and marine biological resources in all natural environments.

Lindsey Grant, Deputy Assistant Secretary of State for Environment and Population Affairs (now retired), takes a global perspective on world problems. He observes: "We must deal with growth before we are overwhelmed with its consequences." But he offers what he calls "A Sober Optimism" that with modernization comes reduced fertility. Particularly by advancing women's educational, social, and economic rights, population growth may be reduced and perhaps people will recognize that arresting population growth is the best answer to many problems. However, referring particularly to the United States, Grant says, "Given the resistance, our population growth is more likely to be stopped by the Four Horsemen (pestilence, famine, war, death) than by conscious policy, but this big country has more time than most, and perhaps we will make the shift of vision in time."

The United States is currently adding about three million people a year. It is now the third most populous nation in the world behind China and India. "Time" to "make the shift in vision" is growing short, and there is no evidence of it in policy-making circles. "Growth has placed strains on the Earth's support systems unlike anything in previous human history. It has led to our usurpation of much of the biosphere that had been used by other creatures. And we are still growing" (Grant, 2000).

Growth and the Steady-State Economy Alternative

Sustainable growth vs. sustainable development

As noted before, Bartlett correctly says that, "sustainable growth is an oxymoron." But sustainable development means to improve in quality (as, for example, in health care, or education) without growth in numbers of things or in size. That sort of development is sustainable and must be our future. It has come to be identified as part of what is called "a steady-state economy."

The steady-state economy

In contrast to most economists, Herman Daly has long advocated a "steady-state economy" (Daly, 1973, 1991, 1996). How and when this may be achieved is as yet unknown. It may be that civilization will rise to unsustainable heights, and then crash to a much reduced level of population and affluence. Such a cycle may be repeated several times before a population stabilizes within its resource limits. Achieving a steady-state economy in an orderly fashion will be a challenge. The time to work on both ends of the problem — getting more serious about alternative energy sources, and holding population growth in check — is now. The year 2050 with 9 billion people or more is within the lifespan of many people reading this book.

Benefits of a steady-state economy

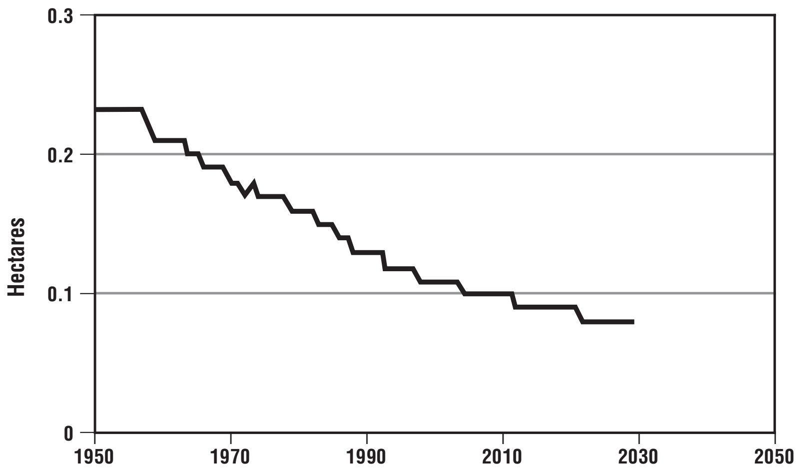
A steady-state economy potentially is a bright alternative where a population, almost certainly smaller than now, could survive in some degree of affluence. This is the scenario Daly outlines in his writings. There are many advantages. The assumptions are a fixed population in balance with renewable resources and low impacts on the environment. The consequences of this balance would be seen in infrastructure repair rather than expansion, health services less strained, and generally improved quality of life for the balanced population.

In such an economy, wild and recreational areas would not be crowded, and very importantly, prime agricultural land would not continue to be converted to housing, malls, and factories. Many aspects of daily life would be less stressful. Taxes could be lower as public agencies would not always have to play "catch-up" to provide services for an ever-increasing population.

With each increment of growth, the fixed environmental resource base decreases per capita. There are natural limits, and we are bumping up against them. Why not begin to implement a steady-state economy now? Transition to a steady-state economy as early as possible will ease the inevitable transition to the renewable resource economy.

One example of the impact incremental population growth has on basic life support, food production, is shown in Figure 22-4. With a steady-state economy based on a stable population, the continued decline in grain land area per person would be halted. Given present population growth, food production is one of several vital trends that deserves but does not get governmental priority. Ignored in the longer term, it will destabilize society worldwide. Hunger overrides all other human concerns.

Figure 22-4. World Grainland Per Person. Actual Trend from 1950–1993. Projected from 1993–2030



Source: Graphed by Brown and Kane, 1994. Based on data from U.S. Census Bureau, and U.S. Department of Agriculture.

The late Rene Dubois wrote: "Man shapes himself through decisions that shape his environment." The most important thing we can leave for our children and all our descendants is a wholesome, intact, sustainable environment, along with an understanding of how vitally important it is to preserve it. We can set the example by beginning now to repair it, knowing that any diversity of life which we destroy can never be replaced or passed on to future generations.

Nature is objective, amoral, and unforgiving. It does not regard us as any more permanent or rightful residents of the Earth or independent of the environment than were the dinosaurs or trilobites, both of which are now extinct. We are among the most recently arrived species. Yet, in an incredibly brief time span, we have spread across the globe as no other species has before. And we brought an ability that no other species has ever had. Other species have to live on the current daily resource "income" that the environment provides. We have been able, with technology, to draw upon and live on the accumulated resources stored in the Earth from past ages — fossil fuels and mineral fertilizers (phosphate, potash). And, in a geological instant, we have exploited these to create the industrial civilization we enjoy. These inherited resources have been consumed to the point that they clearly also are going to disappear in a geological moment. During this brief interval, we have expanded our numbers at an exponential rate that is clearly unsustainable. The human species must, and eventually will, return to where it was a few centuries ago, living on the current daily resource income derived from the immediate environment.

Human numerical expansion already has done considerable damage to the environment, and in some cases, irreparably. No other species has ever done that. This must be stopped and the damage repaired because the same environment that we used (and abused) during this growth period is also what must carry us forward.

Some Bright Spots

Despite these sobering facts, there are things that can be done to reverse current trends. Some local and regional successes have been accomplished. We are doing better in protecting water supplies from contamination. Air quality has improved in places, primarily in the wealthier developed countries, which can afford air pollution control measures and technology. At one time, London experienced deadly fogs caused by myriad small coal-fired furnaces. Central gas-fired heat has eliminated the fogs. Although dams damage fish spawning migrations, some spawning areas have been restored. Some dams have actually been removed including one in the state of Maine, one in Washington State, and one in Oregon. Each removal resulted in restored salmon runs.

Even Russia, which long ignored environmental matters, is beginning to recognize the problem:

> People should understand that, when dealing with nature, we have already exceeded the bounds of the permissible far too much. The situation is becoming dangerous…. If we go on treating nature as we do now, we might find ourselves in a very difficult situation (Mikhail Gorbachev).

Pollution from pulp mills around Russia's Lake Baikal, the deepest lake in the world, with a unique ecosystem, is now being mitigated. When I visited the region in 1980, a society for the protection of the lake already had been formed, with billboards in the lake-side city of Irkutsk telling of the importance of preserving the Baikal environment. In 2006, an oil pipeline, originally planned to be built near the lake's shoreline, was moved 40 miles inland.

In some countries, forests are coming back as marginal agricultural areas revert to trees. But in other areas, such as the foothills of the Himalayas, and in many countries in this hemisphere, including Peru, Colombia, Honduras, and Haiti, the urgent need for firewood and marginal farmland continues to divide the hills with severe loss of soil and increased flooding. In the Pacific, industrial logging to supply Asia's insatiable demand for timber and pulp has taken a heavy ecological toll on the islands of Indonesia, Malaysia, and Borneo.

Edward O. Wilson (1992), writing extensively about the environment and its relationship to human population, offers some suggestions as to how the negative trends might be reversed. Small enclaves here and there have been established to begin the process of restoring the environment. Good things can be done, and various organizations exist to do so. The International Planned Parenthood Federation, Negative Population Growth, Population Environment Balance, Population Institute, Population Media Center are among the groups that attack the most basic problem, population. Dealing more directly with the environment, The Nature Conservancy buys ecologically important lands and puts them in permanent trust for the future. The non-profit Institute for Fisheries Restoration promotes environmental activities for the restoration of fish populations. The Ocean Conservancy is active in promoting the health and protection of marine environments. Many other organizations are achieving good results.

The San Pablo Bay watershed on the California coast is being restored so that streams no longer dump excessive silt into the associated wetlands and bay. San Francisco Bay, which has suffered severe environmental degradation for years, is getting kinder, restorative treatment. A massive wetlands restoration project has been started there, which may take 30 years to complete. Sixteen thousand acres once diked off and used to harvest salt are being reopened to the sea with the intent of restoring the area to the saltwater marsh it once was. Altogether, along the California coast, more than 100,000 acres of wetlands are scheduled for restoration.

Gaining early experience and education in environmental matters, school children have become involved in local projects ranging from restoring riparian areas, to tree planting and local fish hatchery operations. An early role model for such local action was launched in Oregon shortly after the hugely destructive "Tillamook Burn." In August, 1933, 290,000 acres of (mostly public) forestland in the Oregon coastal range were completely destroyed by fire. The conflagration was of historic dimensions. In the years since, school children and civic groups from around the state schedule annual "tree planting" projects to help reforest the burn. A few years ago, those citizen efforts resulted in the first commercial thinning of logs from the new forest. Oregonians can drive to the coast and pass through the miles of today's forest and point out where "their" trees are growing. Personal involvement in environmental projects has various benefits, including acquiring a personal sense of stewardship for the Earth.

Twice a year, the coastal beaches of Oregon are cleaned of trash by citizen volunteers. Such efforts should be encouraged and supported. There are opportunities everywhere to promote successful personal or group actions for the environment. Nature has great resiliency, and with a little help, can often recover very well.

An increasing number of local, national, and international organizations are focused on conservation and habitat restoration. "Earth Day," first observed on April 22, 1970, has become a nationwide annual event, with a variety of pro-environmental activities. The movement is spreading to other countries. Education at all levels is bringing awareness of the importance of the environment to a wider public. David Brower, the first executive director of the Sierra Club, noted, "The wild places are where we began. When they end, so do we." The legacy of naturalist John Muir, regarded as the father of the conservation movement in the United States, persists in many forms. Many people have joined forces to preserve wilderness and wild areas.

Other conservation successes, such as marine reserves, are ongoing. The record of the marine reserve offshore New Zealand has been a particularly notable program in res-toration of local and regional fish populations, with surprisingly good early results.

China, with a current population of 1.3 billion, has had a particularly difficult time establishing conservation projects. Since 2000, however, China has almost completely reversed its approach to forest resources. Although China is now the world's largest exporter of furniture, it has made massive investment in six key forestry programs. It is implementing forest management policies to enhance sustainability, while at the same time balancing land use, economic growth, and demand for forest products. Some 60,000 specially trained police now enforce such policies as logging bans (Wang, et al., 2007).

All these activities, however, to considerable degree, are simply holding actions until sometime in the future when human population and nature reach a true balance. At that point, these islands of preservation can serve as seed for the restoration and maintenance of the greater environment.

Sub-Sahara Africa, where population is growing the fastest at this point in history, is where the environment is most seriously threatened. Soils are being degraded on a massive scale by overgrazing. The widespread removal of vegetative cover is causing erosion. Wildlife in some areas is so decimated, that there are proposals to put endangered African species in reserves on the Great Plains of the United States. Such measures can hardly be a long-term solution to the problem of disappearing wildlife diversity. The problems must be addressed where they originate, and there are some efforts by governments to do so. Richard Leakey in Kenya, son of the famous archeologists Louis and Mary Leakey, and an accomplished paleoanthropologist in his own right, has been a leader in such local work in Africa.

In these situations and many others, the problem is human population growth. Hungry people on the economic margin and on the edge of survival are not concerned with conservation and the environment. Concerns about the environment can be abandoned rather quickly even in an affluent society. In 2005, when gasoline reached $3 a gallon in the United States, a survey by the Pew Research Center for People and the Press reported that six out of ten people said that exploring for new sources of energy was more important than protecting the environment. Both should be done, but the greatest effort should go toward exploring renewable, sustainable energy sources that would have the least impact on the environment.

Humanity in the future will have to live closer again to nature to survive. It has been said that "We are operating the Earth like it was a business in liquidation." This must change.

A Contrary View

In this chapter, and in other parts of this volume, facts have been presented and the argument made for a reduction in population because this is one of the two critical issues of this century. However, there is also a fairly widely endorsed school of thought saying exactly the opposite. As such, it must be recognized as part of the debate. Governments, with the "growth is good" view, are generally in this camp. An editorial endorsement of a book entitled *The Empty Cradle: How Falling Birthrates Threaten World Prosperity and What To Do About It* by Phillip Longman (2004) in the *Wall Street Journal*, June 2, 2006, presented this view. The editorial contained the following statement:

> Philip Longman has exploded one of the planet's most enduring modern myths. He has demonstrated that population growth is not the threat that it has been made out to be and that population decline is the real challenge ahead.… By the time of the book's publication, many developed nations were already struggling to address the obvious result of falling fertility: What to do when so few babies are being born that eventually there won't be enough workers to sustain your country's economy, let alone support the elderly.

The editorial noted that several countries (e.g., Japan, Russia) are now encouraging increased births. The writer continued:

> Falling birthrates are a concern for more than just the most prosperous countries, too. Along with all of Europe, Japan, and Canada, Mr. Longman notes, China and parts of the Middle East are experiencing population loss…there is

> no evidence that over-population has ever been at the root of poverty.... Thanks in part to immigration, the U.S. is not facing a population deficit. Other factors are at work, too. This country has a high rate of religious beliefs, which usually corresponds to a higher birthrate, as well as a general sense of optimism.... With its cradle still full, the U.S. is in effect, seconding Mr. Longman's theme. Our thriving economy is testimony to the fact that human beings, so long demonized as the ultimate threat to the planet, are its most indispensable resource.

Perhaps the most indefatigable exponent of this "growth is good" (always and everywhere and for all time) school of thought was Julian Simon (1932-1998), who argued that "the ultimate resource" is the human mind, and the more of them, the merrier. In Professor Simon's view, if only governments would stand aside and allow economic freedom to flourish unfettered, the ingenious human mind would ultimately solve any and all problems associated with population growth and resource scarcity, through a perpetual process of invention and substitution. It was Julian Simon who penned the line without parallel as an example of pure hubris, hype, and hope: "We have now in our hand — really, in our libraries — the technology to feed, clothe, and supply energy to an ever-growing population for the next seven billion years" (Simon, 1995).

A few facts and comments

Based on the Population Reference Bureau's "World Population Data Sheet" for 2012, few European countries are projected to lose population by 2050, and none by very much. Canada's population, now at 34 million, is projected to be 47 million by 2050. Iran, doing the best in the Middle East on population control, now has a population of 78 million that is projected to reach 100 million in 2050. Projected population growth to 2050 for other parts of the Middle East are Saudi Arabia by 101 percent; Kuwait, 172 percent; Palestinian Territory, 197 percent; Israel, 55 percent; United Arab Emirates, 101 percent; Iraq, 121 percent; and Jordan, 79 percent.

As to Longman's statement that " ...there is no evidence that overpopulation has ever been at the root of poverty." Tell that to Somalis now starving in many areas, as are regions in central Africa. It is doubtful that the editorial writer had ever been to Haiti, where ten million people live in abject poverty on 10,500 square miles. As to the stated "problem of declining population," I know of no scientific studies that fail to endorse a reduction in world population given the depletion of nonrenewable resources, the overdraft of some renewable resources and well-founded doubts that alternative energy sources can adequately replace fossil fuels. Regarding the declaration that "our thriving economy" is evidence that population is the planet's "most indispensable resource," there is no mention that the U.S. economy has an unsustainable current deficit in its international balance of payments. A recent National Academy of Sciences study and several others all conclude that the present population has overshot the sustainable carrying capacity of the Earth. The editorial writer seems oblivious to this very important fact. We are propping up our income, wealth, and current resource consumption only by drawing down what ecologists call "natural capital," and it can't continue much longer, any more than a profligate spendthrift can continue to burn through his inheritance forever without meeting his comeuppance.

These two strongly opposing views on population will be an ongoing debate for some time. Population growth is welcomed in many quarters. It means more business and more demand for goods and services. More real estate development is needed, more shopping malls and roads built, more farmland paved over. Construction is a large industry. The article illustrates that our economy is now based on continued growth endorsed by both government and business interests, therefore, more people are an asset. Little thought is given to depleting our nonrenewable resources, or degrading our renewable resource base on which we must ultimately depend.

As retail "big box" stores expand into many countries with sizeable markets and people wanting to buy and consume more and more goods, we are evolving into landfill societies. As trash accumulates, we are faced with the fact that in our throw-away economies, we are beginning to run out of places to throw away the effluents of industrialization. Industrialization as now exists, both unsustainably exploits the Earth's resources and trashes the planet.

Grant (2007) makes this observation:

> Human activity is already degrading the environment and its resources. There are too many of us to live decently on the impoverished resource base toward which we are moving. It is not enough to hope that 'something will turn up.' This view betrays a realistic view of history. Nothing is likely to turn up by itself. Policy makers do not deal with population at all. It now ranks lower in the national consciousness than it did three decades ago. With fewer people, we could protect a decent level of per capita consumption even as total consumption declines. Our political leadership has completely ignored the role that smaller populations could play, yet that is the most fundamental part of the solution — and the cheapest.

Grant adds:

> The problems I have described are all the product of past and continuing growth in demand, and population is the fundamental driver. The potential solutions are limited by that same growth…. The energy transition is a result of that growing demand, and the potential solutions are hostage to continuing growth…. The common thread in these issues is the need to systematically reduce the immense human impact on global systems, which is a function of recent population growth.

Tensions rise as growing populations press against declining resources. International, national, and even local differences (one state or province vs. others in the same nation) between the "haves" and the "have nots" are causing rising unrest as living standards are under pressure. As these pressures reach the personal level, increased social unrest, even chaos, is inevitable.

There seem to be more forces favoring population growth than there are favoring population reduction. If not changed, current trends will create a catastrophic collapse of the environment in loss of topsoil, groundwater supplies, and biodiversity. This is the century that will see how humanity deals with this fundamental problem of population versus resource limitations.

Summary

The world's ecological systems can get along just fine without us, and they would do much better without us. But humans cannot thrive sustainably without the diverse and inter-related environmental complexities that support us. As our total environmental life support continues to deteriorate, and as population seems likely to grow at least another 40 percent this century, we face a critical combination of problems never before seen.

Most, if not all, environmental and related problems can be summed up in relatively simple terms. We are witnessing a plague of too many people on the planet, destroying natural habitat through dams, monoculture agriculture, rainforest destruction, pollution of freshwater and oceans, loss of topsoil and groundwater, and myriad other negative impacts. Protecting the environment, however, is difficult when a third or more of the population lives in poverty, largely the result of too many people for the resources available to sustain them.

The single most important cause of animal life and planet extinctions is habitat destruction. With extinctions, away goes the biologic diversity necessary for a healthy planet on which humans must depend. A new United Nations study bluntly states that: "Species extinction and a growing human population living beyond its environmental means are putting the global economy and even the survival of humanity at risk. Problems, driven by increasing human population, and environmental damage may pass points of no return." Human activity has reached an unsustainable level, outstripping available resources according to their report. Yet, these problems, key to our survival, are way down the priority list, if they appear there at all, for most governments in the world.

Perhaps, as we recognize that we are dependent on the environment, we should consider the views of the Chinese expressed in the Taoist philosophy:

> How should man relate himself to nature? On the whole the modern Western attitude has been to regard nature as an antagonist, something to be squared off against, dominated, controlled, conquered. Taoism's attitude tends to be the precise opposite of this…. Nature is to be befriended. When Mount Everest was scaled, the phrase commonly used in the West to describe the feat was 'the conquest of Everest.' An Oriental whose writings have deeply influenced by Taoism remarked 'We would put the matter differently. We would speak of the 'befriending of Everest.' Taoism seeks to be in tune with nature. Its approach is basically ecological in nature….

Monget (2007) has a similar ethical view:

> Technological comfort is an illusion. Although technology may give us the impression that we can get by without our natural environment, the reality is entirely different. As long as we haven't learned to live totally self-sufficient in outer space or to colonize other planets, we will be dependent on our terrestrial environment. Sooner or later, abusing our environment — as we have done for too many years — will undoubtedly affect us. By destroying our environment, we are condemning ourselves to certain extinction.

We have gradually come to understand that nature provides many basic services for us, from pollinating fruit trees, to purifying waste water, and "befriending nature" is the long-term constructive thing to do. As we go from the current economy of using a great inheritance of resources (oil, natural gas, soil, groundwater, and others) to an economy based on current sustainable income from the environment, we need the environment as a friend. Friends can help us. If we try to dominate and control them, they will not be friends. We need to get along with our environment and not exploit it in unsustainable ways. Treating nature as a friend will call for a new economic paradigm, which cannot coexist with the continuing material growth paradigm we pursue today.

Some of the world's brightest minds are united in their concern for the effect of population growth on the environment and the future:

> Pressures resulting from unrestrained population growth put demands on the natural world that can overwhelm any effort to achieve a sustainable future. If we are to halt the destruction of our environment, we must accept limits to growth.

As noted earlier, this statement — the *World Scientists' Warning to Humanity* — was signed by 1,700 senior scientists, including 102 Nobel Prize laureates from 70 countries, on November 18, 1992. Unfortunately, the warning largely went unheeded. Since 1992, more than 1.5 billion humans have been added to the world's population, placing an ever-greater demographic load on a weakening ecological support structure.

Chapter 23

Efficiency And Conservation — To What Purpose?

With increasing evidence of the need to make better use of the raw materials and energy supplies we have, there is a growing emphasis on efficiency and conservation and using new technology to do this. One dictionary defines efficiency as: "effective operation as measured by a comparison of production with costs (as in energy, time, and money)." Conservation is defined as: "a careful planned management and protection of something, especially planned management of a natural resource to prevent exploitation, destruction, or neglect." The two oil crises of 1973 and 1979 in the United States served the useful purposes of getting people to think about efficiency and conservation. Efficiency seeks to make better use of the raw materials that are available. Conservation seeks to save raw materials for the future.

Efficiency

Efficiency does not mean giving up anything, although through the more-efficient design of something, some material or amount of energy may be saved. Increased efficiency should leave us just as well off as before. It means doing more with less. Houses can be made more efficient in terms of energy needed to heat or cool them by means of proper construction, particularly insulation. Cars can be made more efficient by using lighter weight materials in construction, and by being smaller. However, this reduces safety, for a small light vehicle comes out second in a collision with a larger, heavier car.

All sorts of equipment and appliances can be made more efficient in their use of energy. The transistor has helped reduce electricity consumption in many things we use. Fluorescent lights are more efficient than filament lights. Refrigerators and water heaters manufactured now use less electricity than they did a few decades ago.

There is a valuable practical aspect to efficiency, from both a business and a personal point of view. For business, making less do the same or more means lower costs and being more competitive. Factories hire engineering efficiency experts. For individuals, it means containing or perhaps cutting the cost of living, or at least reducing the rate at which it would increase if efficiency was not employed. In general, increases in energy costs have an adverse effect on the economies of all countries, except for energy exporting nations, chiefly the oil producers. Since energy is basic to all manufacturing processes, energy efficiency will always be an important goal because the cost of energy winds up in almost everything we use.

Conservation

Conservation implies preserving something for the future. Conserving, therefore, involves looking ahead for many generations, perhaps indefinitely.

By treading lightly or not at all, scenic places may be preserved for future generations. The Nature Conservancy buys and sets aside natural areas in perpetuity, and if they are used, they are to be used so that no permanent damage is done. The U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS, formerly the Soil Conservation Service) tries to save our most valuable mineral complex with no loss, although this is difficult in active agricultural areas. For the most part, the NRCS simply tries to keep loss to a minimum. But current plowing practices continue to put more and more topsoil behind dams and into deltas.

Water can be conserved by more efficient irrigation practices such as drip irrigation, and by regulating the use of water for lawns and golf courses (a large consumer of water, especially in the arid U.S. southwest). Water conservation has helped some regions successfully cope with water supply crises. But gains from water conservation efforts are ultimately defeated by the demands of growing populations. India is the classic example of this problem. The western United States is another.

When one conserves, it may be that something is given up for the moment. If we do not use it today, it can be used by ourselves or others tomorrow. These days especially, one might forego the use of gasoline, perhaps by not taking a trip. But for whom is it being saved; and how and when will the saved resources be used; and who determines that? In this case, conserving something for the future becomes an abstract concept. Conscientiously conserving materials for the future is not a virtue shared by everyone. The result is that those not so inclined can simply continue their ways using resources as they did before and enjoy the benefit of a smaller rise in prices due to those practicing a conscientious conservation ethic. Those with more income could pay the bill and live as before. As resources grow scarce and prices rise, these situations may foster civil unrest. To really work, conservation must be a totally embraced universal national ethic, and a whole world ethic.

In the case of wildlife, forests, a wild river, a scenic area, or soil, the conservation rationale is fairly clear. But with minerals and energy mineral resources, the matter is much more complicated. Unlike wildlife or trees that can be renewed, minerals and energy minerals do not reproduce.

The question comes then as to how we might rationalize saving minerals or energy sources such as coal, oil, gas, and other minerals. These are all one-crop resources. Can enough be saved for future generations to make any difference? And for how long would it make a difference? An example of this is oil. The U.S. is already using more than it produces. Should the U.S. reduce consumption of oil from its own oil fields in order to save for the future, while it imports more oil to make up the difference? And how long can we extend the present uses of oil by our efforts? Would it be significant in the grander scale of things?

There is an economic conundrum. If domestic resources are conserved instead of developed and processed, the industries involved do not survive, along with the many suppliers to these activities. Unemployment results. One job in the oil fields generally results in two jobs in related services. Until the recent uptick in production, United States oil production had been declining for a number of years, and in the process, nearly half a million jobs had been lost (Hodel and Deitz, 1993).

Efficiency and Conservation: The Solution?

Efficiency and conservation are laudable ends and should be pursued. But are they the ultimate solution to our resource problems? In the United States, President Carter put on a sweater and turned down the White House thermostat to conserve energy. That presumably was to help get us through the energy crisis of the time, which was temporary. Do we conserve just to get us past a given energy or resource crisis? Or is it a long-term issue?

Conservation: An Energy Source?

Unfortunately, there is a mistaken impression that conservation is an energy source. In a widely acclaimed national bestseller, there is a chapter entitled "Conservation: The Key Energy Source." It reads:

> There is a source of energy that produces no radioactive waste, nothing in the way of petrodollars, and very little pollution. Moreover the source can provide the energy that conventional sources may not be able to furnish…. The source might be called energy efficiency, for Americans like to think of themselves as an efficient people. But the energy source is generally known by the more prosaic term *conservation* (Stobaugh and Yergin, 1983).

These authors confuse the use of the terms "efficiency" and "conservation," and to call either one a source of energy is an error. Reducing the amount of energy used during a given time period is efficiency. But this is not a *source* of energy. Neither is conservation. Also, there is a limit to the amount that energy consumption can be reduced and still meet basic needs. New energy supplies are continually needed. Both efficiency and conservation are worthwhile endeavors, but not long-term solutions in regard to energy supply problems.

The Population Growth Factor

Growth in population creates a tremendous impediment to any program to solve the world's energy problem. The nearly 80 million people being added each year to world population is more than the combined population of The Netherlands and France.

Some states like Oregon have energy departments, or some similar agency designed to encourage the efficient use of energy supplies, particularly electricity. Oregon is one of the faster growing states caused by the natural increase of the people already there, together with newcomers coming from both within and outside the U.S. The Oregon Department of Energy has an energy conservation program that takes various forms. The question arose as to whether or not the amount of energy saved each year by these programs was equal to the additional amount of energy required to take care of the needs of the new residents of Oregon. The answer was "definitely not" (Sifford, 1993). Reviewing various options for future energy supplies with regard to a possible world energy conservation program at a U.S. Department of Defense-sponsored meeting, one observer stated: "The gain in realistic energy conservation efforts would be nullified within a decade by population growth." Keep this statement in mind whenever a serious discussion of energy problems comes up. It is almost always overlooked.

With a stable population, energy efficiency would result in a reduced need for power, but when the needs of an increasing population are included, it is a losing effort. Admittedly, it would be worse if these energy programs were not in effect. The fact is that more, not less energy, is needed each year, and some limits are already being approached. As an example, no more electrical energy can be developed from the now fully harnessed Columbia River power system (Bonneville).

Yet population keeps growing, and without a stable population, the unwinnable game of "catch-up" on power supplies will continue. In the U.S. Pacific Northwest, wind and solar and perhaps waves may be the ultimate regional energy resources, but they cannot be used as a dependable base load. The regional hydro-base load available to supply power when at times solar, wind, and waves are not available, is now fully utilized. Additional base load is now provided by fossil fuels, but when they are gone, a continu-ally growing population will mean a lower standard of living in terms of energy per capita, and an increasing frequency of power supply interruptions. We clearly cannot conserve ourselves out of our energy problem. If population is reduced to a stable size that can live satisfactorily on renewable energy resources, then efficiency and conservation will have a role in resolving the energy problem.

Nonrenewable resources

The United States has not been self-sufficient in oil since the 1960s. With the large influx of immigrants into the U.S., combined with the natural growth in population, the need to import oil continues to grow. Efficiency and conservation can slow the need for increased imports, but it cannot reverse it.

Renewables

Conserving and being more efficient with renewable resources have long-term merit. But renewables have limits. Only so much sunshine falls on the Earth each day and freshwater supplies, although renewable, are still limited at any given time. So keeping demand low by means of conservation and efficiency within the capabilities of renewables to be renewed is vital. A stable population has to be reached based on available renewables, and at that time, efficiency will determine how many people a steady-state economy can support at a reasonable standard of living.

How to transform to a genuine renewable resource economy and at the very same time achieve a population size that economy will accommodate is the problem we face. In the past, nature has always done so by imposing the harsh realities of famine and disease. Can intelligent humanity fit its population size to a sustainable economy? Johnson (1978) thinks it may be accomplished by a process he calls "muddling toward frugality." How intelligently, orderly, and with no harsh circumstances this muddling toward frugality can be achieved is not certain.

Crises Cause Change

With few exceptions, most people neither plan for nor recognize a problem until it arrives. Then it is usually too late and the damage is done. Unfortunately, it seems that only crises promote change. The oil supply crises of 1973 and 1979 provide examples of crisis-forced change. The lesson, however, was soon forgotten.

The oil crises were damaging to the U.S. automobile industry, which had largely ignored the matter of efficiency, and instead had promoted bigger and more powerful cars. But with the gasoline shortage, Japanese cars and some of the smaller German cars suddenly became popular. Japan, in particular, not having any significant domestic oil supplies, had developed quite efficient cars. Japan established a foothold in the American car and truck market, which has grown substantially in recent decades.

In 2005, the average vehicle miles per gallon in the United Kingdom was 26. In the United States, it was 17. Japan's introduction of the hybrid car challenged the American auto industry. After the price of crude oil and gasoline more than doubled during the first decade of this century, car mileage became a growing concern to many.

The times in which we live now tend to justify the thought that the industrialized world has been living in a "fuels' paradise." Some realize this and have made rational adjustments in their lifestyles. Others have not. Collectively, these attitudes affect the course of a nation. They affect its economic position and its ability to survive, for a time at least, in a world with a continually expanding population using a diminishing resource base.

Recent Change in Ethics

The illusion of endless supplies of Earth resources that tended to dominate the thinking of earlier times in the United States — what former U.S. Interior Secretary and *Quiet Crisis* author, Stewart Udall, once called "the myth of superabundance" — has given way to a more rational view that we have to make the most efficient use of what we have. This ethic has prevailed in Europe for many years, but because of the abundance of natural resources in the United States, and the fact that the U.S. was settled so much later than Europe, that attitude has only recently arrived here. It is welcome, but still only partly accepted. Although there has been much lip service given to efficiency and conservation, in actual practice, the adoption of these goals and practices is by no means universal in the United States. Some people conscientiously recycle their refuse. Others continue the throw-away culture. However, the recycling ethic seems to be growing, and new homes and other construction increasingly stress energy-efficiency features.

The Third World

The foregoing remarks apply mainly to the industrial world and especially the United States and Western Europe. But what about the undeveloped nations, many of which have few natural resources of their own? Whatever low-cost and relatively simple technologies can be developed locally or supplied by the industrialized nations will be very useful. Solar cookers in India are one such example, and can reduce the demand for firewood, which has been deforesting the country and giving rise to floods and soil erosion.

The efficiency ethic can be used immediately to make better use of what resources exist. Implementing a conservation program is more difficult. In already overpopulated areas with increasing poverty, significant conservation of natural resources is given little consideration. Reducing population growth would probably be the most useful of all programs to implement.

Ethics of Mineral Use

The questions of conserving mineral and energy resources in any country, for whom and for how long, are not easily answered.

To whom do resources rightfully belong?

When considering conservation and efficiency to save resources, there is a philosophical question as to whom the resources belong. We now have the ability to produce oil and minerals in quantities that generations past did not. Thus, we are producing them and using them. But if we did not use them now, who in the future would have the ethical right to use them: the next generation, the people who will live 100 years from now, or, those alive 500 years hence?

Physicist Charles Galton Darwin, grandson of Charles Robert Darwin of evolution fame, has considered this problem. He writes:

> For example, consider the inevitable fuel shortage that is to come so soon. I know that my sons will not suffer from it very seriously, but I know that the fifteenth generation of my descendants will get no coal at all. Am I likely to refrain from putting coal on the fire on a cold evening by the thought that it may make one of my fourteenth descendants suffer from it? Such matters are so unreal to our minds that it is not to be expected that they will ever be given much weight. Life is always precarious and it is so hard to be sure of keeping alive for even ten years that is it not surprising that no one should care much about what is going to happen even as short a time as a century. In hardly any of the affairs of the world will man really be interested in the more distant future (Darwin, 1953).

Should we use all the resources we want to use now in any manner we choose, or just for basic daily needs? Should we also use substantial quantities for recreation? Do we ration resources to the consuming public, as has been done in wartime, so we can save some for "future generations"? Or do we assume for certain that in coming genera-tions, "the scientists will think of something," and therefore we need have no thought for resources for the future?

The idea that, "we can do no greater honor to future generations than to have faith that they will have the intellect to solve any problems which we leave to them," may not be such an honor to the future generations once they see what we have left them. It is a rather tenuous assumption that future generations will "think of something" and that we need have no ethical concerns for the future. Today, some segments of the population are consuming larger amounts of resources than other segments. Many people now are consuming very few resources and lead a marginal existence. The whole topic offers a wide area for discussion. It is clear that even with the best efforts of conservation, for all practical purposes, this century will see the exhaustion of nonrenewable energy resources, and the forced beginning of an entirely new energy economy.

Obtaining resources from other lands

Currently, if a country does not have resources and can afford to do it, it will buy them from other countries. Some feel that industrialized countries, in effect, are stealing the resources from other lands. But the Persian Gulf countries, for example, are not required to sell oil to anyone. Nor are Chile or the Congo required to sell copper. These countries sell their energy and mineral resources because they want the benefits of what the money from the sale of these resources can buy, and they want these benefits now. Not having their own industries producing the good things of today's world, they need foreign exchange to buy them. Automobiles are one such item, but others include such things as medical equipment and drugs. Without oil to sell, most of the Gulf nations would still be using camels and living in tents in the desert. For populations that lead a marginal existence, if they have resources to sell, export money helps to prevent their current situation from being even worse.

Today and tomorrow

For the most part, the world view seems to be that resources are for use by the present generation in whatever volume they can obtain. What remains goes to future generations who well may have the same point of view. What is occurring is that each generation uses the least expensive and highest quality resources available, leaving future generations to fend for themselves, with the hope that technology will come to their rescue. But one might question if the dual problems of progressively lower-grade resources, requiring larger and larger amounts of energy to produce, demanded by more and more people for at least several decades to come, can be solved by technology? Can current living standards be maintained for affluent societies, much less be raised for developing world populations against these realities? With rising population facing diminishing volumes and qualities of resources, each future generation faces larger challenges that technology may not entirely solve. Whatever efficiency and conservation technology can offer then will be much more appreciated than it is today. Efficiency and conservation will be part of the mainstay of everyday life. Now is a good time to start.

Summary

Efficiency and conservation are not sources of energy or minerals. They can only buy time to allow populations to be stabilized at a size that renewable resources can sustain. Efficiency and conservation practices today are probably more than canceled out by the increased demands of a growing population. Trying to solve the problem of energy and mineral demands by efficiency and conservation is simply treating the symptoms of the problem rather than the cause, and will ultimately prove futile. The "cause" is population growth, and so far, we are unable to establish a stable population of the size that can be sustainably supported by a renewable resource economy. Eventually, population size will be stabilized within narrow limits, either by reason or by harsh natural forces. When that time arrives, efficiency and conservation can help maintain a steady-state (no-growth) economy.

Efficiency and conservation can help us make the inevitable transition to an economy based on renewable resources. Unfortunately, we do not seem to be making the progress needed in renewable resource development and in reducing population size to make a smooth transition. Spending and human resource priorities must begin to address the inevitable changes this century will bring. Otherwise, the thin veneer of civilization may be severely tested — a thought not to be taken lightly. Murder took place in the gasoline lines during the 1973 oil crisis, which was only a temporary situation. What happens when the gasoline crisis is permanent and growing?

Chapter 24

Minerals, Politics, Taxes, and Religion

This may appear to be a rather mixed group of topics, but in fact they are closely related. In some countries, religion and politics are separate, the separation of church and state. In other countries, religion and government are closely entwined. Religious attitudes and politics may influence the development and free flow of mineral resources. An example is the Arab embargo of oil to the United States in 1973, imposed because the United States supported Israel in its war with Egypt.

Since the time of the ancient Egyptians, who levied a tax on a commodity everybody needed, salt, taxes on minerals have been and continue to be a major source of government revenue. More recently, another item in common use, petroleum products, and especially gasoline, are the object of moderate to very high taxes, levied not only for the purpose of building roads, but as a source of general government revenues. Political bodies recognize that taxes placed on things that people need to use will yield rich revenues.

Perversely in some places, although mineral industries and their products are a source of substantial employment and government revenues, politicians denounce and assail these enterprises in the presumed interest of their constituents. This is commonly done to win popular political favor. Oil companies are among the favorite targets for these politicians. Because petroleum products, especially gasoline, are commodities used by nearly everyone, assailing the companies that sell these products affects the interests of a large portion of the population of industrialized countries.

Together, the matter of minerals, politics, taxes, and religion form a large area of discussion. Some examples of where these have an influence on the future of nations and individuals are described here.

Politics

The politics of minerals, particularly oil, has filled many books, among which is Daniel Yergin's epic volume, *The Prize*. Only a few salient points can be addressed here. There is no doubt that natural resource companies, like other economic enterprises, try to influence politicians for various ends. These range from matters concerning taxes on minerals, obtaining mineral leases (particularly from certain foreign governments where corruption is a way of life), rights-of-way through public lands, workers rights, and a host of other considerations.

Domestic politics

The mineral industries, particularly the oil industry, are involved in politics in another way. Gasoline, especially in the U.S., is such an important everyday commodity that everyone is keenly aware of its price. Oil is priced on the open market, contrary to what many people think, including some elected officials. Domestic companies do not control the price of the crude oil they process. In the past four decades, crude oil prices have fluctu-ated widely, from as low as $3 to as much as $147 a barrel. Retail prices of gasoline have gyrated accordingly.

The nationalization of oil companies abroad, and the continued movement of U.S. oil companies overseas because domestic exploration prospects are diminishing, have made U.S. companies increasingly hostage to foreign governments. There, overseas investor-owned oil companies rarely own the oil, they simply have lease arrangements for developing those resources and may get a percentage of the production. Foreign governments own the oil and have control. In turn, the American oil-consuming public is hostage to foreign governments. The balance of economic power has shifted abroad in the past four decades, and oil has been a chief factor. Shale oil from fracking may shift the balance somewhat back again.

International Politics

The international relations arena dealing with mineral resources has seen great changes the past half century. There are two important trends. One is the rise of nationalism after the colonial period. The other is the increasing dependence of the industrial nations on mineral and energy mineral supplies they do not control, and how this affects their foreign policies. International politics also are influenced by what strained relationships may exist, as, for example, Iran's dislike for the U.S. Reciprocated by the U.S., this enmity dates back to the Iranian Revolution of 1979, when Iran took U.S. Embassy officials hostage for more than a year, and from the Iranian perspective, even further back, to 1953, when the CIA helped overthrow the Iranian prime minister and installed the Western-oriented Shah. The U.S. cut off all purchases of oil from Iran, and blocked American oil companies from doing business with it. The result is that French, British, and Italian oil companies continue to do business in Iran, although to a somewhat limited extent, because Iran controls its petroleum resources through the Iranian National Oil Company.

Restructuring of nations such as occurred after the break up of the Soviet Union with some of its oil resources now under the control of the independent republics that emerged from Soviet disintegration, requires that oil-consuming nations establish new relationships in that region. The new governments have varying degrees of stability. One oil company executive told me that this has made doing business difficult at times. After his company established relations with the presumed government and paid for leases, they were subsequently told that another group was the true government. The earlier leases were not valid and the money disappeared.

In other situations, governments may change through military coups or revolutions, and leases issued by the previous government may be declared invalid or the new government may want to "renegotiate" the leases. The oil-consuming public is unaware of the great variety of political and other factors involved in putting gasoline in their tanks.

Nationalization of mineral resources

One of the advantages that Great Britain had in both World War I and World War II was the ability to draw mineral resources from its worldwide colonial holdings. The colonial era completely ended after World War II, when the colonial holdings of Britain, France, The Netherlands, Belgium, and Italy began to assert their independence. It was said that the chief international sport became "twisting the British lion's tail." India and Pakistan were among the first to do this in 1947.

Almost immediately there was a further move toward creating a national identity by taking over mineral developments formerly held by the colonial powers. The trend spread to almost all foreign mineral holdings in countries that were not previously colonies. The United States had no colonies, but U.S. corporations had large international mining and oil interests. Soon the international sport became one of "yanking the tail feathers out of the American eagle."

Chile nationalized the American copper companies, Kennecott and Anaconda. Zambia and Zaire took over all multinational copper operations there. "American" was rubbed out of the name Arabian American Oil Company in the desert sands of Saudi Arabia. All foreign interests in Iran and Iraq were taken over. Kuwait nationalized Gulf Oil's interest there. Venezuela nationalized Creole Petroleum Corporation, formerly a division of ExxonMobil Corporation, the company that had developed the great oil deposits of the Lake Maracaibo Basin. Peru took over International Petroleum Company, also at the time an Exxon affiliate. This was done with no compensation whatsoever. And was done not long after Exxon had invested large sums in rebuilding the oil camp and related facilities, including a modern hospital free to all employees and their families, and had built the safest water supply system in the entire country, and even a fine large church. I was a geologist there at the time.

"For the people"

The excuse one government gave for the nationalization of a foreign company and its mineral holdings was that "we wanted to have a gift for the people." Whether such a gifT ever reached the people is debatable. In some countries, nationalization meant some increased affluence for the general citizenry. In other nations, it meant only that more money benefited a relative few through graft and corruption. The initial attraction of nationalization for the government officials in power at the time was to get the revenue flow. What happened thereafter has been a mixed bag. In general, the countries of the Gulf region have done better in spreading the mineral wealth throughout the general population than have most other nations.

After nationalization?

After nationalizing their minerals, many countries discovered they did not have the technical expertise to run the nationalized operations. Also, in some cases, so much money was drained from operations into political and social pockets and causes, that there was not enough capital left to maintain and develop the resource facilities. Therefore, many countries invited foreign companies to come back, under various financial arrangements. In a 2-page ad in 1995, Zambia announced it was privatizing the government monopoly of copper mining, and asked for foreign capital to come in and help. On January 1, 1976, Venezuela took over all foreign oil interests. But in 1995, Venezuela needed help to run its oil operations, and made arrangements to auction off some exploration rights in various prospective areas to foreign oil companies. It should be noted that Venezuela was not risking any money. If the leases are unproductive, the companies lose all their lease and exploration costs. However, the terms included taxes that took from 71 percent to 88 percent of the profits from any successful ventures.

Military regimes and oil

In some countries, Nigeria and Libya being recent notable examples, oil revenues have supported oppressive governments. This is an unfortunate situation for which the oil companies occasionally have been severely criticized, but over which they have little or no control. Interference in the internal affairs of a country is not feasible for a foreign com-pany. The options are either to continue operations or to leave.

In Nigeria in late 1995, a particularly outspoken critic of the government complained that the oil income was being taken by a relatively few government officials and not being fairly distributed to the impoverished people in the delta area where the oil was being produced. The Nigerian government's response, in spite of international condemnation, was to execute the individual. Oil income can be so lucrative that it spawns widespread government corruption. This is a continuing problem. About the only thing that can be done is for the international community to support the democratic elements in such countries as best they can. This has been done to a limited extent (for example, the oil embargo against Libya), but these tactics have met with limited success. Foreign oil and mining companies really cannot afford to get involved in a nation's domestic politics. If they back the political faction that loses, the companies have much to lose themselves.

Foreign policies and resource dependency

If an industrial nation were self-sufficient in all necessary mineral and energy resources, it could act independently of other countries. However, no nation is entirely in that position. Japan is one of those most dependent on foreign mineral and energy supplies. This is probably the single most important factor guiding Japan's foreign policy. Japan is exceedingly vulnerable and knows it.

Beginning in the mid-1960s, when the U.S. could no longer supply its own oil needs, its foreign policy had to begin to be modified, especially toward the Gulf oil nations. The United States' strong support of Israel precipitated the oil embargo and crisis of 1973. Since that time, due to increasing U.S. dependence on Arab oil, U.S. foreign policy has been adjusted to accommodate both Arab and Israeli positions. Britain, Germany, France, and Italy have similar foreign policies for the same reason.

Break up of the USSR and the new politics

With the break up of the Soviet Union, a new political order caused by oil appeared in that region. Large oil deposits exist in several countries that split away from the USSR. The extensive Caspian Sea area oil is now owned by Turkmenistan, Azerbaijan, Iran, Russia, and Kazakhstan. Some oil, an estimated 4.1 billion barrels, also is located in nearby Ukraine. Kazakhstan, five times larger than France in area, and larger than all of the other former Soviet Republics combined, excluding Russia itself, is reported to have as much as three to 10 times as much oil as Alaska's Prudhoe Bay

Field. The continued inclination of Russia to meddle in affairs of these new republics has caused the United States to modify its support for Russia, and to try to achieve a balance in its foreign policy between Russia and the other republics. Would-be investors in Kazakhstan must contend with Russia's reassertion of its regional power, disputes over pipeline routes, and rising Kazakh nationalism. For U.S. foreign policy, this has meant somewhat less support for Russia, and in some instances, support for the new republics against Russian influence. Oil creates a difficult international political balancing act for the United States as well as for other industrial nations.

Taxes

In the nineteenth century both China and Mexico imposed a salt tax. At various times it has been a favorite tax of the French government (Multhauf, 1978). In the United States, in 1654, Father Simon Le Moyne, a Jesuit missionary, discovered salt springs in the vicinity of what is now Syracuse, New York. Salt works were set up in 1788, and salt manufactur-ing flourished until the 1860s. For many years, the tax on salt was New York's chief source of revenue.

Gasoline tax, currently the world's favorite

The cost of gasoline in the United States is among the lowest in the world, in large part because the tax on gasoline is low. Attempts have been made in the U.S. Congress to raise gasoline taxes in an effort to reduce consumption, encourage automobile efficiency, and raise revenue. But such actions have been strongly resisted. In many countries, especially in Europe, the price of gasoline is much higher than in the U. S. due to taxes.

Reduce import bill

High gasoline taxes that tend to cut down gasoline use also lower the amount of gaso-line that has to be imported. Reduced gasoline consumption is important to a country for its balance of trade. Some countries simply do not have the money with which to import much crude oil or refined petroleum products. Greece is one example.

Environmental protection

High prices on gasoline and other fossil fuels also are favored by some environmental organizations as a way of cutting down the emissions resulting from burning fossil fuels. Several governments have considered a "carbon tax," but have failed to enact it. The idea is that this would reduce the use of fossil fuels that pollute the atmosphere, and in particular, the ones that produce carbon dioxide.

General government revenue source

The reason why gasoline is so expensive in some countries is that these nations put higher and higher taxes on it as a general source of government revenue. In the United States, there is a popular idea that taxes on transportation fuels, gasoline, and diesel, are to be dedicated to the building and maintenance of the road system. The public is under this impression. However, a study by the American Petroleum Institute revealed that user taxes and fees subsidize many other government activities. At the present time in the United States, the federal excise tax on gasoline collects about $20 billion annually. State and local government taxes add another $30 billion.

Severance tax

Taxes on mineral production are levied by various governmental agencies, usually in the form of what is called a severance tax. The concept is that when the mineral is taken from the ground (severed), there is a loss to the country and this should be compensated for by a tax. The enactment of these taxes and how large they are is a political matter and can be a source of much political maneuvering. Huge sums of money are involved. In addition to severance taxes, mineral resource companies pay taxes on their general income.

Religion and the Gulf oil bonanza

Some 60 percent of the known world oil reserves lie in the region of the Persian Gulf, an area that is almost entirely Muslim. These countries include Saudi Arabia, the country with the world's single largest oil reserves, Iraq, Kuwait, Iran, Bahrain, Qatar, Oman, and the United Arab Emirates. In these nations, religion permeates the governmental structure, and affects how governments deal with the rest of the world.

Divisions of Islam

Islam originated early in the seventh century through revelations to the Prophet Muhammad (one of four spellings) reportedly over a period of 20 years. After Muhammad's death, a controversy arose in determining his successor, and Islam split into two main factions, Sunnis and Shiites. This continued down to the eighteenth century when Muhammad ibn 'Abd al-Wahhab, living in a part of the Arabian Peninsula called the Najd, rose up against the various modifications which Islam had undergone and advocated a return to the original Islamic code and faith. The Najd was a region dominated by the House of Saud, and that tribe embraced Wahhab and his views and split off from the rest of Islam. Wahhabism gained adherents and engaged in military actions, including sacking Karbala, the Shiite holy city in Iraq. As a result, there remain strong feelings between the Wahhabis and other Muslims.

Islam spread widely over the world, all across North Africa and other parts of Africa and to Pakistan, Indonesia and parts of the Philippines. In all these regions, terrorism also emerged. In addition to religious divisions, there are ethnic divisions. Iran is Muslim, specifically Shiite, but it is not an Arab nation. Historically, Iran (Persia) has been at odds with the Arab nations, particularly with what is now Saudi Arabia, which in earlier times, Iran had vowed to invade and annex. And there is a religious power struggle within Iran among the various mullahs who vie for power within the Shia Muslim framework. There are also more moderate elements in Iran. However, there is likely to be continued internal unrest (as in 2008 to 2010) while all this conflict is resolved, which will surely take considerable time.

Oil in the mix

When oil, with its enormous potential wealth, is added to all these diverse political, ethnic, and religious divisions, it creates what one observer called "an unholy mess." For a discussion centered on resources for which petroleum is a major consideration, the socioeconomic background is important to understanding the environment from which more than half the world's remaining conventional oil will have to be produced. In the future, a greater share of oil production will inevitably come from the Middle East, so the problems there will be of increasing international concern. The Wahhabi House of Saud, a minority within Islam, controls 25 percent of the world's oil, and 35 percent of Middle East oil. But Saudi domestic problems are increasing. The oil wealth has been fairly well spread through the population until now, although conspicuous consumption suggests a disproportionate share is being diverted to the Saudi Royal Family. Social subsidies are growing ever larger due to rapidly rising population. As recently as 1961, the population of Saudi Arabia was just four million; it is now about 30 million and is projected to reach 50 million by 2050, even with a high level of out-migration. Unemployment among the population (more than half under 20 years of age) is widespread and is a source of serious unrest, as is the presence of millions of foreign workers. Terrorism within Saudi Arabia is a growing concern.

At various times, the Saudis have suggested a proper price for oil. Each time they set the price higher, because domestic needs have grown and the sale of oil is by far their largest source of revenue. To quiet restive elements in their society, in 2011, the Saudis allocated $130 billion in additional spending to build homes and combat youth unemployment, then estimated to be 25 percent.

To avoid increasing their budget deficit, the Saudis need an oil price of $80 a barrel. By 2016, the price needed is estimated to be $98 a barrel. With the projected surge in population, based on the demographics of the country, the needed price can only continue to increase. That fact and surging oil demand in Asia, assures continued long-term higher prices for oil on world markets.

The Iraq invasion of 2003 and subsequent events

There can hardly be a better example of the chaos that can develop when religion, politics, and oil get mixed up than the U.S.-led invasion of Iraq in 2003. Accompanied by some 30 allies — the "Coalition of the Willing," in President George W. Bush's term — the largest troop contingent of which was provided by the British, the incursion placed coalition forces between the two major factions of Islam as well as between Kurds and Arabs. A *de facto* civil war erupted between the Sunni and the Shiites and neither side group was pleased that Christian nations had invaded their Muslim nation.

However, the concept of democracy and freedom from a despot was acknowledged to a degree, primarily by the Shiites and the long-suffering Kurds, who had been victims *en masse* of ghastly and deadly poison gas attacks unleashed by the dictator, Saddam Hussein. The U.S. and its allies in Iraq were embroiled in the middle of these conflicts. To make matters worse, Osama Bin Laden's terrorist organization, Al Qaeda, which previously had little or no presence in Iraq, entered and exploited the chaos and Sunni anger — Al Qaeda's use of car bombs and suicide bombers indiscriminately killed thousands of innocent Iraqis, including women and children, in a furious attempt to sow further pandemonium. Mixed into all this was the occasional destruction of oil pipelines and oil storage facilities by one side or the other, making effective governance and discovery even more difficult.

Sunis, Shiites, Wahhabis, and oil

The major difference between the Sunnis and Shiites is that the Shiites (about 10 percent of Muslims worldwide) believe that the only valid rulers of Islam must be blood relatives of the Prophet Muhammad. The Sunnis believe that Islamic leaders may be elected. Muslims have been fighting and killing each other over these differing beliefs for centuries. Under Saddam Hussein, the Sunnis controlled Iraq, although a majority of Iraqis are Shiites. These two contending groups are a complicating factor in any effort to establish stable governments in Iraq. This deep-rooted problem — stemming from the post-World War I drawing of boundaries by the British that did not take into account sharp ethnic and sectarian differences — will remain a basis for continuing political instability and upheaval well after the departure of the last American troops from Iraq in 2011.

Wahhabism, also known as Salafism, pursues a much stricter, conservative interpretation of Islam. Wahhabism is also popular in northern Sudan and in some parts of Afghanistan and Pakistan. In Saudi Arabia, a deal was made whereby the monarch would take care of business and finances (meaning mostly oil), and the religious leaders would control the mosques, laws, courts, schools, and fashion (including a strict female dress code and other rules enforced by religious police). The great oil wealth of Saudi Arabia has helped to spread the strict Wahhabi views throughout the Muslim world by means of teachings, and financial aid. But it has not spread far beyond the extremist Taliban of Afghanistan and the frontier provinces of Pakistan. Among these groups, beheading and amputations are a regular part of the justice system, schools are destroyed, and females kept under sharp restrictions and denied education. Throughout much of the Muslim world, however, Muslim Sharia law is applied in varying degrees. Qatar and the United Arab Emirates have both Muslim and civil courts. But nearly everywhere in the oil-wealthy Muslim world, oil and religion are entangled to varying degrees and remain a volatile mix.

The conflict between the Sunnis and Shiites continues to this day, a fact that made the problem of uniting Iraq extremely difficult for the United States — if not a "mission impossible" — after its 2003 invasion of that country. At times the conflict between Sunnis and Shiites put the United States awkwardly between these two factions. Forming a cohesive Iraqi parliament from these fractious religious and ethnic factions continues to be an ongoing problem. Religion invariably gets mixed up with both military operations and national politics. Amidst this chaos, the Western allies tried to construct a political system to accommodate everyone. But given the fervor of the sectarian factions, it was difficult at best. This brings to mind the statement that "there is no fight like a religious fight." The ancient Crusades and more modern "troubles" between Catholics and Protestants in Northern Ireland reflect a similar situation.

Muslim nations: oil

But whatever the politics and the religious attitudes may be, the reality is that Muslim nations have been fortuitously destined by geology to control most of the oil reserves of the world. They call the oil "a gift from Allah." Oil deposits under control of the Western industrial nations are much smaller. Geology has determined that in the future, more and more oil production will come from the Persian Gulf countries, within the realm of Islam. There are other petroleum deposits in Muslim nations, including Libya, Algeria, Brunei, and Indonesia, but the total proved oil reserves of all these countries combined are less than those of Saudi Arabia alone.

In the future, the question will be whether the economic interdependence of oil-rich Muslim nations with the oil-dependent major industrial nations will prevail over religious fundamentalism. The probability is that it will, but with some rough spots along the way.

The United States, among all countries, is by far the largest per capita consumer of oil. Each day, California alone consumes more oil than either Germany or Japan. The rest of the world also has a rising consumption of oil. With regard to the concentration of oil in the Gulf area, the comment has been made that, "Not only is the world addicted to cheap oil, but the largest gas station is in a very dangerous neighborhood."

Religion, population, and resources

Attitudes about family size, and all that relates thereto, such as the appropriate age for marriage and the use of birth control, natural or otherwise, are closely bound with religions. There are also ethnic views that regard birth control as a form of genocide.

A major theme in discussing mineral resources as they affect the destinies of nations, is the effect population size has on resource use and depletion. Therefore, in a very real sense, religious attitudes toward birth control and population size affect national futures. This is a very controversial subject with many ramifications. But if religious beliefs result in a population size beyond the carrying capacity of a country, the nation will suffer and its quality of life will be diminished. In this regard, the observations of Jackson (1971) are pertinent:

> It needs to be said over and over again that the bringing of surplus children into this world, whether from personal desire or from religious edicts, destines not only some of these children but many others to a premature death…. The morality of birth control in today's burgeoning human population has taken on an entirely new aspect. God clearly never meant for man to overpopulate this earth to the point where he would destroy many other forms of life and perhaps even himself.

The Biblical edict from Genesis 1:28, "Be fruitful and multiply," must be tempered with the fact that to survive, those who are "multiplied," which presumably includes all of us, must also divide. We must divide the basic resources of our existence. Since they are unevenly distributed by nature, and then by various human factors are further unevenly divided, they become a cause of conflict.

Summary

Mineral and energy resources are religious and political pawns in several ways. They are widely exploited as a source of tax income, the spoils of which may or may not be widely distributed. Energy resource companies, particularly oil companies, are used at times by political factions as a way of manipulating public opinion to gain votes and power.

The nationalization of mining and oil companies has further complicated the political picture. The inability of some countries to manage their nationalized properties has resulted in various kinds of joint government/private company arrangements that are subject to unpredictable political events.

With petroleum providing so much money and so many jobs to so many diverse groups around the world, and with the importance of petroleum in fueling the world's economies, political maneuvering with regard to this particular resource involves very high stakes. As a result, governmental pressures can be severe, and are applied for a variety of purposes, including religious objectives.

Muslim nations of the Persian or Arabian Gulf control more than half the world's known conventional oil reserves. In the Gulf region, Muslim countries, religion and the state are much more closely linked than in the Western World. Whether or not the economic interdependence that exists between Muslim oil-producing nations and the non-Muslim industrialized countries will prevent problems in the future is uncertain. Minerals, politics, taxes, and religion will continue to be a volatile mixture.

Chapter 25

Earth Resources and Economic, Social, and Political Structures

In our daily lives, we give little if any thought to how fundamentally the mineral resources in common use affect, and in very large measure, control our lifestyles and the structure of society. Until recently, and still today in isolated groups, there are people living much as they did thousands of years ago. But for most of the world's population, the discovery and access to mineral resources has set societies and economies on courses very different from what they were only a few hundred years ago.

Gold is one example of how a mineral changed social and political structures. The search for gold by the Spanish and others, which included killing many indigenous people and more widespread death from the diseases they brought, eventually caused the destruction of entire native cultures. Today in the highlands of New Guinea and the rainforests of Brazil and Peru, gold mining is continuing to impact age-old native cultures. If people and their customs are still being lost, although no longer at the same rate as in the previous few centuries, it is simply because so few remain around the world.

Beyond gold, however, other minerals, especially iron, coal, and oil, have had a huge impact on lifestyles and economies. The Industrial Revolution, built largely on iron and coal, resulted in a great transformation in the way many societies were organized. This is continuing as more and more countries enter the Industrial Age. Among other things, industrialization results in the mass movements of population from rural areas to manufacturing regions, and a concordant change in lifestyle for many people. Oil has greatly transformed societies in the Gulf region. Water was the basis for developing social and political structures, such as Native American groups in the semi-arid southwestern United States. When water supplies declined, social and political structures crumbled, and people moved away. Currently, oil is important, but inevitably its importance too will decline. Fertile soil and freshwater will remain long-term basic necessities and will continue to determine the structure of societies and their economies.

Mobility

In the world today, one of the most visible effects of mineral resources in individual's daily lives is mobility. The automobile and airplane provide freedom for the individual far beyond what could have been imagined even in quite recent times past. The economies that have grown up around this unprecedented mobility are huge. They include motels, hotels, resorts, and other facilities related to travel for business and tourism. Tourism supports many local economies as well as providing important income for a number of countries such as those in the Caribbean on regular routes for cruise lines. Other cruise ships go around the world, and through the rivers of Russia and Western Europe. Eco-tourism has become important to Costa Rica for its rainforests, beaches and wildlife and to some African countries for their great herds of grazers and the predators that feed on them.

Recreation from skiing and golf to fishing, hunting, and hiking is dependent upon ready and fairly cheap mobility. The world's extensive road systems, both local and transcontinental with the attendant commerce that moves by these systems, is one feature of the mobility that oil has given to society. About 25 percent of the U.S. economy is now, one way or another, based on the automobile – a machine that did not even exist 150 years ago.

The option to take the family to the mountains, to the coast, or on an extended trip to national parks and other recreational areas is only as a result of our ability to command energy and mineral resources. It is truly astonishing that intercontinental travel is now available to major segments of the world's industrialized societies. One need only to be part of the older generation to appreciate that. I will always remember when I saw Charles Lindbergh on his triumphal tour after his historic flight across the Atlantic. It was an epic event, and at the time, the "jet airplane" had not been invented. Widespread intercontinental air transport has existed only since World War II. As a child, I never dreamed I would see China, much less fly across the Pacific Ocean in only 11 hours to get there. Like many others, I have now done so. Today, few give special thought to the fact that anyone with the fare can fly around the world in just a few days.

In less-developed countries, where individual ownership of motorized vehicles is still uncommon, mass transport by bus, train, or truck is available to many people. This represents for them a much different lifestyle than they had before the use of oil. Oil is now bringing personal transportation to a rising middle class in China and India. The availability of cheap and abundant oil has had a profound effect on the world beyond any other Earth resource.

The mobility that oil provides to people on an individual basis through the private automobile has changed the social structure. When the younger generation got "wheels," the family fabric began to be stressed. Family togetherness in the past, when weekends were times of local gatherings of clans, was replaced by diverse activities of the several family members, frequently going in different directions and considerable distances. It is no longer remarkable to travel hundreds of miles or more on a weekend to visit some point of interest or engage in a recreational activity. Just a century ago, this was not possible. A hundred years ago, Americans may have dashed through the snow across town in a one-horse open sleigh to get to grandma's in time for Thanksgiving or Christmas; today travelers fill airports, and jet planes fill the skies to whisk people home for these holidays from across the continent.

All this mobility has altered the lifestyles of many millions of people, and illustrates the fact that our daily routines are greatly determined by mineral resources. Were it not for oil, aluminum, and iron, we would lead vastly different lives than we do now. For one thing, a great many more of us would be working on farms.

Political structures

Oil and minerals have altered the political structures of many countries. In some countries in which oil or other minerals are the main sources of national income, internal battles are fought over control of these resources. Ruling parties can maintain control of a country by having control of the income from oil or other minerals. Control of Saudi Arabia by the ruling family largely has been accomplished by controlling the petroleum income. Venezuela's political structure is substantially influenced by the income from oil and natural gas. Nigeria, Saudi Arabia, Mexico, Russia, and several other countries have much of their income and politics revolving around oil.

In a post-petroleum economy where more local and quite different sources of energy supplies will be depended upon, national and local political structures will evolve to reflect this new order of resources, whatever they may be.

Making the world a smaller place

Mineral resources in the form of energy to move people, or to put them in communication by telephone, radio, internet, and television have made the world a much smaller place than it was less than two centuries ago. Through television and the Internet, individuals of many countries and cultures have come to see and know each other as never before, even if they cannot afford to travel.

Several hundred years ago, only a privileged few could visit other countries, and usually those countries were nearby. Now students travel from the Middle East countries, from China, and from other distant lands, to North America and Europe, where they study and encounter different ways of life made possible by a higher standard of living. Ameri-can students, as well, travel to other countries.

When these young people return to their home countries, they bring back impressions and frequently convey parts of the culture acquired when they lived abroad to their families. They influence how things are done at home from their experiences. Some of them become their nation's leaders. In the case of the students from Saudi Arabia and other Gulf nations, it is the oil wealth that allows these cultural influences and interchanges to occur. People from industrialized countries using cheap energy to visit less-developed regions (sometimes to live and work there) also influence cultural interchange.

Cheap energy and the mass meeting of cultures

Cheap energy has made it possible for millions of ordinary people to visit other countries. There is an inevitable interplay of cultures, as people meet one another, and see how others live. There is a story of Russian visitors during the time of the former Soviet Union, who came to Washington, D.C., and were taken to several local supermarkets. It was with difficulty that they were finally persuaded that these were really the way things were in the United States, and not simply showplaces set up for their visit.

Cheap energy has enabled huge military operations conducted halfway around the world. These operations have also greatly changed societies, run up large debts, taken tmany lives, and modified the lives of other people in many ways. Opin-ions on the merits of this kind of international "travel" are mixed. After leaving his position as commander of overall military operations in Iraq and Afghanistan, General David Petraeus said that: "Anyone who in the future considered sending troops and materials halfway around the world should have his head examined."

The gap

People who do not have easy access to these mobility resources lead quite different lives. This includes half the world or more. The average Chinese or Indian, and many people in Latin America and Africa do not have access to this mobile lifestyle, because they don't command the energy resources that other people do. They may still be plowing with a horse, an ox, or a camel; riding a donkey; and pumping water by hand. Their daily lives are far different from people living in the industrialized world. The ability to use oil has strongly divided cultures. In the Stone Age, everyone had pretty much the same standard of living. Perhaps those who had access to deposits of flint or obsidian may have done slightly better than others. But today, the ability of each individual in the industrialized world to command the energy equivalent of 200 to 300 slaves compared to someone in rural India or Africa who has to depend on himself or herself, and their children if any, a wood fire, and perhaps an animal for energy, is a huge difference. It is responsible for an enormous gap in lifestyles never seen before.

Television and aspirations

Related to the gap between the industrialized and underdeveloped countries is the influence of television and the Internet. Even in remote isolated areas, people can now see the affluence of the industrialized world and contrast it to their own. For many, seeing how other parts of the world live, first generates curiosity. Eventually, it raises hopes and expectations of how things might be in those less-developed areas. The availability of energy, usually in the form of gasoline or diesel powered generators (and in some places from photovoltaic panels) that brings one world to the other by television, has given many people windows on a world they would not otherwise have imagined. It should be noted that a television set or computer itself is a complex of minerals, including such things as the rare earth element, yttrium, which makes the colored television screen possible. Being able to buy this mineral complex called a television set or computer has changed the view of the world for many people. As nations, particularly in Asia, increase their degree of industrialization and their exports, their buying power increases. This is certain to increase the demand for energy, for which oil is presenting the main source. Increased energy consumption and a rising standard of living are closely related. As more energy becomes available to less-developed countries, competition will increase for raw materials and energy to produce the material things of the "good life." Great stirrings are now occurring in Asia and Africa, where more than half of the world's people live. China and India illustrate this trend as industrialization, rising expectations, and greatly increased buying power create a global demand for energy and mineral resources by both countries.

Oil and its effect on Gulf area culture

Culture is defined by *Webster's Dictionary* as "a particular stage of advancement in civilization." This would include personal lifestyles, ways of earning a living, political structures, degrees of industrialization, and religious practices and beliefs.

The change in culture made possible by the possession and development of a mineral resource, in this case petroleum, is nowhere more striking than in the nations bordering the Persian Gulf. In a perceptive volume based on many years' observations, Bulloch (1984) described what oil has done:

> For the pace of progress in the Gulf has been faster than anywhere else on earth: money can work miracles, and has; in something less than two decades Kuwait, Qatar, and the Emirates have been transformed from quiet, unknown backwaters into the most modern cities, banking centers, and world financial powers. Traders who ran little hole-in-the-wall stores now control international corporations; boys who could look forward to a lifetime tending their family flocks now write computer programs; men who thought it an adventure to cross the Gulf by dhow now casually take the daily air shuttle between Bahrain and the Saudi mainland…. In every State of the Gulf, oil has worked its magic….

In the early stages of oil development in the Gulf area, some people imagined the old order could remain. But the impact of oil which brought vast sums of money, technology, foreign workers, and international trade with its world contacts, eventually affected everyone. The ways of the past were overwhelmed. A few clung to their old lives, but they were soon washed over by the wave of oil and all that came with it.

Islam, oil, and women

One of the defining features of Islamic society is the traditional isolation of women from the broader economy. But the impact of petroleum wealth on these countries, which resulted in much contact with the West, has begun to modify the status of women. Women have started to work outside the home. In Kuwait, an all-women factory was built, making small electrical components, which make use of the dexterity of women's smaller fingers in their assembly. It was a success. By 2000, women's clothing was a mixture of western and traditional dress, nowhere more evident than the bathing beach. Women have entered government as ambassador, president, planning ministry head, and academically as Kuwait University President. Many in Kuwait expect their society to keep changing. Samira Omar, a scientist who runs a research institute, says conflict is inevitable: "It happens in every society when it moves ahead." Warfare can change lifestyles and societies, but oil has done much more.

In Muslim countries, religion is much more integrated into economic and political life than it is in Western nations. A bank in Kuwait specializes in supporting ventures that promote Islamic objectives, and a special insurance company was created to take care of Muslim interests (Bulloch, 1984). Oil money promotes religious views. In particular, it has enabled the Saudis to promote and project their particularly hard-line version of Islam, Wahhabism, around the world, both in other Islamic countries that traditionally had more tolerant or relaxed versions of the religion and in the growing numbers of mosques in Western countries.

Incipient democracy

Another change petroleum brought to the Gulf is the erosion of the former desert chieftain or tribal rule form of government. It is no longer a one-man government in some countries, as it was but is no longer in Abu Dhabi. In others, however, the ruling families remain. Saudi Arabia is not a democracy, but a kingdom. A more democratic approach is becoming apparent, due to the rise of a middle class based largely on the oil industry and related enterprises.

The great influx of non-Muslims into Saudi Arabia that resulted from the deployment of foreign troops for the first Gulf War upset fundamentalist Muslims. After most of the foreign troops departed, these elements redoubled their efforts to retain more conservative Muslim customs, particularly those relating to women and their dress. Retail business dropped off because women preferred not to appear in public and be harassed. Eventually, the country's mainstream religious leaders turned against the fundamentalists, and the course of Muslim religion was set in a more moderate direction in some places.

Autocracy and democracy

For the most part, the Gulf nations have been ruled by autocratic royal houses. Only Kuwait has a parliament elected by the 80,000 or so male Kuwaitis who can trace their Kuwait ancestry back to before the 1920s. This is only about 10 percent of the native population, but at least it is a start on democracy.

The possible growth of democracy resulting from a growing westernized educated middle class (education, in many cases, in American and European universities) paid for with oil money, is one of the most important influences petroleum has brought to the Gulf. How it plays out will determine much about the future of the region. In the meantime, there is continuing pressure on the tribal monarchies to give up absolute power and share political and economic decision making. In the past, the ruling groups simply bought their way out of trouble when faced with internal dissent by creating generous welfare programs. The income from oil allows these countries to do that again, but a growing population, coupled with what is likely to be a leveling off in oil production and the income from it, will eventually put further strains on social systems. Petroleum wealth will no longer be adequate to mollify dissent. Dissatisfaction will have to be addressed more directly, which means more democratic conduct of national affairs. This has been clear in the uprisings in the Middle East in 2011, collectively called the "Arab Spring." Petroleum-generated wealth has led to great strides in medical care as well as in nutrition. The result is a very large increase in populations of the Gulf nations that is likely to set the stage for future unrest.

Saudi Arabia is named after a family. The country was welded together by the House of Saud and with its many Saudi princes, it has run the nation very much like a family business. Ministerial positions can be held by commoners, but key posts are held by Saudi royalty. The need for educated Saudi nationals to run the increasingly large and complex oil industry now owned by the government has fostered an expanding middle class. This, combined with more stringent economic times, is forcing the House of Saud to reconsider its role in Saudi Arabia's future. The huge oil reservoirs lying beneath the kingdom are bringing changes to its social and economic structure. Incipient signs of democracy are emerging. It is a course destined by oil formed by geological processes millions of years ago.

Due in part to accumulated war debts from its eight-year conflict with Iran, Iraq invaded Kuwait in 1990 to seize its oil riches. Although the invasion was brief, Kuwait's political and social structure has begun to change toward a more democratic form to develop and maintain more governmental support from the common people. The parliament that was disbanded in 1987, was reinstated. Also, a new military conscription law was enacted in 1992 that made the safety of the country a concern and responsibility of everyone. During the First Gulf War, it was widely reported that many young Kuwaitis simply fled abroad to enjoy the good life, while the U.S. and its Gulf War allies did the fighting. Kuwait is now beginning to use its citizens more extensively in expanding its armed forces, making apparent to the population the need to recognize the obligations that go along with oil riches.

The rest of the world's interest in the Gulf region is largely due to its petroleum resources. Without that, the region would be of no special concern. And the world is still likely to lose interest in the Gulf countries again when their oil and gas are gone. The possession of oil has changed the societies around the Gulf in many ways, probably permanently.

Cheap energy and widespread rise of the middle class

The ability to use fossil fuel energy instead of human energy to do many things created the industrialized civilization we know today. One of its most important features is the emergence of a middle class that creates a markedly different situation from the feudal systems of the past. Cheap, abundant energy, mainly in the form of oil and natural gas, lets a relatively small part of the population in industrialized countries produce the food for the rest of the population. People, in turn, do not have to spend their time doing manual labor in the fields, but can be part of industrial complexes that produce a host of products, the manufacture of which again is dependent on abundant, cheap energy. Freeing much of the population from the routines of agriculture, also allows the development and staffing of institutions of higher education and research facilities, all of which further establishes a broad-based, educated middle class.

Petroleum and job creation

Mineral resources and particularly petroleum, have greatly broadened the work spectrum. This ranges from the automobile, aircraft, steel, aluminum, and petrochemical industries, to all facets of the travel industry.

As the population has increased, so has the variety of employment opportunities in fields that did not exist before this age of exploiting minerals. In the industrialized world, demands for physical labor have decreased, providing leisure time for recreational activities that provide jobs in many parts of the world. Before the Drake Well, cheap energy providing leisure time and cheap intercontinental flights to play golf in Scotland or visit the Great Wall of China did not exist. When I found myself in the Gobi Desert of Mongolia, after flying to Japan to start the trip, I was impressed again with how cheap energy, mostly in the form of petroleum, has changed society and lifestyles worldwide. As a youngster reading about Roy Chapman Andrews' trips to Mongolia and the discovery of dinosaur eggs, I never dreamed I would go there and actually see those eggs in the museum in Ulan Bator, Mongolia's capital. (After a conference among museum officials determined the eggs were not of strategic military importance, I was allowed to take a photo of them). Both Andrews' trip into the Gobi Desert, discovering dinosaurs and their eggs, and my trip to Mongolia to photograph the eggs were only made possible by oil.

Leisure time has enhanced various games and sports. Hunting and fishing have greatly expanded their scope of activity thanks to cheap energy for transport. (Sometimes there have been unintended consequences — throughout Alaska, for example, moose populations in very remote areas are now "under the gun" because even these faraway areas are now accessible to guides and hunters using float planes; when moose numbers inevitably decline, this, in turn, can lead to pressure for aerial hunting of wolves as man's chief competitors for moose.) Athletic teams can travel far and wide by air. People fly from the

United States to Africa to photograph big game. The beaches of the Mediterranean and Southeast Asia are favorite vacation spots for Scandinavians. Visit the Grand Canyon of Arizona, and you will hear as many people speaking foreign languages as English among the visitors. Cheap energy has enriched the lives of countless people around the world.

In some places, however, the work ethic has been eroded because of oil. In Brunei, affluence from oil resources has eroded the concept of work (Begawan, 1989).

Prosperity built on a nonrenewable base

One of the great challenges ahead with respect to the development and use of nonrenewable resources is how society will cope with the scarcity or loss of these resources. In a micro-way, this can be seen in the abandoned mining camps across the western United States, in Australia, and Canada, and the decline of petroleum revenue in parts of Texas, Oklahoma, California, and elsewhere. With much of its state revenue and a lot of its employment dependent on North Slope oil, Alaska is interested in opening up a section of the Arctic National Wildlife Refuge for its oil resources. In the meantime, oil revenue is declining along with oil production. Prudhoe Bay already has pumped half of its original oil reserves.

Towns either shrink in size as mineral resources are exhausted, or they must develop some other base for existence. The island country of Nauru is a classic example of riches to rags after its one mineral resource, phosphate was exhausted.

In other parts of the world, whole national economics are largely dependent on a nonrenewable resource base. The oil-rich countries of the Gulf except for Iran, are classic examples of this situation. In these arid areas previously inhabited by nomadic tribes and scattered villages, oil has brought about a colossal transformation of economies and life-styles. But it is all built on a nonrenewable resource. This, then, is also nonrenewable prosperity.

Kuwait is almost totally dependent on its oil income. At the beginning of the twentieth century, the population was less than 50,000. Now the population is nearly 3 million. At Kuwait's current 1.8 percent annual rate of increase, its population will be 3.7 million in 2025 and 5.2 million by 2050 (Population Reference Bureau, 2011). The country's 1962 constitution guaranteed employment for all Kuwaitis. At present, 97 percent of its work force work for the government at one level or another. No doubt Kuwait's higher standard of living, including better sanitary facilities, improved nutrition, and greater access to medical care paid for by oil revenues have accounted for much of its increase in population. Will oil sustain nearly twice the present population in 2050? Kuwait's peak oil production is projected to occur by 2018 (Duncan and Youngquist, 1999). How will the combination of population growth, the dominant employment being in the government, and oil production peaking in 2018 and then declining be resolved? Social, economic, and perhaps political structures will surely change from what they are now.

Some Kuwaitis are concerned that present affluence will adversely affect the ability of the nation to adjust to the coming more competitive times. A culture and economy completely dependent on large oil revenues will find it difficult to adjust to more spartan times. Even a rich oil country like Saudi Arabia may face problems. Chandler (1994) writes:

> 'The problem is that we have all been spoiled for 20 years,' said a prominent Saudi prince who plays an active role in policy making. 'We have become too accustomed to receiving help from the government. Sometimes I wonder if it

> will be possible for us to get used to life as an ordinary economy.'

Saudi Arabian government subsidies now affect nearly every aspect of Saudi life. Population increase is now 2.6 percent a year, meaning it is on track to double in just 27 years. Matching oil income with population growth is likely to be difficult, with unpredictable political results. The Saudi crown rests on an uneasy head.

The Saudi royal family presides over the world's largest and richest family business, and as previously noted, the country has been largely run as a family enterprise. At one time, each Saudi prince received a minimum monthly allowance of $20,000, even as the number of princes swelled to 6,000. To keep its increasingly restive society from upheaval, Saudi Arabia must pump all the oil it can sell without unduly depressing the price. But the demands of the generous social programs now in place, together with the rapidly rising population that receives these benefits, cannot be met by current oil revenues. There are more and more hands out for a limited amount of funds with the result that Saudi Arabian per capita income is falling (Chandler, 1994).

Reed and Rossant (1995) reported that:

> A population explosion has also helped sharply erode per capita gross domestic product from more than $12,000 in 1982 to little more than $7,000 today. Some 3 million Saudis, 44% of the labor force, work in the public sector where salaries have been frozen for almost a decade. This year, in a huge departure from traditional largesse, King Fahd is more than doubling the fees charged residents for electricity, water, and other services…. Such erosion of the desert welfare state sorely strains the paternalistic social contract between the ruling Al-Saud clan and the population.

The sharp increase in the price of oil in 2004 to 2008 raised per capita income somewhat, but did not restore it to the level it was with a much smaller population two decades earlier.

It is the population explosion cited by Reed and Rossant that is the critical and ongoing factor in the unrest of the general populace. Initially, when oil was being produced in substantial quantities, the bounty was spread over relatively few people. With subsequent increases in oil production and attendant increases in national income, the citizenry could look forward to even better times. But as oil production begins to level off and not increase as fast as population does, the outlook changes. In 2009, more than half the Saudi Arabian population was younger than 20 years old, and 42.6 percent were younger than 15. This portends a huge surge in population in the next two decades. It is very unlikely that Saudi Arabia's oil income can increase to maintain the present standard of living for the projected population. The time when money was available for almost any social demand is past. Even the present generation sees that the time of subsidies, free services, and other elements of the affluence oil brought is coming to an end. This is having an unsettling effect. The unemployment rate among Saudi young people continues to rise. Disaffected youth are a fertile breeding ground for terrorism that has already reached Saudi Arabia (Waldman, 1995b; Waldman, et al., 1996). Saudi Arabia has long been among the most stable nations in the Middle East. But stability appears to be less certain in the future.

Other nations also have built up their economies on a non-renewable resource. Nigeria is an example. When the day arrives that Nigeria is not oil rich, it may revert back to the bloody civil wars that marked the country 30 years ago. Today, even with oil riches, or perhaps because of them, corruption and civil unrest continue to plague Nigeria. Shell Oil Company suspended operations in Nigeria in 2003 due to continued sabotage of its operations and fears for the safety of its employees. It resumed operations in 2005, but kidnapping of employees and major pipeline vandalism continues. This is just one example of how oil riches have a destabilizing effect. Now Nigeria has to contend with an armed radical Islamist group, *Boko Haram* (translated as "Western education is sacrilege" in the Hausa language), which has committed many acts of terror against Christians and others, claiming hundreds of lives from 2009 to 2012 alone.

In Venezuela in 1989, there may have been a preview of what could happen more widely when income from a depletable resource, such as petroleum or metals, declines. Oil income began to falter. The government had to change its free-spending ways that were based on abundant oil income from 1974 to 1979, when oil prices moved up very rapidly. It started budget cutting as oil prices declined. When subsidized bus fares were raised along with previously cheap gasoline prices, riots erupted in Caracas and 17 other cities. More than 300 persons were killed, 2,000 were injured, and several thousand arrested. The government had to rescind the increases. When the price of oil dropped in 2008 from $147 a barrel to less than $60, Venezuela's oil-dependent economy was severely affected.

Venezuelan President Hugo Chavez began running into problems. In 2005, Venezuela's oil production declined to 2.2 million barrels a day from its peak of approximately 3.7 million barrels a day several years earlier. To maintain support for his regime, President Chavez diverted more and more of the national oil income to financing growth in social programs, so there was not enough capital left in the industry to keep oil production stable, much less increase it.

Venezuela's social structure, in a country with a growing number of poor, is under severe strain. Recognizing the need to help the poor is commendable. As noted elsewhere, this diverts money needed to maintain oil production, so population and population growth are in conflict with preserving the resource that supports it. A smaller population would help considerably. But Venezuela's population is 29 million and is projected to reach 35.4 million in 2025, and 42 million by 2050. Oil production and the income from it cannot possibly be increased proportionately. As in other oil-rich nations, oil revenues in Venezuela have not kept pace with the growth in population and the related growth in the costs of the social services created in earlier, more affluent oil income years.

Venezuela's situation with its 29 million people and daily oil production of 2.2 million barrels, can be contrasted to Saudi Arabia with 28 million people and daily production of more than nine million barrels. Saudi oil is also higher quality and brings a better price than Venezuelan heavy crude. So Venezuela, with a slightly larger population, is on an oil-income diet less than one-fourth that of Saudi Arabia. Both countries are almost totally dependent on oil income for foreign exchange.

There is no simple solution to Venezuela's dilemma. Oil brings wealth. It also brings problems. As early oil production increases, revenues grow and lead to higher standards of living and population growth. When oil production levels off and starts to decline, the demographics of a growing, younger population, with its attendant bulge in births, compounds the problem.

Outgrowing the Earth

The heading of this section is the title of a book by Lester Brown (2004). People are out-growing their resources, a situation which, in diverse ways, is happening in many nations and affecting the lifestyles and habits of their citizens. The destinies of these nations are now being changed by the unalterable geologic fact that Earth resources including petroleum, metal deposits, water resources, and soils on which our lives and lifestyles depend, are finite.

In the United States, abundant resource-based affluence is under pressure. While the U.S. still has access to ample oil supplies through imports that allows its citizens to continue living pleasantly, the future is far less certain than when the United States was self-sufficient in oil. The costs of using increasingly imported resources of all kinds will gradually affect everyone.

Other resources such as surface water are renewable but are in fixed supply at any given time. Against a rising demand from increased population, their availability or lack thereof, and the demands of cities as opposed to rural areas, are changing lifestyles and societies. Water supplies have become an increasingly contentious issue: city versus rural; industrial and residential users versus agricultural users.

Water rationing is a fact of life in many communities experiencing sustained droughts. "Water police" even patrol cities in times of water shortage, ensuring that citizens do not use water beyond their allotment. You can be fined for watering your lawn at the wrong time or for watering it at all; washing your car may be *verboten*. This is a new social reality altering the social structure perhaps in a minor local way, but indicative of how Earth resources impact our daily lives. Fifty years ago with the same basic water supplies but many fewer people, such a situation never occurred. Population growth is overtaking even our available renewable resources. Although they are renewable, they do not grow.

Abroad, water supplies affect international relations. The loss of water in some areas has been devastating, as in the once highly productive Aral Sea region of Kazakhstan, which is now mostly desert. Ways of life and local economies are being changed by changes in distribution of water, and the upstream use of water by some countries to the detriment of countries downstream on international waters. This is certain to have profound effects on the lives of many people in the Middle East, and indeed, this is already occurring.

Easy to adjust to "more"

Having a continually increasing supply of mineral and energy mineral resources, such as some of the world has enjoyed to date, has been a pleasant experience and has kept industrial societies moving along smoothly. But with continued exponential increase in populations drawing on finite, and in many cases now clearly diminishing resources (e.g., copper in the United States, groundwater in the Middle East, India, and China), how will societies make the needed adjustments? Will it be done thoughtfully and peaceably or will it involve social and political chaos, elements of which seem to already be appearing in parts of the world?

The possession of valuable mineral resources is helpful to a country. It can provide needed foreign exchange. It can enrich national treasuries that can distribute the money to useful domestic undertakings including education, roads, communications, and sanitary and health facilities. Developing mineral resources also provide much needed local employment. But is there a negative side to the possession of mineral wealth?

A destabilizing influence?

In Mexico in 1996, the Democratic Revolutionary Party (PRD) set up blockades at oil installations in the oil field areas of the southeast coast protesting the actions of Pemex, the Mexican government oil monopoly. The PRD said Pemex had contaminated farm land, had not cleaned up oil spills nor raised living standards as promised, but had diverted its oil money to political ends and into politicians' pockets.

Mexico is another example of how oil may prove to be a destabilizing influence on a country. The national oil company, Pemex, provides 40 percent of government income but production has dropped 30 percent from its peak in 2004. In 2009, there was a substantial cut in government employment (10,000 workers), increased personal and corporate income taxes ($13 billion), and reduced subsidies for things such as electric power. The country was living on a diminishing resource, and now "It's crunch time in Mexico" (Smith, 2009). How this increased austerity will affect Mexican social and economic structures is not yet clear, but it will surely do so as it will in all countries dependent on income from nonrenewable resources.

Properly employed mineral wealth can be a stabilizing influence in a country if it is honestly used to help the general populace. But if it is used to support lavish lifestyles for a few individuals or the money is siphoned off in various forms of corruption, it plants the seeds of civil unrest and possible revolt.

When the complaint is heard that oil is too often found in politically unstable countries, it may be that the presence of oil or other mineral riches is what makes the country unstable.

Can foresighted governments, or business interests, or citizen movements, or a combination of all devise new economies that can be put in place early enough in presently resource-rich populations to allow a smooth transition to other sources of revenue? Or can orderly adjustments be made to the standard and modes of living, which will accommodate a less-plentiful resource situation in the future? Facing a growing population that has rising expectations, either of these alternatives will be difficult to implement.

The thin veneer of civilization

The isolated violence that occurred in the gasoline lines in the U.S. during the 1973 and 1979 oil crises suggest that civilization, even in a highly civilized United States, is a perilously thin veneer. The British social critic, C. P. Snow, wrote: "Civilization is hideously fragile and there's not much between us and the horrors beneath, just about a coat of varnish." That thin coat of varnish consists of the availability of the basics of life — food, shelter, and clothing. The ability to produce and distribute them in the huge quantities in which they are in demand today is possible only through the use of mineral and energy resources. Earth resources will increasingly affect the stability of our societies (Lindahl-Kiesling, 1994).

Summary

Governments, cultures, and economies are shaped by the mineral and especially the energy resources available to them. With the depletion of resources we are using now, and the conversion to a renewable resource economy (the most significant part of which will be a new energy base) economies will probably become much less global than they are at present. Their nature will be determined by local and regional resources. Just as nations and cultures today are markedly changed from the past when they had different resource bases, future cultures will also be vastly different from what we know today. Cultures consist of social, economic, and political structures, and all of these will have to adjust to new realities of using a different energy base. The long-term survival of the industrialized society we know today is in question (Duncan, 2001).

Chapter 26

Myths and Realities of Mineral Resources

Although minerals, including energy minerals, are fundamental to our existence, the facts about these resources and the industries that produce them are subject to many myths and much misinformation. This is unfortunate because it clouds the ability of individuals to make intelligent choices. Some of the distortions are made deliberately by political interests who play upon the fears and hopes of the electorate casting themselves in the role of the "defender" of the public interest against the oil or mineral producers. During election campaigns, politicians speak in ways to keep people happy. In recent years, they have been saying how alternative fuels can easily replace oil. Realities and "political speak" are often far apart. Some statements are made from ignorance, and some are made by people who have their own political, economic, or social agenda they wish to perpetrate upon the public. Some are made by people who are over-enthusiastic about a particular resource and do not carefully examine the hard facts, or may not be aware of them. Some statements are made by promoters wanting to raise money for a particular resource development, whether that program has a sound economic basis or not. Whatever the sources, myths and extravagant statements about Earth resources abound because Earth resources are vital to our survival, and good news sells. Realty may not.

Facts must be separated from fiction if democracy is to be the form of government that guides international, national, and personal affairs. The tax structure, which is a political matter, has much to do with the success or failure of many mineral ventures.

It is important for public policy that basic geologic, economic, and technical facts be known about a given resource, so that there are no illusions by government leaders or citizens about how important that resource is now or may be in the future. There are numerous glowing statements in print about what can be expected from oil shale to mining the Moon. It is indeed nothing short of amazing what claims are made, and what people may believe. This also applies to solutions to resource-based problems such as population pressure, where colonizing space has been suggested. Several of these myths are discussed here. In part, this is a summary of statements made and data presented previously. However, for the sake of emphasis, I am assembling the facts here for convenience and analysis.

My good friend, the late Garrett Hardin, inscribed a copy for me of his last book, *The Ostrich Factor: Our Population Myopia*, writing: "For Walt, premier critic of unsupported optimism." Garrett Hardin's comment is correct, for we were good friends and he knew me well. I miss his friendship and the intellectual and common sense stimulus he brought to all our conversations and in his writings with such epic studies as *Living Within Limits*.

Over the years, I have seen so many statements made that proved to be false, fanciful illusions, or myths, that I started a collection of them. The file is now extensive. I have extracted a few representative items from it. The lesson is to read beyond the headline, and apply your own good sense about how valid a statement may be. Simple mathematics is frequently helpful.

We are witnessing rising public concern about energy and oil supplies, in particular. It is a sensitivity brought on by what is known as "pain at the pump." Fuel prices keep going up. Increasingly, there are solutions (especially during political campaigns) put forth for what new technology can do. The statement "we will become energy independent" has been used in every presidential campaign since 1976.

Political optimism: check these out

Basing his energy plan for the U.S. on a mixture of solar, wind, and biofuel sources to make us independent of foreign oil, in his third presidential debate (Hempstead, New York, October 15, 2008), candidate Barrack Obama said, "I think that in 10 years we can reduce our dependence so that we no longer have to import oil from the Middle East or Venezuela. I think that's a realistic time frame." In 2009, Al Gore declared that we can produce, "100 percent of electricity from renewable and truly clean carbon-free sources within 10 years." When the time arrives, check out these predictions as to whether they are myth or accomplished reality.

Myth: Just drill deeper for more oil

Reality: Sometimes the statement is made that deeper drilling would find more oil. Oil occurs in sedimentary rocks, which are a fairly thin part of the Earth's crust. In the oil-producing state of Kansas, for example, granite or something else besides sedimentary rock exists everywhere at depths of 15,000 feet or less. All over the world, non-petroliferous rocks are encountered at some depth below which there is no oil. Where there is a great thicknesses of sedimentary rocks, 16,000 feet is, with a few exceptions, the limit of oil occurrence. There are exceptions in the Gulf of Mexico and in the Santos and Campos basins offshore Brazil, where a thick salt bed has altered the Earth's heat flow and oil still exists a few thousand feet deeper. Below that depth, because of increased temperature, only gas exists.

The myth persists that oil is not of organic origin. A letter to the editor in *Geotimes*, December, 2002, says, " … that petroleum cannot have formed from dead plants and animals and must come up from deep sources in the mantle, more than 100 kilometers." The writer goes on to say that when oil companies hit basement rock (which is commonly granite or metamorphic rock), they should just keep drilling instead of stopping as they do now. This reflects a theory proposed by the late Professor of Astronomy, Thomas Gold, Ph.D., of Cornell University. He wrote, " … oil is formed deep in the Earth by inorganic processes and this 'goop' continually oozes to the surface, and therefore is in virtually inexhaustible supply."

At a depth of 100 kilometers (62 miles), the temperature would be at least 900° C (1652° F) or more. At that temperature, oil could not possibly exist. For a comprehensive statement on the organic origin of oil, consult the 743-page volume by geochemist John Hunt (1996) who writes, "The overwhelming geochemical and geological evidence from both sediment and petroleum studies of the past few decades, clearly shows that most petroleum originated from organic matter buried with the sediments in sedimentary basins … . Although a few hydrocarbons in the crust may be derived from inorganic sources, the quantities are negligible compared with those from organic sources." If Gold's theory were correct, oil would be oozing up through the cracks in the granitic rocks of my native Minnesota. To my knowledge, this is not happening.

Myth: Oil companies have capped producing wells to keep the price of oil high

Reality: This is one of the oldest and most persistent myths about the oil industry. The idea is that oil companies will drill wells and then cap them to withhold production from the market until the price of oil goes up.

It is true that some wells are drilled and then capped. Almost all of them are capped because they are dry holes — that is, failures. Less than one in eleven exploration wells are successful. U.S. law requires that failed wells be filled with cement at key points to avoid groundwater contamination, and then capped. To the landowner, who had great hopes for a well drilled on his property, a face-saving statement to the neighbors is that "they found oil but just capped the well." Only when the oil company abandons the lease, does reality arrive.

Some wells that could produce oil are capped temporarily. There are two common reasons. One is that no facility exists for transporting the oil from the well at the moment. Either a pipeline does not exist or the well is too remote and the oil is too expensive to truck out. Generally, if the well is a producing one, other wells will be drilled in the area to create enough recoverable oil volume to justify developing a transport system to bring the oil out economically.

Occasionally a well may be drilled, completed, and capped when the price of oil is not high enough to pay for the expense of producing the oil, including pumping costs and perhaps disposing of the saltwater that may be produced with the oil. However, capping a well and leaving it for a time is a risky venture, because sometimes the well cannot be restored to production.

Drilling a well is so costly that if it is productive and capable of bringing a return on investment, the oil will be produced. If a million dollars is involved in exploration, lease, and drilling costs (and one million dollars is much less than many wells cost; some cost over $100 million), then the cost in lost interest that money would earn otherwise demands that the well be produced. No one can afford to tie up a million dollars, or many millions with no return, and it does not happen.

Myth: Don't drill this prospective field. There is only 90 days of U.S. oil supply there

Reality: One of the most misleading arguments used against drilling a particular field is the assertion that it would only supply X number of days or months of U.S. oil demand. To the average citizen, this is one of the most "logical" reasons for not allowing drilling in a particular area. So it is one of the most widely and effectively used arguments against oil drilling. It pops up frequently in newspaper editorials, letters to the editor, and ~~at~~ public hearings.

During the long-running debate about opening one percent or less of the Arctic National Wildlife Refuge in Alaska for oil exploration in 1995, the president of a prestigious environmental organization said, " … there may be at best only 90 days supply of oil for the U.S. There can be no justification to develop the Arctic refuge" (Sullivan, 1995). Let us pursue this argument. At the present time, the U.S. uses about 20 to 21 million barrels of oil a day. A 100-million barrel oil field is regarded in the petroleum industry as a "giant." They have been discovered only infrequently. If one of these giant oil fields could be used to supply all U.S. oil demand, it would last theoretically about five days. Why drill it?

To put this in further perspective, at the present time, only 15 oil fields in the United States have produced as much as a billion barrels of oil. This is, of course, over a period of many years. But if we apply the argument that the oil field would only supply oil for a given length of time in the U.S., it should be noted that a billion barrels from one of these 15 fields would have only supplied the U.S. for about 49 days at its current rate of consumption of about 7.5 billion barrels a year.

If that argument used by the president of the environmental organization were to be followed, there would be no oil drilling at all in the United States. These days, a ten million barrel oil field discovery is an important event in U.S. oil exploration. But that amount would last the U.S. about 12 hours! The fact is, we are not discovering ten million barrel oil fields every 12 hours in the U.S. Prudhoe Bay, the largest oil field ever discovered in North America, would last the U.S. less than two years if it alone was used to supply our needs. So, presumably, Prudhoe Bay should not have been drilled. But it has been producing oil for more than 30 years and has saved the United States billions of dollars for oil that did not have to be imported.

Of course, it is not possible to produce all the oil in Prudhoe Bay or any other field in 90 days, or six months or two years. The oil is produced over many years from many fields and wells that add up to total U.S. production. Production is now about 5.7 million barrels a day from about 530,000 wells that translate to an average of slightly less than 11 barrels a day per well.

Each well and field makes a contribution, and each new discovery serves to stretch out domestic supplies a little longer. Individually, most fields (with the notable exception of the huge Prudhoe Bay Field) produce only a small amount of oil relative to total U.S. production, but collectively they are important.

Myth: So-called "Big Oil" controls world oil supplies and the price of oil

Reality: "Big oil" of the past is now a myth. Ninety percent of the world's oil today is controlled by the national oil companies, such as Saudi Aramco. The price of oil can be controlled to some degree by OPEC. But the law of supply and demand is the basic cause of crude oil (and gasoline) price changes. When the margin between supply and demand is small, price swings become larger, as each increment either way is felt almost immediately in the oil market and reflected in the price.

Myth: Demand is same as supply

Reality: "World demand for oil is expected to total almost 118 million barrels per day by 2025" (Energy Information Administration, 2004). There are frequent projections of future world oil *demand*. The myth is the implication that demand can or will be met by supply. The demand may be there, but the supply is questionable. *Demand* does not necessarily equate to *supply*.

To have supply meet the projected 118 million barrel a day demand in 2025, it would have to discover the following facts: World oil discovery peaked in 1965. More than half the oil-producing countries have passed their peak in production. The average barrel of oil produced today was discovered before 1973. Most major oil companies are not replacing their production each year with new discoveries. These facts would have to be reversed and production not only maintained at today's level of 85 million barrels a day, but an additional 33 million barrels a day production would have to be added. It is exceedingly unlikely that this can ever be done.

One wonders what circumstances the people making this 118 million barrel a day projection see occurring to make the prediction possible. I know of no geologists significantly involved in oil exploration who hold this view. Quite contrary views are held by Campbell and Laherrere, 1998; Duncan and Youngquist, 1999; Deffeyes, 2001; Campbell, 2004; Bakhtiari, 2004; and others.

Myth: We find more oil worldwide annually than we produce

Reality: An article in the February 5, 2012 issue of *Bloomberg Businessweek* states we are finding 1.6 barrels of oil for every barrel we are producing. Fact: We are now producing about 30 billion barrels of oil a year. To find 1.6 barrels for each barrel produced would mean we are finding 48 billion barrels of oil a year. We are far from doing that. The last big discovery in North America was Prudhoe Bay in 1967 with estimated reserves of 12 billion barrels. To find 48 billion barrels a year means we would have to find four Prudhoe Bay fields in the world every year. Recent large discoveries of oil offshore Brazil in the combined Campos and Santos basins are estimated to be about 16 billion barrels.

The article also says that the oil sands in Alberta, " … alone contain 1.7 trillion barrels of oil. That is equal to roughly a half century's supply at current global use." Fact: The estimate of 1.7 trillion barrels is oil in place (resources), not economically recoverable oil (reserves), which the Alberta government estimates at 174 billion barrels, about one-tenth the oil in place.

Myth: "They" own the oil companies

Reality: To win popular favor, many politicians, frequently joined by the media, assert that oil companies are vague and distant entities owned by "them." But who does own the oil companies? During the 1979 oil crisis, I was asked to address a luncheon meeting of the Oregon State Employees Association in the state capitol. The topic was the oil crisis. The oil industry was being widely blamed. I asked who among the state employees owned any oil company stock. Not a hand was raised. However, just prior to the meeting, I had been in the office where they administered the state employees' pension plans. I had examined the holdings of the fund and discovered that the largest single industry holding in terms of dollar value was oil company securities. The fact was that everyone in the room owned oil company stock. The conventional myth is that large oil companies are owned by some vague alien group distinct from the general public. The reality is that "they" are us.

And this is very broadly true. Insurance and investment companies invest the funds of their clients in a variety of investments among which are oil companies. Through life insurance, and other insurance policies, pension plans, annuities, and mutual funds, the major oil companies, as well as the mining companies, are owned by the general public. A recent study of the ownership of stock in the six largest oil companies in the United States disclosed the following: Nearly 200 mutual insurance companies hold close to 16 million shares. Ninety-one colleges and universities own the stocks, and about 1,000 charities and educational foundations in the United States are owners of these oil company securities. In direct ownership, more than 2.3 million Americans hold stock in these six companies. Many other Americans own interests in smaller oil companies that are becoming the main onshore oil producers in the United States, because the big companies operate mostly off-shore U.S. or abroad.

Myth: Large oil companies are the problem

Reality: It is true that worldwide oil production is becoming a bigger and bigger business. The reason is that easy to find, shallow oil has been found. Now, significant discover-ies have to be searched for in remote "frontier" areas (Arctic, or jungle) or sought in deep water offshore areas that involve very expensive exploration programs. Costly leases must be negotiated with foreign governments, and if the area of interest is offshore, huge drilling platforms, which may cost up to several billion dollars, have to be built. Oil exploration is being conducted in the frequently violent stormy North Sea, in hurricane regions such as the Gulf of Mexico, and at the lower end of "iceberg alley" off the coast of Newfoundland. These are expensive areas in which to operate. Small companies do not have the resources to pursue large, expensive, long-term oil projects.

Myth: Oil companies own oil

Reality: In many countries, including Saudi Arabia, Venezuela, Kuwait, Iran, Iraq, Peru, and Mexico, oil was originally discovered and developed by foreign companies with the expertise and capital that the country itself did not have. Subsequently, with the rising tide of nationalism following the colonial period, oil company properties, oil fields, pipelines, and shipping facilities were nationalized and taken over by the respective governments, at times with little or no compensation.

Most of the oil in foreign countries (90 percent) is owned by their governments, not independent oil companies. Only about 10 percent of the world's oil is owned by public investor-owned companies. Oil companies simply hold leases to develop oil deposits. The companies are allowed to search for and produce what commercial oil may be found. Sometimes the oil companies are allowed to sell it themselves and pay a royalty fee to the government. Sometimes they have to market it through foreign state-owned companies. They never really own the oil in the ground. They only have the right to produce it. This is an important point, because it means that U.S. companies, or any other companies operating in a foreign country, do not own an assured resource base.

The United States is unusual in that mineral rights, which include oil and gas, usually belong to the owner of the land. The owner can sell these rights to a resource development company, so, in effect there can be more than one owner of a piece of land. The surface can be owned by one individual and the subsurface can be owned by someone else. Oil companies can buy the mineral rights to oil and, therefore, can own the oil in the ground. However, even in the United States, more often than not, the oil companies lease the mineral rights. Offshore oil belongs either to the adjacent state, or beyond the state offshore boundaries, to the federal government. Oil companies, for the most part, do not own much oil. Many own no oil. On the oil they do own, they pay a royalty fee to the private owner, or royalties and taxes to the government. These costs can range from 12 percent to as much as 90 percent of the value of the oil.

In other countries, the government usually owns all the mineral resources, which may be leased to developers. But governments can change their minds about lease terms or cancel them with or without compensation. Quite a few have done so — another severe hazard of the mineral resource business.

Myth: Oil companies make big profits compared with other enterprises

Reality: The profits of oil companies are frequent targets of criticism by politicians and the media. Many people believe that mineral resource companies are excessively profit-able relative to other enterprises. As pointed out in Chapter 21 on Mineral Economics, the amount of capital that has to be invested in the production of oil is very large and it takes a long time, in some cases many years, before any return can be realized on the investment, if, indeed, there is a return at all.

Oil exploration and production is a high-risk venture. Companies that do survive, on average over the years, earn a relatively modest return on investment. On records kept since 1968, the average return on stockholder investment in 30 representative U.S. oil companies has been 12.5 percent. For 30 representative manufacturing companies, the return has been 13.1 percent. The average return for oil companies is less than the average return for the manufacturing industry in general. The industry has been subject to wild fluctuations in the price of oil. In 1999, it was as low as $10 a barrel. It traded above $147 in 2008, and then fell to below $40. To retain the highly trained staff necessary in the industry, the companies must have some capital reserve built up to ride out the downturns, and wait for more prosperous times. Oil company earnings were high in years 2006 to 2008, but fell dramatically (as much as 70 percent) in 2009.

Based on the price of a gallon of gasoline we buy, the big winners in the gasoline price sweepstakes are the federal and state governments. They collect six times or more in taxes per gallon than the companies earn in profits. Some of the larger increases in retail gas prices have been caused by state tax increases. The state of California not only has a gas tax presumably for road maintenance, but it also levies a sales tax on the total price of gasoline including all other taxes, so they levy a tax on the other taxes paid as well as on the basic product. Some companies (e.g., ExxonMobil) are starting to leave the retail gasoline market because it is not profitable for them.

At the upper end of the profitable segments of the economy are the so-called "sin-stocks," the tobacco and liquor companies. It is ironic that companies whose products are harmful to the health and welfare of the country are much more profitable than the oil industry that produces a basic necessity that makes life far more pleasant than it would be without this important energy source. One of the main reasons for this difference in profitability between the petroleum industry and other segments of the economy is the huge capital investment and the long-lead time required for exploration and development before there is any profit. The average is seven years.

Offshore drilling platforms costing hundreds of millions of dollars are not required to make cigarettes. The oil industry involves high risks and huge investments. In contrast, the highly profitable tobacco industry does not incur large costs except for advertising.

Myth: Alternative energy sources can readily replace oil

Reality: This is the assumption made by many people who advocate alternative energy sources as an early solution to our dependence on imported oil, and the perceived negative environmental effects of burning oil.

The facts relative to this matter are mixed. Alternative energy sources may, in some cases, replace oil. But there is nothing in sight to replace the convenience of handling, and the high energy density of oil in use for transport vehicles, especially air transport. And there is considerable doubt that alternative sources can readily replace oil in the volumes in which it is now used – about 85 million barrels a day. Going to another fuel source to equal the huge energy demand now met by the convenient, easily transported, and high density energy in oil will not be easy. At present, there is no comprehensive replacement for oil in sight.

In some uses, there is no replacement for oil. Millions of miles of the world's roads are paved with billions of tons of asphalt, a mixture of crushed rock and the bottoms of oil refining operations, for which there is absolutely no real economic substitute. Roads cannot be paved with ethanol or hydrogen or cellulose. Technology may ultimately devise ways to replace oil in some uses, but when this happens, it will change the way society lives.

Myth: The transition to a nonrenewable energy economy will be easy

Reality: Contrary to popular opinion, there are many reasons why such a transition will not be easy or simple, including the fact that solar and wind energy are not constant energy sources, and biofuels in significant volume would require very large amounts of land and water now devoted to food crops.

Conversion to a solar and/or wind energy economy would involve vast construction projects to install huge collecting systems. Houses and factories would have to be redesigned to much more energy efficient standards. Electricity is not a primary source of energy. It must be generated from other energy sources such as coal-fired or nuclear-fueled power plants, gas turbines, water power, wind, solar cells, or by other methods. The amount of electricity needed to power the vehicles now run on oil would be enormous. The problems of storing electricity are not yet satisfactorily solved. The battery disposal problem and the various methods by which large additional amounts of electricity would have to be generated, lead to the third problem for using alternative energy sources — the matter of environmental impact. Alternatives to produce electricity are not necessarily environmentally friendly. Also, the electric car, as far as can be visualized with foreseeable technology, would not offer the same degree of mobility that gasoline powered vehicles do.

Myth: Ethanol reduces U.S. dependence on foreign oil

Reality: Promoting ethanol (alcohol) as an additive to partially replace gasoline is a happy hunting ground for politicians to get votes. Enthusiasm can reach astounding heights. The governor of Minnesota, a state strongly promoting ethanol production, said: "We could be the Saudi Arabia of the Midwest." Ethanol combines winning the corn-belt farm vote (a large bloc) with the public's hope that we can escape the clutches of foreign oil producers. The idea is that ethanol, made from corn and, therefore, supporting the price of corn, can partially substitute for gasoline in the form of "gasohol," which is 10 to 15 percent ethanol. In the 2004 presidential campaign, both major candidates endorsed increasing production of ethanol.

It takes gasoline or diesel to run the machinery needed to plant, plow, fertilize, harvest, and transport the corn to the processing plant, further reducing the energy replacement value of ethanol for gasoline. Ethanol production is probably an energy negative when the full scope of production costs is included. The environmental cost also must be considered. Corn is the hardest of all crops on soil fertility and in causing soil loss by erosion. Ethanol will do virtually nothing to reduce our dependence on foreign oil. It does generate profit for ethanol producers.

Myth: " … we have learned to extract limitless amounts of material from the depths of the Earth…. All the rest of the old scarcities are tumbling down the same steep slope, toward unlimited supply at zero cost" (Huber, 1999).

Reality: On a finite Earth, nothing is limitless. And it is impossible to obtain any resource at zero cost! Even "free" solar and wind energy requires equipment to be built to capture energy from these sources. In regard to the "depths of the Earth," mining at best can only reach a depth of about 10,000 feet because the geothermal gradient is about 2° F for every hundred feet. That means the temperature at 10,000 feet down is about 200° F higher than at the surface. Mines at that depth require expensive cooling systems. A lot of pumps are also needed to keep out the water that would otherwise flood the mine. A major hazard at greater depths is overlying rock pressure. It is so great that walls of the mine are subject to "rock bursts," in which rocks burst out of the sides of the mine and crush anything in their path, including mine cars and people. Yet the article containing these absurd claims appeared in respected *Forbes* magazine (December 22, 1999).

Myth: Alternative energy sources are environmentally benign

Reality: Converting coal to some liquid form that could be used to fuel transportation is possible. But to replace oil in current use would involve the greatest mining endeavor the world has ever seen. It would require strip mining vast areas of western land each year. If alternative energy considerations do not include coal, but rather are thought of in terms of solar energy, biomass, nuclear power, wind, hydropower, tidal, ocean thermal energy conversion (OTEC), or shale oil, they all also have environmental impacts.

These were discussed in more detail in Chapter 20 on mineral and energy develop-ment and the environment. Solar energy collectors in numbers large enough to be signifi-cant in our energy sources would occupy very large amounts of land. Mining the materi-als to make these collectors would have an impact. Because the collectors do not have an infinite life, there would be the continual problem of replacement, involving more mining operations.

The environmental impact of using biomass as a major source of energy would be huge, especially in terms of the degradation of the highly important resource, soil. Biomass forms humus, a vital component in all healthy soils. Wind power devices are unsightly, noisy, kill birds, and like solar collectors, deteriorate and have to be replaced with more materials mined from the Earth. Both wind farms and solar farms need access roads to service the equipment and the motor vehicles to do it.

In brief, "there is no free lunch" in the use of any alternative energy source with respect to the environment. All have an impact. Eventually some or perhaps all of these sources will be used. The decisions involve which sources have the least environmental effects and cost and yet can help meet projected energy demands. With an ever-increasing world population requiring more and more energy, any energy source or combination of sources that would meet this demand would inevitably have a large environmental impact through the sheer size of the operations. This is recognized and referred to by some as the "energy sprawl" of the green economy (Alexander, 2009). A further comment was, "We are about to destroy the environment in the name of saving it … . Renewable energy is not a free lunch. It is an unprecedented assault on the American landscape."

Myth: Biomass can be a major source of liquid fuels

Reality: This assertion is frequently made. But it has been thoroughly explored and proven to be a myth. A variety of plants, including greasewood in the arid Southwest, sugar cane, sugar beets, trees in general, seaweed, and seeds have all been cited as important possible sources of liquid fuel for the future.

The Energy Research Advisory Board of the U.S. Department of Energy reported in 1981 (U.S. population then was 258 million compared with 312 million now), that Americans used 40 percent more fossil energy than the total amount of solar energy captured each year by all U.S. plant life. Annually, available biomass is not a feasible replacement for the large storehouse of organic energy accumulated over millions of years in the form of coal and petroleum.

Myth: There are billions of barrels of oil that can be readily recovered from oil shale in the U.S.

Reality: The United States has the world's largest and richest deposits of so-called oil shale, which I pointed out previously, contain no oil. (This is in contrast to the shale strata that have passed through the "oil window" temperature that converts kerogen to oil, and are now being exploited by "fracking.") The great prospects for the production of oil from oil shale in the United States has been one of the most widely promoted and often repeated energy myths for many years. Statements made even by government agencies can be quite misleading. They also may be due to a less than careful examination of the facts, and perhaps to a bit of promotion for the agency involved. One such statement concluded that, " … using demonstrated methods of extraction, recovery of about 80 billion barrels of oil from accessible high-grade deposits of the Green River Formation is possible at costs competitive with petroleum of comparable quality" (Duncan, 1981). This is a clear misstatement of the facts. When this was written in 1981, there had been no demonstrated methods of oil recovery at costs competitive with oil of comparable quality, nor have there been any such methods demonstrated to date. A variety of experimental processes have been tried. All have failed. Unocal, Exxon, Occidental Petroleum, Shell, and other companies have made substantial attempts, but with no commercial results to date.

A state government agency issued a pamphlet about oil shale saying "The deposits are estimated to contain 562 billion barrels of recoverable oil. This is more than 64 percent of the world's total proven crude oil reserves" (state of Utah, 1990). The implication was that the oil was "recoverable" could be produced at a net energy profit as if it were barrels of oil from a conventional well. The average citizen reading this statement in a government publication would be led to conclude that the United States really has no oil supply problem if oil shales hold "recoverable" oil equal to more than 64 percent of the world's total proven crude oil reserves." Presumably, the United States could tap into this great oil reserve at any time. This is just not true (Youngquist, 1998a). All attempts to extract this oil economically in significant quantities have failed. Furthermore, the "oil" (and, it is not the same oil as crude oil, but this is usually not reported) may be recoverable, but the energy recovered may not equal the energy input required to recover it, that is, the net energy may be negative. If oil is "recovered," but at a net energy loss, the operation is a failure. Also, the environmental impacts of developing oil shale resources, especially related to the available water supply (the headwaters of the already over-used Colorado River), and the disposal of wastes, do not seem manageable, at present, and perhaps not ever.

The clear implication of both of these government statements is that oil shale is a huge, readily available resource. But despite the oil shale debacle in northwestern Colorado in the late 1980s and early 1990s, the myth lives on: "Huge untapped reserves of oil exist in oil shale deposits in the western United States, with a potential oil content exceeding that of all other petroleum resources in the entire world" (oil shale investment promotional, 1995).

Myth: Wind could significantly replace oil for fuel in U.S. electric power plants

Reality: Advocates of wind power frequently claim that wind-produced electric power can significantly substitute for oil in the U.S. electric power grid. An official of the American Council for an Energy Efficient Economy in 2004 asserted that "Wind technology has already shown its worth. If long-armed windmills were driving electric utilities, there would be more oil for transportation: planes, trucks, and cars." It is true there might be more oil available, but because less than two percent of U.S. electric power is currently generated from oil, it wouldn't be much. The chief fuels in electric power generation are coal, natural gas, hydropower, and oil, in that order.

Other Myths

Myth: Science and technology can solve any resource problem

Reality: In brief, this is the popular idea that because of all the great technological and scientific advances and discoveries of the past, science and technology can solve all future resource problems.

Alan Overton of the American Mining Congress reminded us: "the American people have forgotten one important fact: It takes stuff to make things."

The basic problem is that even scientists cannot create something out of nothing. Minerals and fossil energy resources on which we are so dependent, do not reproduce themselves. They do not grow. But human population does. There must be raw material with which to work. The idea that science will come to the rescue in some fashion is a popular public placebo.

It is an observable fact that people other than scientists and technologists are frequently more confident of what these disciplines can do for the future than scientists and technologists themselves — the people who are aware of the basic facts about the availabil-ity of resources and what can be done to replace them. Technology alone cannot produce anything. Technology can provide access to resources previously unavailable, but it can-not create a barrel of oil or a pound of copper

In 1992, the U.S. National Academy of Sciences and the Royal Society of London together issued a warning that "If current predictions of population growth prove accurate and patterns of human activity on the planet remain unchanged, science and technology may not be able to prevent either irreversible degradation of the environment or continued poverty for much of the world."

Ryerson (1995), commenting on the concept of a technology fix with respect to population growth, states:

> Some of the more outlandish claims of the technology fix advocates — for example, that we could ship our excess people to other planets — have almost

> been forgotten (imagine sending aloft 90 million people per year). Yet, while extraterrestrial migration is no longer taken seriously by most people, many of the unsubstantiated claims of new technologies that will 'save the day' are still seen by many as a reason not to worry about population growth.

It is important to understand that a technology fix is not an answer to unrestrained population growth. It is a decision made by people, and they may or may not choose to use the "technology" of family planning.

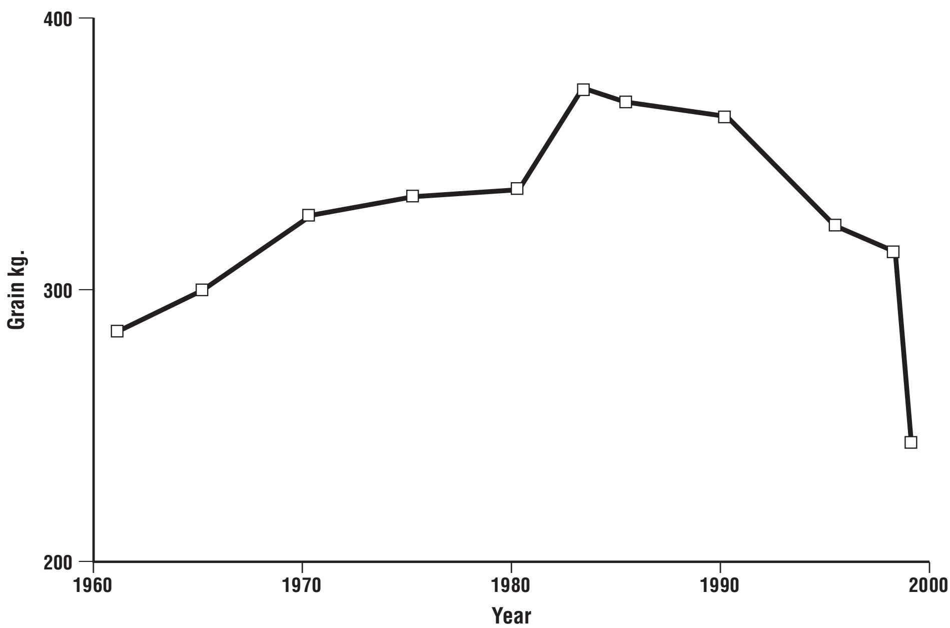
Myth: Because past predictions of resource and population problems have proved incorrect, future predictions will not come true; therefore there is no need to be concerned

Reality: Malthus then and now: This view stems in part from past predictions of impending disasters that did not materialize as scheduled. Notable were those made by Thomas Malthus in 1798. The argument presented by those who apparently see no need to relate population to resources is that since Malthus' predictions of two centuries ago proved so wrong, why should similar predictions be taken seriously today?

Malthus' predictions were wrong because he could not foresee the coming industrial and scientific revolution, including the Green Revolution. The Industrial Revolution provided much improved housing with adequate space heating, greatly improved sanitary facilities, and the machines and the energy to run them. It provided the basis for supporting an enormously much-expanded population. Huge resources not known to Malthus were discovered and developed.

But, in the long run, Malthus was clearly right. Unchecked population growth will outstrip food supply (Ferguson, 2008d). That time may be near at hand. In 2008, world grain supplies stood at a 60-year low and per capita cereal grain production was the lowest it had been in more than 50 years. It is still on a steep downward trend (Figure 26-1).

Figure 26-1. Per Capita World Cereal Grain Production



Source: Food and Agricultural Organization (FAO)

Ferguson further observes that "For many decades, there has been a willful blindness to recognize that population is the pre-eminent problem." In 1798, Malthus wrote, "Population, when unchecked, increases in a geometrical ratio, but subsistence increases only in an arithmetical ratio." This is an early recognition of the importance of the exponential factor, which applies to many aspects of human existence and resource consumption.

We are running out of more Earth to explore and exploit. In Malthus' time, the entire world's mineral and energy resources were virtually undeveloped, and the means to exploit them did not exist. The situation is now reversing. The difference is the present peaking or declining energy and mineral production in many parts of the world, and an already huge and continually expanding population. We live on a finite globe, and there are no more new continents to move to as one region becomes depleted. The globe has been encircled.

Myth: "There is an easy, painless, solution" to our energy problem

Reality: After one of more than 500 talks I have given on energy problems, especially on petroleum supply, the common question is: "What's the answer?" What the person is really asking is: "How can we keep the current game going?" There must be some alternative, and the question is sometimes bolstered by the thought that "we put men on the Moon, we can solve the oil supply problem." Putting men on the moon was a neat techno-logical trick designed to show the Russians that whatever they could do — Sputnik satellite and men in space first — we could do better. But that technology has only limited applica-tions, not related to oil supply problems.

The answer to the question "what's the answer?" is that it is not going to be possible to keep the current game going, hugely dependent as we are on fossil fuels. When I say this, I sometimes add that if I did have "the answer" and could patent it, within five years, I would be the world's richest man. When I tell the audience there is no simple solution, I generally do not get invited back. We all like simple, inexpensive answers to problems. The problem of replacing oil offers no easy or inexpensive solutions.

Myth: At the current rate of consumption …

Reality: This is often used as a comforting phrase to assure the public that "at the current rate of consumption," a given resource will last for at least X number of years – usually, this is quite a long time. The fallacy is that "the current rate of consumption" does not continue into the future. The rate of consumption almost always increases. The increase in resource consumption is due to three factors: (1) population growth, (2) demand for an increase in per capita consumption of a resource to raise living standards, and (3) discussing a larger number of uses for a given resource.

The assertion that a depletable resource will last for X number of years "at the current rate of consumption" bears little relation to the reality of the actual life of the resource. A resource may have a life of 100 years at the current rate of consumption. But, at a seemingly low rate of a five percent annual increase in demand, the resource will only last about 36 years.

One example of such a statement regarding world oil reserves was made on a popular TV investment program (*Wall Street Week*, 1996). It was that current supplies were enough to last us for 40 years "at the current consumption rates." This statement is misleading for two reasons. First, current consumption rates are transitory. Demand for oil will continue to increase as population increases. Second, if the statement were taken literally, it would mean that for 40 years, we would have the same amount of oil available as we have today. But in the 41st year, there would be none. This also has no relation to reality.

The graphic representation of the production of a finite resource such as oil is never a flat line. In broad form, after smoothing out irregularities caused by political, economic, and technological events, the production tends toward a bell-shaped curve (Figure 9-9). The critical point is when world oil production begins to decline, not when the last drop of oil is pumped from the ground.

Myth: There is some undiscovered energy source that will eventually be found that will save us.

Reality: The energy spectrum from fusion (Sun) to wood has been thoroughly studied, with no indication there is any undiscovered energy source. The popular hope that "the scientists will think of something" has no basis in fact.

Myth: One mineral/metal can freely and equally replace another

Reality: As we enter the age of depleting resources, both in quality and quantity, there is a view that one metal can freely and equally replace another. This is a carryover of ancient attempts at alchemy, the classic effort to change lead into gold. But the myth persists. The late economist, Julian Simon, carried it to the extreme when he said, "Copper can be made from other metals."

In long-distance electrical transmission lines, aluminum is now being used instead of copper because aluminum is cheaper and lighter weight. In making this substitution, some efficiency is lost because aluminum does not transmit electricity as efficiently as copper does. Each metal has its own distinct physical and chemical properties. Molybdenum makes steel tough so it can be rolled out in sheets and not crack. But within the alloy, molybdenum does not replace steel, it simply adds a quality to it. Similarly with nonmetals, every living cell has to have potassium and phosphorus for which there are no substitutes. (Indeed, when one substance does substitute for another in the body, it is typically a poison or a toxin!) There is no genuine substitute for oil in its many uses.

As we face the depletion of the Earth's resources, there may be limited substitutes for some minerals, but each resource has qualities not found in any other.

Myth: Solar and wind energy are free

Reality: Although it is true sunshine and wind arrive at no cost, converting them into useful energy is not free. There is an energy cost incurred in manufacturing the equipment needed to capture them. The equipment wears out and suffers weather damage, and from time to time needs to be replaced. Wind and solar installations also need to be serviced, which means construction of roads and the manufacture of equipment to service the facilities. Building roads and service equipment takes energy, which must be subtracted from energy recovered to determine the true net energy recovery of these "free" energy sources. A free lunch will never arrive in securing energy supplies.

Myth: We can eventually create a completely renewable recyclable economy.

Reality: This is the happy nirvana, which many dedicated environmentalists and others visualize reaching – that it could be achieved! Very early primitive societies came and went using virtually no Earth resources (even the rock thrown at small game was recyclable). But theirs was a standard of living we would not want to accept now. To sustain any reasonable standard of living, a completely renewable recyclable economy is a myth, as much a myth as that other will-o'-the-wisp, the perpetual motion machine. People would want electricity – electric lights, for example. The metal and glass in a light bulb must be mined. So must the metal in power lines needed to transmit electricity to homes, businesses, and the local hospital. How does one recycle a light bulb? This problem can be pursued in numerous other aspects of daily life. The best we can do is to use as little of the Earth's nonrenewable resources as possible to make them last a very long time.

Promotion of Myths

The media — newspapers, magazines, television, Internet, radio — report the news. But in their competitive haste to do so, they sometimes become an accessory to spreading misinformation. Assertions made by uninformed people, politicians pursuing votes, unscrupulous promoters, or citizen groups trying to further a particular point of view, may ignore realities. Too often these statements are picked up by the media and reported as fact.

For the sake of human survival at a reasonable standard of living, myths must be replaced by reality on which intelligent decisions can be made. It is distressing to see that in many instances the general public cannot differentiate between what might be in the realm of possibility, and the absurd or utterly impossible. If society is to survive, reason and clear recognition of reality must prevail, with policy and actions made on that basis. Part of public education should be directed toward truly analytical thinking. Political leadership, especially, must correctly state and differentiate between the possible and the absurd, even when the facts are not happy facts. This is particularly important when it comes to decisions about the basic needs of civilization — the energy and mineral resources upon which so much depends.

Conclusions

It has been said that "optimists have more fun in life, but pessimists may be right." The late Congresswoman Clare Booth Luce from Connecticut said, "The difference between optimists and pessimists is that the pessimists are better informed." Scientists are fre-quently labeled as pessimists because, in applying reality, many things they report are not all that cheerful. Unfortunately, factual current information about the environment and energy resource availability is not particularly encouraging. And that is a fact. Why not call such people realists instead of pessimists. People discount pessimists, but they would perhaps listen a bit more to people called realists. Unfortunately the general public only likes good news, true or not.

Hardin has aptly noted, "If the reception of *The Limits to Growth* and *The Global 2000 Report* taught us nothing else it should have taught us that the Greeks were right. In the public relations game only optimism sells." Hardin (1993) quotes Teiresias in Euripides' *The Phoenician Woman*, "A man's a fool to use the prophet's trade. For if he happens to bring bitter news he's hated by the man for whom he works." Hardin might have further noted that in political elections, which are the quintessence of the public relations game, the same applies.

Who likes to read a magazine or journal with ominous statements? Cheerful news sells, and editors are always glad to use it. Frequently, people with little or no background in a subject write such articles. One example was the pairing of an economist and a director of Asian studies who collaborated to write an article with these statements:

> But contrary to much perceived wisdom, the energy problem looming in the 21st century is neither skyrocketing prices nor shortages that herald the beginning of the end of the age of oil. Instead the danger is precisely the opposite; long-term trends point to a prolonged oil surplus and low oil prices over the next two decades…. The world's problem is not scarcity but glut (Jaffe and Manning, 2000).

They take to task a geologist of long experience who holds the opposite view. At the time the article was written, oil cost about $25 a barrel. Within five years, oil traded above $58 dollars a barrel, and in 2008, briefly above $147. A "prolonged oil surplus and low oil prices over the next two decades" earned its place with other myths.

The lesson from this example is to consider the professional background and experience of the source of scientific and technical statements. Respect the view with the best credentials. Long industry experience is far better than people from outside the subject field who simply decide to "write an article."

Regardless of the popularity of optimism over realism, the wisest route for humanity would be one that plans and bases decisions on today's scientific and technological realities and reasonably visible resources, rather than on hope for things that may never arrive. Optimism is vital in looking toward the future. One must be optimistic to have a basis for making an effort. But optimism should be tempered with facts. Campaigns for public office should not give citizens false hopes. As civilization proceeds, it will be much more convenient and far less disruptive to be pleasantly surprised along the way than unpleasantly surprised. Myths must be replaced by reality on which intelligent decisions are made.

"Facts do not cease to exist because they are ignored."
—Aldous Huxley

Chapter 27

Earth Resources, the Future, and "Sustainable"

The word "sustainable" is now widely repeated. The word can be interpreted in various ways, but it usually is used in the context of continuing things as they are going now — that is, growing population and production of goods to take care of that growth — and sustaining such trends for the foreseeable future.

I doubt if the word "sustainable" was ever heard in the year 1800, or even in 1900. In those times people went about their daily tasks with little thought of resource depletion. The western world was dominated by Great Britain and later by the United States. Britain imported all the resources it needed from its far-flung colonies. In North America, resources appeared to have no limits. As the continent was explored, there were new discoveries of more and more of nearly everything — iron, copper, gold, silver, oil, coal. There were vast reaches of fertile lands untouched by the plow, abundant water — tens of thousands of lakes, many rivers and streams, and huge underground water supplies including extensive artesian systems. No one thought of "limits." The phrase "limits to growth" would have been jeered or thought simply incomprehensible.

Even beyond the midpoint of the last century, to most people, there were still no visible limits to the resources of North America. Pearce and Turner (1990) wrote:

"Between 1870 and 1970, mainstream economists (with some notable exceptions) appeared to believe that economic growth was sustainable indefinitely. After 1970 a majority of economists continued to argue that economic growth remained both feasible (a growing economy need not run out of natural resources) and desirable (economic growth need not reduce the overall quality of life). What was required was an efficiently functioning price system. Such a system was capable of accommodating higher levels of economic activity while still preserving an acceptable level of ambient environmental quality. The 'depletion effect' of resource exhaustion would be countered by technical change (including recycling) and substitutions that would augment the quality of labor and capital, and allow for, among other things, the continued extraction of lower quality non-renewable resources."

The illusions of no limits — that our destiny and right is continued growth unhampered by resource limitations — continues to be the view of many economists.

In his studies of worldwide mineral deposits, Park (1968), who was then Dean of Min-eral Sciences at Stanford University, made this observation:

> Our study of minerals and their place in the political economy has brought us inevitably to the conclusion that a constantly expanding economy, keeping step with a growing population, is impossible, because mineral resources and cheap energy are not available on this earth in unlimited quantities. The affluence of modern civilization is indeed in jeopardy.

Successful cultures, economic growth, and growth in population are closely related, and all depended on Earth resources in the past. But resources are limited, and most of the resources vital to our current cultures are nonrenewable.

Sustainable development

The widely used general definition of "sustainable development" is from the "Brundtland Report," a publication of the United Nations World Commission on Environment and Development in 1987. It states: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Considering present conditions, it is obvious that "sustainable development" as defined is nowhere in sight. Populations are not only plundering resources from the past, but renewable resources are being used beyond a sustainable rate, including soil and groundwater, which impair the ability of the Earth to sustain future generations. This seems unlikely to change, at least in the near future, rendering the prospect of sustainable development, as defined by the United Nations, a happy, hopeful illusion.

There are many ramifications of the concept of "sustainable" to consider. These are comprehensively examined by several authors in the book, *The Future of Sustainability*, edited by Mark Keiner (2006). In Albert Bartlett's discussion of sustainability, he lists 21 laws, 17 of which are related to Earth resources or the impact humans have on the environment. First Law: Population growth and/or growth in the rates of consumption of resources cannot be sustained. Second Law: In a society with a growing population and/or growing rates of consumption of resources, the larger the population and/or the larger the rates of consumption of resources, the more difficult it will be to transform society to a condition of sustainability.

Bartlett's fourth law of sustainability says: "The size of the population that can be sustained (the carrying capacity) and the sustainable average standard of living of the population are inversely related to one another." This is a simple equation that resources divided by population equals standard of living. There surely is a lower limit on how small a functioning effective population can be. But above that level, the standard of living will be controlled by the renewable resources available to each individual. Just as available resources are unevenly distributed on the planet today, large differences in standard of living will exist in the future. Industrial civilizations have the most to lose in the post-industrial paradigm.

Bartlett's nineteenth law of sustainability: "Starving people don't care about sustainability."

Defining "sustainable"

This is an optimistic word. A survey of people who use it finds no general agreement on a definition, especially in the details of how "sustainable" can be accomplished. Bartlett (1997a) writes: "There are cases where one suspects that the word 'sustainable' is used carelessly, perhaps as though the belief exists that the frequent use of the adjective 'sustainable' is all that is needed to create a sustainable society."

We surely want the human race to be sustained in the future, especially as the future is arriving with increasing rapidity and intensity every day. Sustainability is a genuine concern. But defining and applying what "sustainable" means is difficult, involving a number of assumptions and variables. A simple definition might be that "sustainable" means being capable of doing what we are doing now until the end of the week, the end of the decade, the end of the century — *indefinitely*.

Some questions about "sustainability" are:

- Is there a time limit on "sustainable?" If not, then what technologies do we now have or think we could devise to permanently carry us forward?
- What Earth resources have indefinite future usefulness that we can draw upon?
- What size population can be supported indefinitely?
- What material standard of living should be the goal for a sustainable population?
- How is an acceptable standard of living defined and is it the same for all cultures in all climates?

As we contemplate all this, the unfortunate reality is that 100 percent recovery through materials by recycling cannot be achieved. Some is inevitably lost in the process. Furthermore, to recycle materials requires energy. Even solar and wind energy (converted to electricity) both require energy and Earth materials to build the gathering and generating devices. How can the rate of soil erosion be reduced to be equal to or less than its natural rate of replacement in order to support an ongoing civilization? Topsoil replacement time, at best, is now equal to human lifetimes. Realistically, "sustainable" may be only a relative term, not an absolute. No culture beyond a primitive hunting and gathering one is sus-tainable without using some nonrenewable Earth materials.

An interesting exercise is to ask someone to precisely define "sustainable" and to describe in detail how it can be accomplished. Through correspondence and conversation, I have pursued this matter of "sustainable" in terms of what technologies and materials would be involved and how many people could be supported and how well. People I contacted have been confidently using the word over the years because it is a nice concept, and just thinking about it, makes people comfortable. Comfortable, that is, until faced with identifying details of how this can be accomplished with zero drawdown of Earth resources. Such would have to occur if a truly sustainable society could be established. Only about half replied, and those that did, dealt only in generalities with factually unsupported assurance that "it can be done."

There are many books and articles on the question of "sustainability" (Bartelmus, 1994; Clayton and Radcliffe, 1996; and others). They have numerous suggestions, but lack a detailed blueprint of how to achieve "sustainability." One of the most difficult problems is how to stabilize population size, and at what level? The issue of population size is frequently ignored, and when it is considered, it is treated very cautiously because it involves delicate cultural, religious, and racial matters. But some population size must be assumed to rationally describe what resources and technologies would be required to sustain humans indefinitely. "Sustainability" cannot be achieved if one part of the equation for balance is continually changing. If we want to create a sustainable world, we are headed in the wrong direction because population continues to grow.

At present, the concept of "sustainability,' in whatever context it is used, seems to be only a hopeful generality. Probably the most realistic and simplest description comes from Lester Brown:

> There is no empirical calculation of sustainable that I know of. Conceptually, it is that development which satisfies the needs of the current generation without jeopardizing the prospects for future generations.

Pimentel and Pimentel (1979) and others at Cornell University have made perhaps the most comprehensive and quantitative study of "sustainability," relating it to the two most vital parts of our resource base — soil and water. "For erosion under agricultural conditions, we should be losing less than 1 ton per hectare per year for sustainable farming. For groundwater resources, we should be pumping no more than 0.1 percent of the total aquifer for use." But, we rarely manage these two vital resources based on these criteria. Pimentel et al. (1994), have suggested a figure of about two billion as the sustainable population of the Earth, and about 100 million for the United States. Other estimates for the United States range as low as 16 million. Professor Kenneth Watt, University of California Davis, calculates that the sustainable world population at any reasonable standard of living would be about 1/70th of today's population. With as little as we really know about all aspects of maintaining a sustainable resource economy, Watt may be closest to reality.

As resource demands have started to create problems both in price and availability, developed nations are growing more aware of the finite nature of resources like water, metals, and fossil fuels. Nevertheless, the term "sustainable development" is commonly used with optimism that implies the growth trends we now experience can really be indefinitely sustained. Economists, in particular, are very fond of it. So are real estate developers and chambers of commerce. To meet objections about the continuing growth of various projects, the term "smart growth" has been invented and is widely used. However, as Bartlett (1997a) pointed out: "The claim is made that growth management will save the environment. Whether the growth is smart or dumb, the growth destroys the environment."

Some other aspects of sustainability

Problems relating to "sustainability" come in many forms. Land use and food production are important issues. From 1980 to 2002, the U.S. per capita agricultural land declined from 1.5 acres to one acre. At the same time, population increased by 60 million. For the first time, the United States became a net importer of agricultural products (Hartmann, 2006). Similar trends are taking place elsewhere as more and more countries become dependent on international food assistance due to population growth and/or degradation of the land.

The United States adds about three million people to its population each year. "Can you visualize the number of hospital rooms and beds that will have to be made available — the number of doctors, nurses, and other health care professionals that has to be made available — to provide health services for…3 million people? And for another three million the following year, and…? Can you visualize the amount of food and water and energy that will be required to feed and serve…3 million people" (Hartmann, 2006). To this list should be added the number of additional schools and teachers needed, plus houses, and, unfortunately, jails. More paved-over agricultural land is an inevitable result.

In the U.S., cities occupy only three percent of the land area, but 26 percent of the best agricultural land. This annual increment of needs will continue as long as our population grows, but the resources available to meet these needs are finite and are now in decline.

We talk about energy conservation as a way to balance demand and supply. But, the goal is constantly overwhelmed by population growth. California is a good example. "Per capita energy use dropped 5 percent between 1979 and 1999. However, during that same 20 years the state's population grew 43 percent largely as a result of immigration" (Hartmann, 2006). In spite of the per capita reduction in energy use (conservation), the amount of energy used in California increased by 93 percent.

Sustainability is rendered impossible now by *any* increase in population since we have already exceeded the long-term carrying capacity of the Earth. When will this basic fact be recognized and addressed?

As the British writer, Bligh, has stated: "Contraception is so much kinder than starvation and genocide." The family planning route to a sustainable population size at a decent standard of living is surely better than any alternative. But getting the message accepted and acted upon by the world at large is a formidable task, and there are few willing to carry the message because it is politically taboo.

Nation sustainability

Global trade in commodities including energy (oil, natural gas, coal, uranium), and food, fertilizer, timber, and metals is a massive operation. Looking forward to a time when the resources no longer exist to ship these world-wide commodities between nations, the distinguished, now retired Professor James Duguid (2004) from Scotland has made this observation on individual nation sustainability:

> The guiding ethical principle should be that each nation should live within the resources of its own country, with only such trade in surpluses as is beneficial to all. None should depend on foreign aid, on large imports, on exporting surplus people, or in otherwise appropriating the biocapacity of other countries.

A future without precedent

History repeats itself. But the future we are entering has no precedent in terms of the use of resources, population size and growth, and stress on the environment. In his book, *Collapse: How Societies Choose to Fail or Survive*, Diamond (2005) documents how some civilizations destroyed the environment on which they depended. His examples of Easter Island, the Mayan Civilization, and the Chaco Canyon inhabitants were relatively small societies. But now the stakes are worldwide. "Local overruns of life-support systems are not new, but for the first time, growing human demand is crossing the sustainability threshold of global ecosystems" (Brown and Kane, 1994).

The scale at which civilization currently consumes oil is illustrated by Leggett's (2005) calculation that a billion barrels is used in less than 12 days. The oil industry, both national and investor-owned, is far from finding a billion barrels of oil in less than 12 days. Francis Harper of British Petroleum (BP) observed: "We have looked around the world many times. I'd say there is no North Sea out there. There certainly isn't a Saudi Arabia."

Far more energy and mineral resources have been used in the world since 1900, than over all previous time. In the case of oil, the first 200 billion barrels of oil in the world were consumed between 1859 and 1968, but it only took the following 10 years to consume the second 200 billion barrels. Now 200 billion barrels of oil are just a six and one-half year supply. We have used the first trillion barrels of oil during the past 125 years. We will use the next trillion in 30 years. Then what?

Energy the critical resource

It is clear that among the various resources we are considering, excluding soil and water, energy is the most important. Without energy, other mineral resources cannot easily be obtained, nor can they be effectively used once they have been obtained. Energy is truly the key that unlocks the storehouse of all other mineral wealth.

Currently in the United States, about 25 percent of all energy produced is used to produce other energy. Energy is essential to drill for oil, mine coal, mine uranium, cut wood, make solar and wind energy conversion devices, and so on. As the easily recoverable energy mineral resources (petroleum, coal, uranium) are increasingly exhausted, the cost in energy to produce more energy is estimated to rise to about 33 percent in the next ten years. It will almost certainly continue to rise after that. This trend in energy costs can be fatal. If it ultimately takes as much in energy as the energy produced by the effort, there is no energy surplus to use in other energy consuming sectors of the economy. At that point, the game is up. As noted previously, the net energy recovery of an energy capture process is the critical figure.

One thing is certain: Almost all alternative energy sources, as well as the principal sources of energy in current use — coal, oil, and natural gas — will cost more, and in some cases, much more in the future than they do today. Alternative energy sources are now more expensive — that is obvious from the fact that if they were equal or lower in cost than what we now use, alternatives would be in much greater use. We use the cheapest, most convenient energy sources first. Energy will take an increasing percentage of government and personal income. Success of fusion technology may change this outlook, but that is unlikely for decades to come, and may never become a reality.

A new economy emerging

This new economy, the one we will live in after fossil fuels, cannot be based on continually drawing on our resource inheritance. We eventually will be back to lifestyles of earlier times, dependent on currently available renewable sources. But there will be the advantage of technologies that can capture renewables such as solar and wind in greater amounts and the ability to convert this energy into versatile electricity, in contrast to past generations, who lacked this technology and, therefore, lacked electricity. The question is, can these technologies based on renewable resources maintain the present or future larger population at an acceptable living standard?

The human race at times may believe itself to be beyond the laws of nature, but nature will ultimately prevail. The history of petroleum will be the same chronicle of resource discovery, abundance, use, and decline that has been repeated for other resources in local areas in the past. An abundance of a life-sustaining resource is discovered. The consumers flourish and multiply and multiply again. Eventually, however, the region is depleted of its resource and consumers are reduced in numbers, or they try to migrate to other areas. This is apparently what happened to some of the native cultures of the American Southwest, such as the Chaco Canyon people.

New technologies and social systems must develop that will adapt to the alternative energy sources and the economic lifestyles these require. These adaptations, together with reduction in human numbers, are likely to characterize this century.

There is no parallel in history for such a rapid development and use of a resource like oil, and the profound changes it triggered worldwide. It is well to keep in mind that change works both ways, with the coming of oil and the going of oil. The *status quo* cannot be preserved.

Nations that produce mineral resources are destined by their geological endowment to gradually take away industries and jobs from the industrialized resource-consuming nations. There will be an ongoing series of adjustments for both sides, with the nations that have minerals gaining economically at the expense of the mineral-importing nations.

In the industrial world, the principal metals consumed are aluminum, chromium, cobalt, copper, iron, lead, manganese, magnesium, molybdenum, nickel, platinum, tin, tungsten, vanadium, and zinc. Just since 1950, the production and use of these materials has increased between 100 and 500 percent. With somewhat less than 30 percent of the world population, the industrialized countries consume more than 80 percent of these metals. Some of them, like platinum, rare earths, and tungsten, are becoming scarce. Copper mining is now reworking discoveries made many years ago. We are beginning to see a world becoming increasingly competitive for the remaining, and more expensive mineral and energy resources.

"Only" a two percent population growth rate

To illustrate how fast the human population target moves, and the inability of material resources to keep up with the demand from such growth, the late geochemist Harrison Brown (1978) calculated that if world population continued to increase at the rate of two percent annually, in two thousand years, the Earth would be a solid mass of people expanding out into the universe at the speed of light. In just six hundred years (not really long in terms of human history), the Earth would pass the standing room only situation of five square feet per person, covering both the continents and the oceans. This is what "only a two percent growth rate" means. It's obvious that *no* growth rate is the first requirement of "sustainable." "An ethics for a finite world cannot be one that promotes or even allows continual growth in human population or in the production of material goods or services" (Elliott, 2005).

Sustainability elsewhere

Two centuries ago, when the British ruled India, that country had a population of 60 million. Today, it is 1.1 billion and still growing at the rate of 1.4 percent a year. This means that India's population will double to 2.2 billion in just 50 years, if the trend continues. Poverty is already widespread in India and many other countries. Soil is being lost far faster than it is being formed, and groundwater supplies are being overdrawn. Thus, two basic resources are declining while the population keeps growing. Allowing for a probable decline in the rate of growth, India's population is projected to reach 1.75 billion by 2050, 300 million more at that date than China, but with land mass less than one-third that of

China. Even now, two-fifths of the world's undernourished children reside in India, and the number of children there increases every day.

Population growth is especially high in Sub-Sahara Africa. The great majority of Africa's countries have growth rates that will double their populations in 35 years or less. The continent as a whole is projected to grow from about a billion today to about two billion by 2050 (Population Reference Bureau, 2009). With crushing poverty already, one wonders what Africa will look like by the year 2100. The goal of "sustainable" almost anywhere will be a huge challenge.

Boulding's theorems

Kenneth Boulding (1910-1993) was an economics professor at the University of Colorado and, for awhile, president of the American Economic Association. He was that rare economist with a realistic view of world population and resources. Boulding (1971) postulated three possible theorems for the future:

> The Dismal Theorem: If the only ultimate check on the growth of population is misery, then the population will grow until it is miserable enough to stop its growth.
> The Utterly Dismal Theorem: Any technical improvement can only relieve misery for a while, for so long as misery is the only check on population the (technical) improvement will enable more people to live in misery than before. The final result of (technical) improvements, therefore, is to increase the equilibrium population which is to increase the total sum of human misery.
> The Moderately Cheerful Form of the Dismal Theorem: Fortunately, it is not too difficult to restate the Dismal Theorem in a moderately cheerful form, which states that if something else, other than misery and starvation, can be found, which will keep a prosperous population in check, the population does not have to grow until it is miserable and starves, and it can be stably prosperous.

Boulding continues:

> Until we know more, the Cheerful Theorem remains a question mark. Misery we know will do the trick. This is the only surefire automatic way of bringing population to an equilibrium. Other things may do it…. The economic analysis I presented earlier indicates that the major priority, and one in which the United Nations can be of great utility, is a world campaign for the reduction of birthrates. This, I suggest, is more important than any program of foreign aid and investments. Indeed, if it is neglected, all programs of aid and investment will, I believe, be ultimately self-defeating and will simply increase the amount of human misery.

Boulding makes this very clear. The only question is whether adjustment to the carrying capacity of the Earth will be accomplished by intelligent actions or by the harsh methods nature has used in the past.

The term sustainable growth (or sometimes the term sustainable economic growth) seems to imply maintaining a continually growing population at least at the present standard of living, presumably indefinitely, as there is no explicit limit to growth. Indeed, the term sustainable growth, as Bartlett (1994) noted, is clearly an oxymoron. Porritt (1993) commented:

> Indeed the concept of sustainable growth is a contradiction of terms: exponential growth (in either human numbers or volumes of production and consumption) cannot be sustained indefinitely off a finite resource base. A growth rate of 3 percent implies a doubling of production and consumption every twenty-five years. Nobody actually disagrees with that, not even the most manic growthists. But professional Macawbers that they all are, they just go on hoping that something will turn up before their bluff is finally called.

Geological inheritance versus current income

Hardin (1993) wrote: " … once we have come to the end of our fossil fuels, the sustainable population will probably be far less than the present 5 billion human beings. (Note: in 2012, it was 7 billion.) Our species is living on borrowed time. Unfortunately academic economists are almost completely unprepared to deal with a steady-state world, although it may be right around the corner."

Huxley (1977) related the policy difficulties of population issues:

> There are colossal difficulties in the way of implementing any large-scale policy of limitation of population: whereas death control is extremely easy under modern circumstances, birth control is extremely difficult. The reason is very simple: death control — the control, for example, of infectious diseases — can be accomplished by a handful of experts…. But when it comes to decreasing the birthrate, we find ourselves confronted with problems which can only be solved by the cooperation of the entire population."

This concept is embodied in the saying, "Population control is everybody's baby."

Today's industrial economy draws heavily from the past, but in a "sustainable" economy, the population will have to live on renewable "current income" resources. But no energy source can replace valuable topsoil, increase groundwater supplies, restore collapsed groundwater aquifers, or cause more water to flow in rivers where, for many rivers, demand already exceeds supply.

How much is enough?

At various places in this book, the terms "physical standard" or "material standard" of living are used. This includes essential human needs for food, shelter, clothing, and a command, both directly and indirectly, of some amount of energy beyond our own muscles. But above a basic level of existence, there are countless things that can be included in a physical standard of living. Inventors in the industrialized nations together with manufacturing and marketing organizations have combined to make a phenomenal spectrum of goods available. All these are using up resources at an exponential rate and rapidly filling landfills.

It is important to consider how much is enough. Many people are better off now than people a century ago because great progress in medicine eliminated plagues, provided vaccines against such scourges as polio and typhoid fever, and provided advanced sanitary and heating arrangements to many of us. But at what point do more goods cease to make people happier?

It is estimated that people in the United States "… are on the average now four-and-a-half times richer than their great-grandparents were at the turn of the century, but they are not four-and-a-half times happier. Psychological evidence shows that the relationship between consumption and personal happiness is weak. Worse, two primary sources of human fulfillment, social relations and leisure, appear to have withered or stagnated in the rush to riches" (Durning, 1992).

Some people are rejecting "modern" conveniences and trying to live simpler, less stressful lives. and say they are happier for it. They view the emotional costs of high pressure jobs and commuting in heavy traffic not worth the luxury goods that such lives provide. The opposite of over-consumption, which is abject poverty, is not desirable either. Somewhere between lies a proper balance.

As resources grow scarce and their costs rise, perhaps an adjustment in values about what is important and worthwhile can compensate for a reduced amount of material things. Can a sustainable lifestyle be developed that balances a modest physical standard of living with a way of life that also provides a satisfying emotional and spiritual wellbeing (Babbitt and Babbitt, 1993)?

How much IS enough? Some people in the affluent industrialized world are now giving this some thought.

Priorities

Related to the question "how much is enough" are questions of social values and priorities. World population will grow for at least several more decades. At the same time, nonrenewable resources will continue to diminish. Whether or not renewables can replace them soon enough in sufficient volume to bridge to a sustainable society is questionable. What priorities in the interim will make the most of the resources we have?

The budget of the United States could increasingly be devoted to preserving the environment on which we depend, improving the quality, not quantity of life, and working toward a sustainable future. This would involve medical, environmental, and other biological research. We frequently see "drives" by dedicated citizen groups to raise money to find cures for specific diseases. But that money is minor compared to what might be obtained by cutting "pork barrel" items from the general budget.

Entering the future

Entering the future is not a well-defined moment. There is no abrupt event. It is an ongoing process, which in the long term will involve great changes. Future problems considered "then" become "now" every day.

Herman Daly, a founder of the emerging field of ecological economics, and one of the few economists who recognizes the limits of growth, commented on prospects for continued growth after the worldwide financial debacle that started in 2007:

> "It is a crisis of overgrowth of financial assets relative to growth and real wealth. To keep up the illusion that growth is making us richer, we deferred cost by issuing financial assets almost without limit, conveniently forgetting that these so-called assets are, for a society as a whole, debts to be paid back out of future real growth…future real growth is very doubtful…." (Daly, 2008).

Can present political structures cope with a future of less?

Richard Lamm (2006), former three-term governor of Colorado and co-director of the Institute for Public Policy Studies at the University of Denver, made an interesting and thought-provoking observation. From his experience in administrative government and looking ahead from today's affluent times toward a more resource-restricted future, he writes:

> Can the government institutions that distributed a growing economic pie turn around and administer sustainability? Can we really anticipate the magnitude of the problems and the solutions that it will take to get to a sustainable future? Can we solve the problems of growth with more growth? Will existing mechanisms (including capitalism) be sufficient and successful for the next 200 years as they have been for the last 200 years? The assumptions that undergird our whole industrial society incorporate infinite resources.

Using renewable resources beyond actual renewable sustainability creates the illusion of having more than we really have of those resources.

A common expression is that history repeats itself. But the brief fossil fuel interval will never be repeated. Likewise, the opportunity for multitudes to move west into the relatively unoccupied continents of North and South America that happened during the last four hundred years can never be duplicated. We have run out of new continents with untapped natural resources to take care of more and more population. There is a new paradigm arriving, still unrecognized by many, and for which inadequate preparations are being made.

"Unlimited" and "renewable" should not be confused. Solar energy, wind, river flow, and biological resources are renewable but not unlimited. What a reasonable standard of living is differs widely among cultures. But in each culture, that standard will clearly be affected by the size of population.

Pimentel and Pimentel (2006), title a section of their study "Transition to a 2 Billion Optimum Population." They write:

> The adjustment of the world population from 6.3 billion (now 7 billion) to 2 billion could be made over approximately a century if the majority of people of the world agree that protecting human health and welfare is vital, and all are willing to work to provide a stable quality of life for ourselves and our children. Although a rapid reduction in population numbers to 2 billion humans could cause social, economic, and political problems, the continued rapid growth to 10 to 12 billion people will result in an even more dire situation with potentially greater problems…. Fifty-eight academies of science, including the U.S. National Academy of Sciences, summed up the problem as follows: 'Humanity is approaching a crisis point with respect to the interlocking issues of population, natural resources, and sustainability.'

Summary

The future presents three problems of unprecedented scale: (1) The current rate of use of both renewable and nonrenewable resources is unsustainable. We are now chiefly dependent on nonrenewable resources, but renewable resources are also finite at any given time. (2) Human population continues to grow. We are making little or no progress in matching human population size with the development of renewable resources. (3) The assault on the environment, with a few hopeful exceptions where wild areas are being preserved, continues worldwide.

Because population is the critical force impacting the environment, achieving sustainability means reducing population size, a circumstance subject to human control. Fac-tors such as the exhaustion of nonrenewable fuels may be accommodated by a change of lifestyles combined with renewable energy technology, but again, the degree of success is related to population size. Renewable energy sources cannot sustain a reasonable standard of living for the Earth's seven billion people, much less the nine billion or more projected in 2050 (Trainer, 1997).

Begin NOW

The most important factor in achieving a livable sustainable future is to begin now. But, it is hard because we are very much like the proverbial frog in the kettle slowly coming to a boil. At any given moment we do not sense a crisis situation. When we do, will it be too late to change the things that are bringing the water to a boil?

Political agendas are notably short-term. Responding to a problem that is here and now is far more politically feasible than calling upon the public to change and sacrifice its current lifestyle to solve a problem certain to occur, but that may be years away. People in the industrial world do not want to make lifestyle changes for objectives that appear relatively remote. For the most part, changes are made only when a crisis has clearly arrived. By then it may be too late to allow for a smooth transition to new circumstances. Diamond (2005) suggests that in the case of the Easter Island disaster, people apparently did not recognize in time that their course of action would lead their society to extinction. The present course of humanity is unsustainable. If population rises to nine billion or more by 2050, and world fossil fuel production declines at least 50 percent as seems probable, the collision of resource depletion and population growth could be catastrophic.

One important aspect of energy and mineral supply is the effect it has on a nation as it loses its ability to produce its own needed energy and mineral resources. The American public has only recently begun to recognize that as more resources have to be imported, industries and jobs, and the jobs peripheral to those industries, are lost. This not only increases the balance of payments problem, but it erodes the value of the currency if exports cannot balance the drain on a nation's monetary position. A nation cannot print money indefinitely to pay for imported material things. Sooner or later, suppliers will resist weak money. And, with a weak currency, goes a general decline in economic influence and world prestige. It is a slow process, and the citizenry may fail to notice what is happening for a time, but eventually the declining standard of living will be felt by all. This began to be apparent to U.S. citizens in the 1990s, as the international balance of payments reached record deficits, and the value of the dollar fell and continues to do so. The U.S. standard of living has been reported to be falling beginning in 2007.

The U.S. has been living on borrowed money, and thus beyond its means. At some time, this imbalance must be faced. The challenge is to do it gradually, without undue social and economic turmoil. But, as the national debt increases each year, we are in denial of the trend, which, if not altered, can eventually destroy our economy and culture.

Trends in industrialization and technology are not encouraging about an easy transition to a non-oil economy. Populations continue to increase, and as more and more coun-tries become industrialized, so does the combination which makes increased demands on Earth resources. India and China are making great strides in this direction. At the same time, technological advances moving toward alternative energy sources, particularly those for transportation needs, are proceeding very slowly.

World energy mix, now dominated by oil, is beginning to change. The energy mix will continue to change until all nations have reached the stage where total energy supplies come from renewable sources. This transition may take most of this century if not longer to be accomplished, but it is inevitable.

An important philosophical question must also be considered. How many generations ahead should be our concern? Forever cannot realistically be our problem. So for how far ahead should we be concerned to work toward a sustainable life for mankind? Charles Galton Darwin (1953), grandson of Charles Robert Darwin, addressed this in his book *The Next Million Years*. He said that during such a time frame, there are so many unpredictable circumstances and happenings that predictions are futile. And, in fact, he says that he is concerned with much less time than that. So how far ahead should we be concerned? We are, of course, concerned about ourselves, and also our children and their children and perhaps their children, our great grandchildren. The changes we are now witnessing and for which we are in good part responsible — depletion of resources, increase in population, and injury to the environment — will affect them. Beyond that, the future becomes hazy. Charles Galton Darwin says, "I know that the fifteenth generation of my descendants will get no coal at all." Sooner than that, our descendants will have no oil nor natural gas.

This generation and one or two more will play a major role in shaping the most significant century in human history — the one that transitions to a permanent renewable resource economy.

The future could be good, but trends must change dramatically to accomplish it. It will be what we make it. Our direction now is increasingly stressing the Earth's finite resources and putting more population under greater stress. Anarchy, of which Kaplan (1994) writes, cannot be an option. But the enormous problem of growing populations contending for depleting resources can erode civil society. As more and more people come into the world, the value of life declines. I have seen this in Haiti. It is also apparent in parts of Africa, where people struggle to survive among unimaginable atrocities.

Enumerating the ways in which humanity is negatively impacting the environment, especially through the loss of forests and their important role in water retention and preservation of the soil, Osborn (1968) made a pointed observation: "In a way this is one of the crowning ironies of human life today. This is warfare of man with himself."

A sustainable society is achievable. But in whatever way the future may unfold, it will have to be "living within limits," as Hardin wrote. As it always has been and always will be, the Earth's materials will be the base for civilization and will control its destiny.

Chapter 28

The Ultimate Resource — Can It Secure Our Future?

There are limits to Earth resources, and technology cannot create more. We must live with what we have. The question then is what technology can do with our limited resources in the future? "Technology" involves the application of the human mind to a particular problem or need. The human mind has brought humanity to where it is today, and it is the ultimate resource we have to carry us into the future. How well will it serve us? How much of its collective knowledge will we use?

Technology, combined with abundant but nonrenewable Earth resources, up to now have sustained industrial growth. The importance of mineral and energy mineral resources to nations and individuals cannot be overstated. Countries such as Japan and Switzerland enjoy a high standard of living, yet have almost no mineral or energy mineral resources. They have a highly educated society, well versed in modern technology, which produces many useful things. The ultimate resource of these mineral-poor nations, and of all nations, is the educated, creative human mind.

However, Switzerland must use steel to make turbines and watches. Japan could not be a world-class automobile manufacturer were it not for imported aluminum and steel and virtually all the other materials that go into an automobile, because Japan has almost none of these resources.

What has moved civilization ahead has been the innovative and educated human mind. Oil is an illustration. Native Americans living in east Texas and on Alaska's North Slope walked over the two greatest oil fields in North America. Nomads of the Arabian Peninsula rode camels over the largest oil deposits in the world. But what could they have done about them even if they had known they existed? Lacking technical knowledge that could unlock and utilize these resources left these people poor. But the educated human mind changed everything. Combining the educated human mind with available natural resources makes the difference.

In more detail, the same reality applies. Even if crude oil is obtained from wells or at natural oil seeps as occur many places in the world (almost all major oil fields exhibit oil seeps), it still has relatively few applications in its unprocessed form. When technology is applied and the crude oil is put through a refinery, and these refined products are further processed, the end result is literally thousands of items that make for better living worldwide.

Similar situations exist with the metals. Iron is an example. Occurring very rarely in natural form, iron was first discovered in meteorites. Swords fashioned from this hard material were called "swords of heaven" and very highly prized in battle. Because of the high melting point of iron, the metallurgy was discovered and developed at a rather late date. But, finally, what had been huge deposits of unusable iron ore in many parts of the world became valuable resources to be exploited. After the discovery that iron could be extracted from previously worthless rocks, it was further discovered that the addition of vanadium, chromium, tungsten, molybdenum, and other minor metals gave iron a variety of valuable properties, producing alloys for many important specialized purposes.

In the Mesabi Iron Range in Minnesota, the rich hematite (iron) ore has been exhausted, but very large quantities of lower-grade ore called taconite remain. This low-grade ore is crushed, and the iron content particles are separated and concentrated into pellets, and then shipped to steel mills. The uniform iron content of the pellets compensates in part for the lower-grade ore by allowing blast-furnace operations to be more efficient than when using raw but somewhat variable quality higher-grade ores. Despite competition from foreign high-grade ores, technology partially compensates for the depletion of the high-grade ores of Minnesota. This enables that area to continue being a competitive source of iron ore, although iron mining is substantially reduced from what it once was. It is the educated human mind creating the technology that allows the continued survival of this industry.

Knowledge has discovered how to produce more food with the use of abundant and cheap energy, and has provided the energy to do so. Medical knowledge has enabled more people to survive and live longer, with the result that the world's population is at an all-time high.

There are more scientists and engineers alive today than at any time in history, and probably collectively during all past time. Technical and scientific journals have increased to the point that libraries across the world can only store the amount of information available electronically. And knowledge continues to grow. But the belief that all resource problems can be solved by scientists allows people to ignore unpleasant facts. Bartlett (1976) writes:

> There will always be popular and persuasive technological optimists who believe that population increases are good, and who believe that the human mind has unlimited capacity to find technological solutions to all problems of crowding, environmental destruction, and resource shortages. These technological optimists are usually not biological or physical scientists. Politicians and business people tend to be eager disciples of the technological optimists.

What Bartlett is saying is that scientists might NOT be able to think of something to save humanity from every predicament it has gotten itself into. The thought that science may not always rescue them will disturb many people. Fortunately, for scientists who want to share their concerns regarding resource supplies and population growth today, we have gotten beyond the time when the bearer of bad news to the king was beheaded. However, telling a chamber of commerce meeting that there are limits to growth usually does not get the speaker invited back again. I can vouch for that. For a politician to campaign on realities that are unpleasant to digest is political suicide. No American president would be elected saying the fact that we are near or past the time when world oil production will meet our demands and when the world runs out of oil, there is no apparent substitute for the ways we use that vital material.

The idea that continues to prevail, however, is that somehow scientists will think of something that will let us continue on our present path. Population growth is considered a sign of good things ahead. "We have a growing economy." Every president likes to say that. The reality is that a "growing economy," in terms of a greater population and more "things" being produced, is actually a major problem. The depletion of nonrenewable resources is not mentioned. We elect government officials to find "solutions" to problems that arise, so government has a vested interest in remaining optimistic, and makes us less prepared for unpleasant surprises.

Occasionally, a government official lends a note of realism to the discussion. Richard E. Bennett, of the U.S. Department of State, voiced his concerns about the ability of technology to save the day, saying "While it is true that technology has generally been able to come up with solutions to human dilemmas, there is no guarantee that ingenuity will always rise to the task. Policymakers must contend with a nagging thought: what if it does not, or what if it is too late?"

There is a limit to how much the ingenuity of the educated human mind can compensate for the scarcity or exhaustion of raw materials. So far, however, human intelligence has been doing quite well with finding and using resources even though some are lower and lower grade and harder to locate. We are in 10,000 feet of ocean water searching for oil, and down to mining 4/10ths of one percent copper ore for that very useful metal. But there are limits, and we are reaching the point where technology is beginning to show the strain. Every resource has unique qualities. Total replacement by alternatives may not be possible.

In the case of mined groundwater and soil lost by erosion, such resources are beyond technology's renewable or repairable reach. For oil, gas, coal, metals, and essential nonmetals (e.g., phosphate and potash for fertilizer), at some point technology cannot generate more at an economic or energy cost that society can afford. A new economy with a balance between population and renewable resources will have to emerge.

Wealth we can continue to accumulate

As our mineral wealth and conventional energy resources are depleted, there is yet one resource we can continue to accumulate: knowledge. Like the Greeks who were prevailed upon to forgo their annual tribute of silver from the mines at Laurium in order to build the fleet that defeated the Persians at the Battle of Salamis, so the human race must apportion part of its current wealth toward the development of "shiploads" of information, which can carry humanity into a sustainable future with a reasonable standard of living. Education has been the vehicle that moved civilization forward, and it must continue to do so.

Teaching "future"

The imperative of thinking and working toward the long-term future did not exist a century ago, but clearly it is before us now. History has been taught for centuries, but the study of the future has only recently been considered a logical part of education. Many universities now have "future studies." When I taught at the University of Oregon, there was no "futures" course offered, but there was a need to discuss resource issues. The dean was willing to support it on a trial basis if 10 students registered for it. "Energy and Mineral Resources for the Future" was posted on a temporary notice board during registration. It did not appear in the university catalogue, but we had to close registration at 110 students for lack of a large enough classroom. It immediately became the second largest course (after Geology 101) taught in the Geology Department. It attracted students from journalism, political science, sociology, economics, and business – students we would otherwise not have seen taking geology. Discussions were enthusiastic and spirited because the course opened up new areas of thought. Students became aware that the future offers both great challenges and opportunities. It was a most encouraging experience personally. Why not teach "future" right along with history at every academic institution? We learn from the past, we live in the present, and each day, part of the future arrives. That future is arriving in terms of change more rapidly than ever before.

Allocation of human resources

Basic research is an endless frontier. It holds our future in ways we cannot now foresee. Government financing and tax incentives to encourage basic research in the public and private sectors should be expanded. Currently in the United States, there is a distorted allocation of educational resources, and a misplaced emphasis. Japan trains 1,000 engineers for every 100 lawyers. In the United States, the ratio is reversed. The abundance of Japanese cars in the U.S. gives mute testimony to the consequences of that ratio. Every year in the United States, three times as many lawyers graduate as there are in all of Japan. Japan is producing. The United States is suing. The United States is the most litigious nation in the world. The insurance group, Lloyds of London, reports that only 12 percent of its insurance business is in the United States, but 90 percent of its claims are.

The human mind should be put to developing knowledge in all its varied manifestations. The British statesman, Sir Winston Churchill, observed, "The frontiers of the twentieth century are the frontiers of the mind." Earth resources will be important indefinitely. The human mind cannot conjure something out of thin air. But can the human mind intelligently and economically manage the available resources? This ability will surely be needed in the coming decades in the search for viable energy sources. But there is more involved than knowledge and intelligence.

Constructive use of knowledge and resources

There is another facet in applying the human mind to Earth resources. Resources can be used for both constructive and destructive purposes. Uranium is an example. It can produce electricity. But two nuclear physicists, Wiesner and York (1964), during the "Cold War," commented on the arms race where one side produced an atomic bomb, the other side produced a more destructive nuclear weapon, and so on. They concluded, "It is our considered professional judgment that this dilemma has no technical solution."

Not just uranium can be used to destroy, as it was in Japan in 1945. Large quantities of many other Earth resources are used in vast quantities in modern warfare. The energy expense of flying one bomber from Missouri to the Balkans and back to deliver a single load of bombs, as the U.S. did, is enormous and requires an in-flight refueling once each way. The technology needed to develop and control guided missiles, "smart bombs," and many other aspects of modern warfare involves the use of great amounts of technical talent as well as special metals and other costly materials.

The cost of war is enormous. It reaches well beyond the immediate conduct of war, continuing for decades after combat ends. Columbia University Economist Joseph Stiglitz, a Nobel Prize winner in economics, and Harvard lecturer Linda Bilmes estimated that the total cost of the U.S. war in Iraq beginning in 2003 could top $2 trillion (Bender, 2006). Besides the direct cost of the war in payments to personnel, supplies, maintenance and attrition of equipment, and in rebuilding the Iraqi infrastructure, the loss of domestic productivity from personnel in uniform, interest costs from the rising budget deficit caused by war expenditures, death benefits and bonuses paid to military families and soldiers, medical costs for wounded military personnel, and disability pensions for some to the end of their lives were some of the many items included in the estimate. The cost in human grief and tragedy, of course, is immeasurable and can never be expressed in monetary terms.

In the United States, there are numerous annual "drives" to raise money for various causes such as the search for a cure for muscular dystrophy. The cost of just a few large bombs is greater than the money raised by most of these drives. We still know little about many of the complexities of the human body, and that is a place where much more money could and should be spent for the long-term good of humankind.

One of the unexpected positive side effects of the rapidly increasing cost of energy supplies, metals, and other Earth materials may be to make large-scale warfare too expensive to continue. The Cold War bankrupted Russia and added a huge amount to U.S. debt, on which we continue to pay interest.

In their book *The Lessons of History* (1968), Will and Ariel Durant wrote: "In the last 3,421 years of recorded history only 268 have seen no war … . The causes of war are the same as the causes of competition among individuals: acquisitiveness, pugnacity, and pride, the desire for food, land, materials, fuels, mastery." As international warfare becomes too expensive, it might be hoped that warfare everywhere would cease. But as populations increase and contend for depleting soil and other Earth resources, the danger of local warfare for survival may rise. There are already feasible examples in Africa.

Technology alone does not hold the answer for achieving a bright human future. The intelligent human mind also must have good judgment about how resources may best be employed. Warfare consumes valuable and irreplaceable mineral resources in gigantic quantities. Scientists and technologists can produce resources from the Earth, but the decision about how to use them has, for the most part, not been their province. Lapp (1973) observed, "It is a waste of time to hunt witches and seek to pillory scientists and technologists as responsible for national ills; they have never been in the driver's seat. If technology is to be controlled, if it is to be used wisely, and if its ill effects are to be avoided, the nation needs not castigation but leadership that combines the technical skills of specialists with the responsible management of those charged with our political administration."

Count Axel Oxenstierna, Lord High Chancellor of Sweden (1612-1654), is famous for writing his son, "Did you not know, my son, with how little wisdom the world is governed?" Wise political leadership elected by an informed public is the best hope for a successful future.

Ability to visualize the future

Another very useful and unique aspect to the human mind, if it is applied, is to visualize the future. Individually and collectively, we alone are responsible for our future. We now know a great deal more about the basic resources that control our lives — the energy and mineral supplies that determine our destinies. We now also can visualize much better than people could just 200 years ago, where existing trends in population growth and mineral resource use may be taking us.

Disregard for the problem of overpopulation is generated by an arrogant attitude of the human species toward the rest of nature that sees humans as distinct from the natural realm. For their own sake, humans have to learn how to include in their cultural identity values and moral obligations that are based on respect for the rest of the biosphere to which they belong. Toynbee wrote, “Maximum welfare, not maximum population, is our human objective.” Dr. George Wald said, “We need to make a world in which fewer children are born, and in which we take better care of them.”

Natural resources, the educated human mind, and most importantly, the will to use the educated mind effectively, combine to create the ultimate resource on which we must depend. Even as knowledge to exploit the Earth has clearly created problems, growth of knowledge about resources and their peaceful, intelligent use also offers a path to humankind’s successful survival.

Reordering education

The huge task is that each generation everywhere should be educated to the facts of what the environment can provide and why and how the environment must be treated. Our educational system needs to reorder its priorities. People living 50 years hence will probably think back to the “good old days” and define them as the time when fossil fuel was still widely available and affordable. A complete adjustment to the permanent renewable energy future may not be entirely accomplished by the end of this century, but by 2050, much of the framework of that future will surely have emerged. In an increasingly crowded world faced with diminishing resources, it is critical that the “civil” in civilization be maintained.

To give the educational process at least a reasonable chance for success, people must be educated to the facts of the resources basic to our existence, and where we are now in regard to these resources. Perhaps more importantly, individuals must develop the responsibility to effectively use this knowledge.

The will to do

Whereas knowledge is important, there is another important factor, and that is, “the will to do.” Knowing is one thing, doing is another. Rossman’s essay (1994) “The Will To Do What We Ought To Do” is a very perceptive statement of the problem. Sir Crispin Tickell (1994), in considering the future and the need for decisions, wrote:

> I was recently asked if I was an optimist or a pessimist. The best answer was given by someone else. He said that he had optimism of the intellect but pessimism of the will. In short we have most of the means for coping with the problems we face, but are distinctly short on our readiness to use them. It is never easy to bring the long term into the short term. Our leaders, whether in politics or business, rarely have a time horizon of more than five years.... It is

> still within our power to make the future congenial to ourselves and future generations. The choice is ours.

Bartlett put it bluntly, saying that the human mind is the ultimate resource, but, "only if it is used."

Summary

The human mind must not just devise technological applications. Technology holds only a part of the answer to a secure future. Human intellect must also address problems such as population and population growth. Human intellect and wisdom will be required to achieve peaceful, not resource-wasting war resolution of conflict. Many problems have no technological solution. Solutions lie in the domain of applying the rational, ethical, educated human mind to human relations and using it also to make good individual decisions that ultimately affect everyone – such as the choice of family size and the recognition of its relation to quality of life. Political science and other social science disciplines have as much responsibility making the future sustainable and pleasant as do Earth scientists and technologists. Technology is neither moral nor immoral. It needs intelligent control that lies not in science, but somewhere in the human psyche. The evidence of continual strife, at times mindless violence, suggests the psyche needs more development.

With the knowledge we have and the unique ability above all other organisms to visualize what present trends of resource use and population growth will lead to, we should have the will and capability to adopt a course that will lead to a sustainable future at a reasonable standard of living for all. We can combine the educated human mind and the will to use it with available Earth resources to successfully adapt to the resource environment that the geology of the Earth created for us, and in which we are inevitably destined to live.

Chapter 29

Earth Limits, Population, and a Defining, Turbulent Century

The Earth in its many aspects is continually changing, and adaptation to these changes is the key to survival. This concluding chapter is part review of the previous ideas and facts in this book, and part projection of where current trends will take us. A few solutions are suggested, and a number of negative trends are identified as problems that need to be realistically recognized and met. For the most part, the purpose of this volume is to provide a framework for anticipating the events of the new century. It can be said with certainty that world societies and economies will be greatly different as irreplaceable Earth resource supplies, especially fossil fuels, are depleted. Sometime beyond this century our mines, factories, and industrial complexes may be archeological sites from the time that finite nonrenewable resources supported a population for a few fortunate centuries.

Humans are very recent arrivals on this unique planet. It had well-established natural systems, some geologic, some biologic, within which we developed and must continue to adapt if we are to survive. The Earth, with its resources and processes, controls our future. We can only use the resources the Earth has the ability to supply. In the renewable energy paradigm we are entering, the daily reality of limited resources will make us much more aware of the basic intertwining relationships between population size, resource availability, and standard of living.

The twentieth century began with a world population of 1.6 billion people and the oil interval in its very early stages. Most roads, even in industrialized countries were not paved, and automobiles were a rarity. Most work was done by human or animal labor. In 2012, the world has 7 billion people and most of the heavy work is done by machines using fossil fuels. Electricity generated mostly by fossil fuels, transforms everyday life in many parts of the world and connects the entire world in one communication network. The world has nearly 1 billion motor vehicles, and a system of roads paved mostly with asphalt. The transportation of goods and people by car, train, or plane has never been easier. But the brief petroleum interval, which did so much to change the world, has limits and an end.

With a still-growing population, we are launched into a totally new paradigm of energy, food production, and economies based on renewable and probably more localized resources. The challenges are great and the outcomes uncertain. One-third or more of world population today lives in marginal subsistence circumstances. Some barely survive, and some, particularly children, do not.

Entering a turbulent century

The confluence of factors soon at hand may make this century the most turbulent in human history. There will be adjustment of population size. There will be a new energy paradigm. There will be lifestyle change. There will be great economic change. There will be environmental change. Although change has always been the order of life, the particular confluence of major factors in each of these areas will make the twenty-first century a fundamental turning point for mankind.

It is often said that history repeats itself. In some ways it may, but in others it will not, it cannot. The brief period of humanity's exploitation of fossil fuels will never be repeated. The tripling of world and U.S. population in just one century will never happen again because the Earth's resources cannot support it. The exploitation of high-grade mineral deposits such as iron, copper, silver, phosphate, and potash cannot be repeated. Those easy to mine, high-grade deposits are mined out…gone. We are likely, however, to see a repeat of local agrarian economies and lifestyles in post-fossil fuel times.

The coming changes will be turbulent in their combined impact. Loss of abundant, cheap transportation fuels will change lifestyles. Loss of large-scale mechanized farming will affect food supplies and labor needs. The combinations of these factors around the Earth will be manifest in many ways. Such great changes are certain to cause major human adjustments.

The global demand for adequate medical facilities, doctors, and technicians is already overwhelming some countries, which are becoming failed states (Brown, 2011c). Sewage and water systems are breaking down, unable to continue meeting the demands placed on them. Most importantly, the basic elements of food production, arable land and groundwater for irrigation, have been in decline for several decades. With a growing population to feed, limitations of the finite Earth have reduced food stocks to the point that the world now lives from harvest to harvest with no grain storage buffer for bad crop years. The demand for food is approaching the Earth's capacity to meet it.

Political agendas versus the longer view

Much of this chapter consists of observations from scientists and researchers who have spent their professional lives gathering information on which they base their conclusions. They take the long view of processes, systems, and consequences. Geologists in particular, are students of long-term data, and have a view of the Earth unlike most others. In contrast, political agendas are largely concerned with immediate issues and immediate consequences for voters who often do not associate public policy with longer-term global issues of population size, water supplies, or land fertility. The saying "all politics is local," is true. Serious discussions of global concerns often bring out conflict with local religious or cultural mores. The future of humanity is too far out and too big a topic for much of the world's existing political agenda, but that is likely to change as events unfold. Grant (2008) writes:

> This will be a tumultuous century, as competition grows for diminishing resources. The human race will not get through it without fundamental changes of our population size, our living arrangements, our consumption patterns, and our expectations — and probably not without mounting hunger and violence.

The stakes have never been higher for people all over the world. This century could end with worldwide poverty, or with some remaining islands of modest affluence. It could end with a much-reduced population with living standards more equalized and reduced from those we know today. There are other possible scenarios, but nearly all include a reduction in population. We have clearly exceeded the carrying capacity of the Earth.

Population, food, and jobs

The Earth's supply of arable land is seriously decreasing due to current agricultural practices. Population is growing despite this shrinking food-producing land base and is already causing problems.

In many parts of the world, people are in greater supply than jobs. India estimates that it needs nine to 12 million additional jobs each year to accommodate its population growth. The United States needs to create 125,000 new jobs a month to keep even with population growth. Work is a universal human need and perhaps the characteristic that keeps us civilized.

Technology has displaced many workers by making it possible to produce more with fewer workers. This is likely to be a long-term reality. One result may be that governments are overwhelmed by the needs and demands of their citizens. Articles bearing titles "The Coming Anarchy" and "The Coming Chaos" have examined this prospect. Increased strife seems inevitable when producing the basic necessities of increasing populations cannot be met by producing employment.

Those who still argue that population can continue to grow without negative consequence are clearly suffering from what Hardin (1999) chose to entitle his final book, *The Ostrich Factor: Our Population Myopia*.

Ultimate limiting factor of population

If human action does not reduce world population to a sustainable size, food supplies will, as history clearly shows. Starvation is already rife in some regions. Professor James Duguid (2007) of Scotland puts it very simply: "The ultimate danger facing our children and grandchildren in the coming century is shortage of food caused by continued growth of population and consumption." He further notes that, "Even now the UK has to import about 40 percent of its food…." And, he adds that the "UK's population will have increased by 7.6 million in 2031 with 89 percent due to immigration."

Food — the most basic energy

As we begin life after fossil fuels, great attention will be directed toward finding alternative energy sources. Often overlooked is the fact that food is the most elemental source of human energy. The United Nations (UN) projects global population will reach 9 to 10 billion by 2050. It also estimates that the world needs to produce 50 percent more food by 2030. With declining supplies of oil on which current agricultural production depends, meeting the expectations of the UN will be difficult. Soil also is being lost by erosion and various forms of land degradation such as salinization and the loss of humus from removing biomass from the land. These are serious losses, as Ferguson (2008d) describes, "The number of hectares being abandoned per year (from all other causes) now equals the loss due to soil erosion, 10 million hectares (24 million acres)." In total, far more arable land is being abandoned than is being replaced, and the land used for replacement is usually more marginally productive than the land being abandoned.

Depleting energy resources will increase the importance of fertile, local farmland. These farmlands will become a critical economic asset for communities. Future food supplies will depend more on local sources because the present worldwide shipping of food is unsustainable. Without abundant fossil fuel, the importance of local farmland and hand labor is assured.

Current trends and 219,000 more mouths to feed each day

Population now grows at a rate of about 80 million a year. This means there are 219,000 more mouths to feed each day. Agricultural scientist Lester Brown views the world from his extensive experience here and abroad. He was an international analyst with the U.S. Department of Agriculture's Foreign Agricultural Service and an administrator of the department's International Agricultural Development Service. With this background, Brown makes some important observations:

> Official projections of food supplies by the UN Food and Agricultural Organization are hypothetical delusions. The economists who do these models and projections, merely take the grain yield per acre in 1960 and 1990, draw a line between the two points and extrapolate into the future. They rationalize their method by claiming that past is the only guide to the future we have. They refuse to acknowledge the entire body of literature on S-shaped growth curves in biology. Any biological growth curve process in a finite environment will eventually conform to an S-shaped growth curve, showing rapid increase followed by a decline. Food production on Earth is a biological process in a finite environment so it will follow this curve. But economists are not biologists, so they are oblivious to reality.
>
> I have a feeling we are moving toward a major scare, a wakeup call of some sort… as population grows, everything else suffers…. Our forests are shrinking, our soils are eroding, deserts are expanding, and our water is disappearing … we are moving into a new era when we can no longer assume the rapid growth in food production that characterized most of the last half century. It is difficult for people to grasp because we are conditioned to unprecedented growth during our lifetime… which will totally overtax its natural systems if we do not change. The only thing that will matter in the end is whether we turn around the destructive trends. We are failing to do that.

The food factor and nations' stability

Brown (2009b), sounded an alarm that worsening food crises in a number of nations is a threat to global stability. He does not cite single event weather-driven crop failures, but rather, identifies four critical long-term trends: rapid population growth, loss of topsoils, growing water shortages, and rising temperatures.

Food shortages have the potential to destabilize even the most well-established societies. No country will be stable in face of the loss of adequate supplies of either of the two essential human survival needs: food and water. Both are under increasing stress in many countries.

The Fund for Peace and the Carnegie Endowment for International Peace analyze and score countries on their well-being each year. Brown provides this 2007 list of the 20 countries closest to collapse, ranked from worst case (Somalia) to better (Sri Lanka), and including in between, Sudan, Zimbabwe, Chad, Iraq, Afghanistan, Haiti, Bangladesh, Ethiopia, Uganda, and Nigeria among others. These are failing states. Law and order break down and crime explodes when people are starving.

Brown (2006b) reports:

> The recent merging of food and energy economies implies that if food value of grain is less than its fuel value, the markets will move the grain into the energy economy. That double demand is leading to an epic competition between cars and people for the grain supply and to a political and moral issue of unprecedented dimensions. The U.S., in a misguided effort to reduce its dependence on foreign oil by substituting grain-based fuels, is generating global food insecurity on a scale not seen before.

Nature always adjusts the population to fit the amount of food available. Fox populations in northern regions are controlled by the fluctuations in numbers of lemmings. In the western parts of the U.S., coyote populations closely fluctuate according to fluctuations in rodent populations, and also in the number of rabbits. A poor winter range reduces the size of deer and elk herds. Food supply is the unavoidable population controlling factor throughout the natural world, and humans are not exempt.

From about 1950 to 1993, we were able to substitute fertilizers for additional acreage to produce increased food crop yields (Brown and Kane, 1994). The fertilizer provided "ghost productive acres," which did not exist in the ground. But since that time, additional fertilizer has not resulted in increased yields. World population growth continues, but total arable land is decreasing. As a result, less grain land per person is a looming and serious problem. The unhappy intersection of these trends — population growth and lower-food productivity — deserves world attention sooner rather than to be left to future crises.

The "Green Revolution"

Norman Borlaug was the author and engineer of the "Green Revolution." By genetic engineering of crops and adaptive agricultural practices, he was able to greatly increase food supply, especially in developing nations like India. His success may be a reason for the great population expansion we have witnessed. Borlaug himself recognized the problem when he received the Nobel Prize in 1970 at a time when the world population was 3.5 billion. In his acceptance speech, he noted "The Green Revolution had won a temporary success…it has given man a breathing space. If fully implemented, the revolution can provide sufficient food for sustenance during the next three decades…. But the frightening power of human reproduction must also be curbed, otherwise the success of the Green Revolution will be ephemeral only" (Elliott, et al., 2012).

The unfortunate result is that the Green Revolution was, in effect, self-defeating because it allowed people to continue to multiply because food supply temporarily was not a population limiting factor. With world population still growing, one of the world's greatest achievements became the world's greatest missed opportunity. India, where Borlaug did much of his work, had a population of about 540 million at the time. It is projected to be 1.7 billion by 2050. Like many other technology advances, particularly in the supply and use of energy, Borlaug's work has been offset or even canceled out by population growth. There is no new Green Revolution in sight according to Borlaug's own observation.

Even worse, the Green Revolution is highly dependent on higher inputs of fossil fuel-derived fertilizers and copious amounts of water for irrigation. Thus, even without the population growth it enabled, much of its gains may be ephemeral and unsustainable in a world where fossil fuels and water are in short supply.

Survival of the fittest in human affairs

Natural selection — survival of the fittest — will continue to prevail in human affairs despite the arrival of different economic or social environments. The late Harvard paleontologist, Stephen Jay Gould, suggested that evolution proceeds by a spurt of activity followed by a longer relatively dormant time as organisms are sorted out and the survivors successfully settle into a new environmental framework that will remain stable — for a time. The new environmental paradigm that will follow the rapid depletion of many natural resources, and the changing demographics of a more crowded world, may be an example of this punctuated evolution. We cannot foresee the result.

Huge resources, insignificant use — then the Industrial Revolution

From several billion years of Earth's biological and geological processes, we inherited a great storehouse of mineral and energy resource wealth (Poss, 1975). For millennia, humans used these resources in insignificant amounts relative to their abundance in the Earth. But in just the past three centuries, the Industrial Revolution technologies allowed Earth resources to be exploited quickly and in great volumes. The parallel exponential expansion of human population that resulted has reached the point that the concept of "depletion" that hardly existed before, is now very real. Just as more than half the world's oil produced today was discovered before 1973, the world's copper industry is living off discoveries made years ago. "The mining industry is living off the fruits and labors of prospectors of 100 years ago," Steven Whisler, Chief Executive of copper company Phelps Dodge, told a Morgan Stanley mining conference. Increasing amounts of energy are now required for extraction and processing of lower-grade deposits to sustain the availability of large volumes of minerals.

Industrial civilization and the exponential factor

The use of machines and the energy to power them is the defining fact of what we call an industrialized nation. Human and animal labor has been largely replaced by machines that do countless tasks.

Earth materials and energy sustain industrialized nations. But we have been using these resources at an unsustainable exponential rate. Hughes (2007) studied energy supply issues, and points out that 50 percent of all oil consumed has been used since 1984, and 90 percent of all oil consumed has been used since 1958. Hughes also reports that 50 percent of all coal consumed has been used since 1970, and 90 percent has been used since 1909. Hughes says world coal production will peak by 2025, as do several other recent studies, much earlier than those who have been saying the significant production life for coal is hundreds of years. These consumption patterns also generally apply to the consumption of all metals and nonmetals.

Cooke (2007) describes the stark realities of our situation:

> There isn't enough fossil fuel energy left on our planet to sustain our existing OECD (developed nations) lifestyles through the end of the 21st century. Worse, there isn't enough fossil fuel energy left to support the lifestyle dreams of developing nations.

Cooke goes on to say that the most important projected alternative energy sources – solar, wind, biofuels, and hydrogen — will not be able to replace fossil fuels despite illusions to the contrary.

Industrial civilization — benefits and costs

Modern civilization has provided many good things. Unquestionably, those living in industrialized countries have lived better lives than previous generations did. People living in undeveloped countries to a lesser degree, have also benefitted. Although the use of oil is not universal, the motorized transport of goods and people has been of benefit to many.

But for all the benefits of industrialization, there is a price to pay. Countries that were once self-sufficient in most things, like the United States and European countries, increasingly depend on resources from other lands, which see their resources depleting.

Through its very success in extracting nonrenewable resources from the Earth (minerals and fossil fuels), industrial society possesses the seeds of its own destruction. We have used more of these vital Earth resources in the past 60 years in all previous Earth history. This is clearly unsustainable. The two billion people in the industrialized world have benefitted with a material standard of living that developing economies now are trying to achieve for their citizens. Inevitably, there is growing competition for Earth's remaining vital resources.

In the industrialized world, we live in very good times. How much will continue and how many of the benefits it has brought us will it be possible to share with the world's less-fortunate citizens is unknowable. What will the limits to available resources mean to us and to them?

Freed from dawn to dusk labor on the land just to survive, millions of people migrated to cities and to factories where there were jobs and abundant metals and cheap energy to improve the material quality of life for more and more people. Cheap energy allowed the easy transport of large quantities of food to cities. People no longer needed to be dispersed in small farming units over the landscape. Larger and larger cities developed, even mega-cities. In 1900, only 13 percent of world population lived in cities. By 2050, that number is projected to rise to 70 percent. But there may be some reason to doubt that. Depletion of fossil fuels, particularly oil and natural gas, now so vital to agricultural production, will curtail food supplies. Cities are almost entirely dependent on food produced outside cities. Agrarian lifestyles may grow more appealing than city dwelling. In fact, they may become a necessity.

People in cities have become detached from the land, and most are unaware of the importance of the environment to support them. Food comes to people in cans and plastic containers in supermarkets, not from their personal labor in a field adjacent to their home. Many are oblivious to the "ecological footprint" required for their survival.

Most people do not realize that our largely fossil fuel and metal based-industrial civilization is living on a finite inheritance of energy captured by organisms from ancient sunlight during distant geological ages and on metal deposits formed during millions of years in the Earth's interior. Hubbert (1971) said "It is difficult for people living now, who have become accustomed to steady exponential growth in consumption of energy from fossil fuels, to realize how transitory the fossil-fuel epoch will eventually prove to be when it is viewed over a longer span of human history."

The fifth revolution

Reflecting on the several "revolutions" in human history, Charles Galton Darwin (1953) made this observation:

> The fifth revolution will come when we have spent the stores of coal and oil that have been accumulating in the earth during hundreds of millions of years … it is obvious that there will be a very great difference in ways of life … a man has to alter his way of life very considerably, when, after living for years on his capital, he suddenly finds he has to earn any money he wants to spend … this change may justly be called a revolution, but it differs from all preceding ones in that there is no likelihood of its leading to increases of population, but even perhaps to the reverse.

A plundered planet in less than three centuries

The energy subsidy from fossil fuels since the beginning of the eighteenth century until its peak this century, was the greatest agent of change in human history. In less than 300 years, human societies changed more than they did since settled agriculture was developed 10,000 years ago. The future cannot be known in specific detail, but the certainty of a huge impending change in economies and lifestyles in the years ahead seems clear.

Commenting on this, Heinberg (2007) writes, "The recent fossil fuel era has seen so much growth of population and consumption that there is an overwhelming likelihood of a crash of titanic proportions." Heinberg points out that scientists from several disciplines are aware of this prospect:

> This should be glaringly obvious to everyone. Our ecologists have studied population booms and crashes in other species. Our soil scientists appreciate the limits of modern agriculture. Our geologists understand perfectly well that fossil fuels are finite in quantity. Our mathematicians can easily calculate expo-nential growth rates to show how quickly population increase and resource depletion will outstrip our ability to satisfy even the most basic human needs. Verbal and mathematical logic, joined with empirical evidence, make an air-tight case: we're headed toward a cliff.

Spending our great inheritance

We have been squandering our irreplaceable resource inheritance at an exponential rate. The Fossil Fuel Interval probably will be the shortest and possibly the most resource significant epoch in human history. We have been fortunate to live in this brief bright blip of hydrocarbon abundance – those of us lucky enough to make use of it. It will bypass large segments of world population.

We currently pay our way to comfort and well being with checks written against our great resource inheritance. But soon we will have only "current accounts" to draw from. Nonrenewable resources that still exist must be harnessed in a peaceful, economical, and intelligent manner toward the goal of building a renewable, sustainable economy. We are far behind schedule on that project (Tickell, 1994).

Thanks to world population growth, we are pushing more and more people out on a limb that relies on nonrenewable resources. Increasing resource exploitation and deple-tion means the limb is slowly but surely being sawed off. Beneath this limb, when it finally crashes this century, is the presumed safety net of "sustainable, renewable natural resources."

Some argue that the projected world population of more than nine billion by 2050 will never be reached, despite the present momentum of population growth. If it levels off before then, it will be done either by a concerted worldwide effort at severe population reduction, or by starvation. Brown (1978) wrote, " …population growth intensifies almost every important problem with which humanity wrestles today." But even thirty years on, this fact has yet to appear significantly on any political platform or agenda.

Shaping the future

We may learn from the past, but we can never live in it. We are designing the future through our present decisions and actions. It is the world our children, and our descen-dants will inhabit. Making decisions now on crucial issues will define how and how well they will live. If we are to have a hand in shaping a rational future within the inevitable limits of Earth's finite resources, the time to do so is now. Planning is not a mysterious unfathomable process; rather it is, as Professor Kirby Warren of Columbia University said "essentially a process for making today's decisions with tomorrow in mind."

The Cassandras

We have made a number of sobering predictions. But, as Hardin (1985) wrote, "It may be tragic that Cassandra's predictions are so often rejected…. Most of life's decisions are made on the implicit assumption that the future will be much like the past. This has been a winning strategy for eons of time…. How can people believe in a prediction of an event that has never occurred before? The acceleration of science and technology ensures that more and more often Cassandra's predictions will be of the kind that raises this hard question."

Cassandra was a mythical Greek seeress who was given a curse that although *she spoke the truth*, nobody would believe her. The term "Cassandra" is now widely and incor-rectly used to discredit people who bear bad news that turns out not to be true. But the mythical Cassandra always proved correct. Policymakers and the public ignore the Cas-sandras at their peril. They should be respected for their foresight and their willingness to be criticized for stating unpopular but irrefutable facts.

Realists

Currently the terms "optimist" and "pessimist" seem to be the only two options we have to characterize the way people view the future. But the time is overdue when we should have a third option of the "realist," to describe those who try to present the facts of the situ-ation objectively. Rarely does argument change minds, but knowing the facts might.

Unique times — and the future

In various contexts throughout this volume, we pointed out that we live in unique times, unlike any in the past, and unlike any times are likely to be in the future. We look upon today as the normal state of things. The truth is quite the contrary, and as a framework to understand both the present and what may lie ahead, it cannot be overemphasized.

We have developed technologies that enabled us to exploit the Earth's resources to a degree never seen before. We have drawn on the past and also mortgaged the future of people for centuries to come by degrading the vital renewable resources of soil and freshwater, not renewable within the span of several lifetimes.

By small increments, a future of less and a future of many changes is now arriving in the industrial and developing countries. It is unlikely there will be catastrophic changes in lifestyles and economies. But inevitably, the related problems of resource depletion and population growth will become increasingly apparent and disruptive. By recognizing this now, we could avoid some of the unhappy results.

Many people now living will see the year 2050. The twentieth and twenty-first centuries, in their beginning and ending, will be vastly different from any other back-to-back centuries the world has seen, or probably ever will see. Just as those alive in 1900 could not have foreseen the changes that occurred in the next 50 years, we cannot foresee the changes that will occur in the next 50 years. But it is safe to say that energy and population will be among the most prominent things to change. Perhaps the most difficult thing to visualize is what sort of social structures will arise in response to the new resource and energy paradigm. What we do know is the changes are likely to be profound. Because increasing depletion is a new paradigm, history offers no guidance on the future.

The twentieth century witnessed the rise of the nonrenewable resource-based industrial economy. In some respects, the twenty-first century will be like the twentieth century in reverse. Instead of being able to divide up more and more oil, natural gas, groundwater supplies, and fertile land, we will be dividing up less.

Tempering expectations with realities

For all the media enthusiasm about the near future in the realm of alternative energy sources, the realities should also be recognized. In a gathering President Carter called at the White House after the first oil embargo crisis of 1973, the convened group predicted that if action were taken then, by the year 2000, solar energy could provide 25 percent of the nation's energy needs. By 2009, it provided less than one percent. Fossil fuels, oil, coal, and natural gas are likely to remain the dominant fuels in our energy mix in 2040, and perhaps later. But the depletion of these fossil fuels without being replaced by renewable sources will soon be apparent.

One of several examples of the need to temper expectations with realities is the enthusiasm for biofuels or electricity. And to use these fuels to replace petroleum and the internal combustion engine for transport needs.

Biofuel production is water-use intensive. Recent studies show that the entire production cycle — from growing irrigated crops on a farm to pumping biofuel into a car — can consume 20 or more times as much water per mile traveled than is consumed in the production of gasoline. Scaling this up to the 2.7 trillion miles that U.S. passenger vehicles now travel a year (even more with a growing population) would make water demand a limiting factor.

Electric cars may be an answer for urban driving, but present a problem in more rural areas where long-distance travel is common. Also, battery replacement and battery disposal for electric vehicles will add costs. For the much heralded lithium-ion battery, the world supply of lithium may be a long-term limiting factor.

It is difficult to do only one thing. Every action impacts other things. Economic and technological trial and error will determine future vehicles and the fuel(s) to energize them.

Priorities

Present priorities in policy and in the ways money is spent will have to change. In 2009, an astounding $1.5 trillion dollars was spent for military purposes around the world. What sort of "civilization" have we achieved? That wealth could be used to discover the means to a sustainable renewable resource future, or in medical research to enhance quality of life. Our priorities greatly need adjustment. We are misallocating the *non*renewable resources we still have. Time is short to spend our limited inherited resource wealth wisely.

Materialism and what is important

Many studies indicate that individuals worldwide believe the most important values are not material. They are caring, compassionate, and have a reverence for human life and intellect. Whether one believes we are a special creation or a product of what evolutionary biologist Loren Eiseley so well described in his classic book, *The Immense Journey* (1962), life is a gift to be cherished. Continual strife with its enormous suffering and loss of life and waste of huge material resources is human folly at its worst.

Energy to 2060?

Looking out to the year 2060, Royal Dutch Shell Chief Executive Officer, Jeroen van de Veer, said "Long-term energy demand will double between now and 2060 because of population growth." To meet this demand only from oil, an estimated $1 trillion annually would have to be invested to increase world oil supply by 64 million barrels a day. Comparing this to Saudi Arabia's projection that they might be able, as the world's largest oil producer, to sustain a daily production of 12.5 million barrels, means adding more than five times the projected Saudi oil production, and allowing for current oil field depletion. It seems obvious this cannot be done, and whether the possible sources of renewable energy -- wind, solar, and all others (tides, waves, geothermal, etc.) -- can fill this looming gap, is also highly unlikely.

Heinberg (2009), in his comprehensive study of most of the known energy sources, concludes:

> …there is little likelihood that either conventional fossil fuels or alternative energy sources can reliably be counted on to provide the amount and quality of energy that will be needed to sustain economic growth — or even current levels of economic activity — during the remainder of the current century.

The National Petroleum Council (2008), in a 585-page comprehensive study of energy requested by the U.S. Department of Energy, concluded that the entire spectrum of energy sources will be needed to reach 2030 without a crisis in energy supply.

Infinite energy not the ultimate answer

Even if we finally achieved infinite power from fusion, it would not assure the future of humanity. In fact, an infinite supply of energy allowing a huge increase in population would be very much a negative by enabling further destruction of the environment.

Energy has been essential to maintaining or increasing standards of living. But the ultimate resources are fertile soil and freshwater. It might be argued that infinite energy could desalinize as much ocean water as necessary for freshwater supplies. But no amount of energy can replace fertile topsoil with its essential organic component, humus. Soils around the world are under great stress from over-cropping, over-grazing, or over-building. Alternative forms of energy will not solve the problem.

Length of current level of industrial civilization

Using total energy use per capita as an index of the beginning of our present industrial civilization, Duncan (2005) places the date at 1930. At that time, total energy production began to outstrip population growth chiefly because of strong growth in world oil and gas production. This fostered an unprecedented expansion in production output by industrial societies. Total energy production per capita, however, reached its maximum in 1979. From then on, the per capita output paralleled population, "running neck to neck," until 2007. Energy production from oil and natural gas was then briefly slightly ahead of population demand due to the world economic downturn. Duncan projects that energy production following the economic downturn may run slightly ahead of population demand for a few years beyond 2007, but after that, total energy production will be outstripped by population growth and demand, and continue to decline to 2030. At that time, Duncan projects total per capita energy production will fall back to its level in 1930. When total energy production can no longer meet growing population demand in industrial societies, people will revert again to a more agrarian lifestyle. Thus, Duncan estimates modern industrial civilization has a lifespan of approximately 100 years from 1930 to 2030.

The scale of things is becoming unmanageable

The huge and continuing rise in size of population has created an unfortunate reality — the scale of things has reached a point in many situations that the problems are so large they have become unmanageable, inducing what Smail has called "scale paralysis."

There are an increasing number of examples. One is the volume of raw sewage dumped into the rivers of India and China. Stone (2008) reports that each year, 30 billion tons are dumped in the Yangtze River, 4.5 million tons for every kilometer of river. Most of the world's people now live in cities. The analogy has been drawn that cities are like feedlots. In multimillion-person cities including Shanghai, Cairo, Mumbai, Lagos, London, Mexico City, Paris, Tokyo, Rome, New York, Chicago, San Francisco (and the Bay Area), and Los Angeles for example, huge amounts of food are imported from farmlands near and far where they are converted into huge quantities of human waste to be exported. But to where? Some cities have efficient sewer systems, some do not. Forty percent of world population has no access to sewers, and millions of gallons of raw sewage are put daily into the remaining already degraded wetlands and rivers, sometimes called the Earth's kidneys. They can no longer absorb it all. The scale of this universal human pollution problem is beginning to grow beyond what nature can effectively recycle back into the environment (George, 2008). Severe problems exist with a world population of seven billion today. Coping with an expected nine billion people in 2050 deserves planning now.

One example of how problems are growing beyond governments' capacity to deal with them is India's province, Uttar Pradesh. Lucknow is the capital city of that province. "Lucknow has attracted hundreds of thousands of migrants from rural areas swelling the city's population. Yet the city hasn't completed any major sewage infrastructure since before the country won independence in 1974. As much as 70 percent of residents don't have sewage services leaving much of the waste to flow directly into the main river, the Gomti, which has become a stinking cesspool. Much of Lucknow's rubbish is left to rot in piles or strewn about in residential neighborhoods" (Barta and Pokharel, 2009). Since 1979, the slums around Lucknow have quintupled, and most people have neither sanitation nor water services. Clearly, the main problem is too many people.

At all levels of government, we are seeing "scale paralysis" because the size of prob-lems continues to grow as the population increases, and the scale of problems becomes unmanageable at all levels of government. As Hardin (1993) wrote, "Human Population: Growth Outruns Solutions."

G8 Nations — "Growth"

In response to the global economic meltdown that began in 2008, the G20 (Group of Twenty) was formed consisting of the leaders of the 20 largest and richest developed and emerging economies. A summary statement of their objectives was printed in the *New York Times*, November 16, 2008. The primary objective, variously phrased, was to "restore global growth," to enhance "economic growth," to foster "sustainable growth," and "stimulate demand." In total, the term "growth" appears nine times in the stated objectives.

The reality that the world faces finite and depleting Earth resources with a growing population was ignored. Each country's citizens were urged to consume more. Wherever the term "growth" was use, the G20 group meant to encourage continued expansion of consumption of material things to keep industries growing, businesses expanding, and to provide more jobs for a growing population. That "sustainable growth" is an oxymoron was apparently never understood. Continued growth in the consumption of nonrenewable and renewable natural resources, especially by the G20 nations themselves, is the problem, not the solution. However, at the G20 meeting in 2009, the group called for each nation to implement a policy for "strong and balanced growth."

"It seems that governments will listen to economists, the vast majority of whom are concerned only with growth, irrespective of the environmental cost…. It seems ironic that, with all our highly-evolved intelligence, we can indulge in mass self-deception that economic growth and increased complexity of society is the only way to solve our problems. This only encourages that oxymoron called *sustainable growth* when our resources are now so obviously limited" (Desvaux, 2009).

But the G20 agreed to, " … use fiscal measures to stimulate domestic demand…." The U.S. tried this approach in 2008, printing $160 billion dollars and distributing it to a selected segment of the population, encouraged by the president to go out and "spend it," to buy more "things." This failed to help the economy, so an even larger "stimulus package" of $787 billion was signed into law in 2009, partly designed to "restore demand," with more consumption of everything. If there is one thing that a finite Earth and its already degrading environment does not need, it is more demand. Yet almost all developed and developing nations (China included) established "fiscal stimulus packages" to promote more consumption. In the internationally read magazine, *The Economist*, a January, 2009, issue carried an article, "Accelerating Downhill: Why China and Germany need to do more to boost demand." These were already, respectively, the two leading consumers in Asia and Europe. China now equals or exceeds the United States in the consumption of many commodities.

China, capitalism, and global reach for Earth resources

In 1978, Chinese Premier Deng Xiaoping launched market-based reforms in Communist China. This trend has grown, fostering new enterprises in China, bringing it to the point of being a *de facto* industrialized nation, now in the G20, but not yet in the G8. Though still a nominally Communist country, China has encouraged private enterprise, joint investments with national companies, and has developed a stock market. China merged these elements with its mass cheap labor, but needs increasing amounts of energy and mineral supplies to continue to industrialize. It lacks enough of these resources, and now reaches across the globe to secure them through investments and joint ventures. China imports Earth resources from Australia, Algeria, Angola, Azerbaijan, Canada, Chad, Ecuador, Egypt, Kazakhstan, Indonesia, Iran, Mongolia, Myanmar, Niger, Nigeria, New Guinea, Peru, Russia, Saudi Arabia, Sudan, Syria, Thailand, Venezuela, and Vietnam, as well as other countries. China has become a major, if not *the* major, competitor for the remaining Earth resources.

China and the brief world interval of industrialization

China illustrates the general problem that unsustainable resource demands driven by industrialization place on the Earth. In a study by the Chinese themselves (Oster, 2008), they reported, "China is using double the amount of water, land, and other natural resources that its ecosystem can provide over the long term." The report also notes the impact of China's resource demands on the rest of the Earth, saying, "In the next 10 to 20 years, China's consumption will likely continue to pose threats to China's own ecosystems and place increasing pressures on global biocapacity."

The exploitation by the industrialized world, together with those striving to become so, will greatly diminish the Earth resource base on which industrialization has been built, bringing that brief interval to a close this century. As Paul Krugman (2008) wrote, " … the good times may have just stopped rolling."

Total energy per capita peaks

Peak United States energy use per capita was in 1973, and since 2000, it has gone down quite rapidly. Whatever U.S. gains may have been achieved through increased energy supplies, efficiency, and conservation, they have been more than offset by increased demand from population growth. The U.S. is now the only industrialized nation experiencing a significant annual increase in population. The additional three million each year that need more food and other forms of energy, as well as material things, must now be increasingly supplied by massive imports, financed by a concurrent increase in international debt. Domestic resources cannot meet the demand, raising the question of how large and crowded the U.S. wants to be. Is there any logic or any value in continued population growth? This question is seldom discussed in U.S. political forums.

In the developed 30 OECD nations, the historic maximum per capita total energy consumption appears to have been reached. The calculation for the world is still slightly rising, based chiefly on growth numbers in China and India. In other countries, many in Africa with high rates of population growth, per capita total energy use is going down, indicating a declining standard of living. This is already evident in food shortages, including famine in parts of Ethiopia, The Democratic Republic of Congo, Somalia, Sudan, and others. More than 27 countries now depend on imported food, including the United Kingdom and the United States. By any estimates, the future seems certain to be a future of less.

Living on the pale blue dot

We are the first generation of humans to see the Earth from space, a tiny pale blue dot floating on the sea of the infinite, very much alone and finite, "a lonely speck in the great enveloping cosmic dark" (Carl Sagan, 1980). The Mars Society enthusiastically promotes colonizing Mars as a home for the Earth's surplus population. But Mars is far from being a viable alternative. Among the key differences, Mars has very little atmosphere with no oxygen and what atmosphere exists has a pressure only about one-tenth that of Earth. This means that without wearing an oxygenated pressurized space suit at all times, anyone getting out of a space suit would have no life-sustaining oxygen to breath. And, because of our internal adjustment to atmospheric pressure at sea level of 14.7 pounds per square inch, we would explode.

U.S. Viking 1, after a six-month trip, reached Mars during the Martian summer. Its instruments reported that in the heat of the day there, the temperature was -31° C (-24° F) and the low just before sunrise was -86° C (-123° F). At times, the entire planet is engulfed in dust storms with winds reaching 130 miles per hour or more. No valuable mineral resources were detected. What can a human do under such adverse circumstances that a robot, much better able to stand extremes and needing no oxygen, cannot do, and at far less cost than the manned flight National Aeronautics and Space Administration (NASA) has proposed? Adding it all up, one dissenting NASA astronaut simply asked, "Why go?"

Those enthusiasts who talk about "terraforming" Mars to give it a more Earth-like environment admit that, if feasible at all, this would be a colossal, multi-generational, multi-civilizational undertaking likely lasting thousands of years. Mars has a surface area only one-fourth that of Earth's. Given that a key justification for Mars colonization is overpopulation, environmental degradation and resource depletion here on Earth, increasing the area available for human habitation by 25 percent would provide additional "elbow room" for a population growing at say, one percent, by about 20 years. This assumes that tens of millions could be transported there affordably. It hardly seems worth the thousands of years and trillions of dollars that terraforming would take.

Toward the Sun, our nearest planetary neighbor is Venus, which has an atmospheric temperature of 470° C — considerably higher than the boiling point of lead. The atmosphere of Venus consists mostly of carbon dioxide (indeed, it is described as having a "runaway greenhouse effect") and nitrogen, again, free oxygen (O_2), is conspicuously absent. What we enjoy seeing from Earth as a lovely, bright "evening star" after the Sun has set, is actually enshrouded by dense clouds of sulfuric acid. Not even the wildest dreamer fantasizes of ever trying to terraform Venus. We are indeed a pale blue dot alone in a great expanse of space. Appreciate and consider for a moment how unique and wonderful the planet is on which we live!

Finding a planet comparable to Earth anywhere else in the universe has been difficult. The nearest star is four light years or about 24 trillion miles away (a light year is the distance light travels at the speed of approximately 186,000 feet a second in a year). It has no planets. The nearest Earth-sized planet outside our solar system discovered recently by the NASA's Kepler Mission is 950 light years away and would take a space shuttle 36 million years to get there. We are alone indeed.

The iconic photograph of Earth taken December 7, 1972, by the astronauts on the Apollo 17 Mission — a planet with blue oceans, swirling patches of white clouds, and green and brown continents — adrift in the black vastness of space played an important role in accelerating the appeal of the environmental movement in the 1970s. Later, the image of the Earth as a finite, pale blue dot taken by the satellite Voyager I from four billion miles away, as it approached the outer edge of our solar system, reinforced the concept of finitude in the face of infinity. The reality of a finite Earth is the perspective we need to keep in mind as we see a growing population rapidly depleting our resources. Population growth and living standards are now in an inverse relationship. This important fact is largely ignored, but the reality is increasingly obvious.

Problem — adjusting developed economies to a future of less

The furor in the G20 countries created by a drop in the growth of consumption during the economic meltdown that began in 2007, is evidence that transitioning to a no-growth economy and a stable (lower) population as a start toward a sustainable future will be exceedingly stressful. The changes necessary are not politically attractive. It may require changes in the kinds of jobs we have and in our standard of living.

Few officials in developed nations have the courage to tell their citizens they have to make an orderly and inevitable adjustment to a future of less in order to reduce resource consumption. It is possible, and in some places, "frugality" is once again becoming a respected lifestyle.

Although "economic growth" may be temporarily restored among the G20 nations and perhaps others through various "stimulus" packages, economic growth cannot continue indefinitely. Grant (2007) visualizes the adjustment period ahead as a "turbulent century." He says, "We live between two mutually uncomprehending worlds. Scientists are documenting the rising damage that increasing human activity is causing the natural systems that support us, but mainstream economists regularly call for more growth and more economic activity."

A time for growth — then. And now?

At one time, growth was an acceptable, even a desirable economic goal, and standards of living were raised for millions of people. In 1750, at the beginning of the Industrial Revolution when the world had an estimated population of 700 million, growth was a worthy economic goal. In 1850, when world population was estimated to be 1.2 billion, and even as late as 1900 when population was 1.6 billion, there was room for more growth in terms of land, resources, and population. But, that was then, and this is now. In one century, we have quadrupled world population, and still it is growing. The time for increased "growth," "demand," or "consumption" is over.

Re-orienting the direction of economies and capitalism

Capitalism is based on the concept of private ownership, wherein economic decisions are made by individuals rather than by the state. Drawing upon talents of individuals, capitalism has been a vital force in the advancement of civilization. Also, since it respects the individual, it has been the basis for democracy as well.

However, no one ethic or economic system will always fit changing circumstances. In the case of the economy we have, the continued exploitation of nonrenewable resources, especially including fossil fuels, but also of renewable resources such as freshwater and fertile soils, are unsustainable paths. The vibrancy of individual talent and the financial resources that characterize capitalism henceforth will have to be more socially sensitive and directed toward developing all aspects of a sustainable society, including energy sources, and preserving the environment that sustains us. It is interesting that China, nominally a communist country, has increasingly moved toward free enterprise and private investment recognizing the vitality these forces give to an economy. To try and advance a sustainable population, China has adopted a "one child" population program, not entirely successful so far, but helpful in the face of a still-growing population of 1.3 billion.

Re-directing capital toward the environmentally sustainable exploitation of limited Earth resources is a very large challenge given the continued increase in population. Capitalism needs to recognize and work toward this goal in as orderly a way as possible.

Lamm (2007) makes this observation regarding the need for a new economic model:

> We cannot solve growth-related problems with more growth, we must move to sustainability. It took a billion years or more for nature to create the limited stocks of petroleum and mineral wealth that modern technology and human ingenuity have recently learned to exploit. But we are squandering our one-time inheritance of cheap energy and handy resources. The models so painstakingly developed over 300 years to create more jobs and more goods and services, must be dramatically modified.

It is noteworthy that considerable capital and talent is already being directed toward developing renewable resources, primarily energy. And, as happens in a free enterprise economy, the market will gradually sort out which ventures are economic and sustainable and which are not. Both failure and success are part of that system, even as they have been over the ages in the evolution of organisms to adjust to changing environments.

The statements from the G20 calling for more growth reflect current values in the world economies that now depend on consumption. However, it is possible the "good life" can be constructed from a renewable natural resource base with many things of value that are not measured by the GDP. As many have learned, "more stuff" just means more things to look after, and may not produce more happiness. Even in the midst of our affluent lifestyle, some people are "downsizing" and finding pleasure in a simpler life. It may be the beginning of a trend. High-consuming economies, especially, need a change in values that will lead to a change in behavior in which natural capital is valued more than material accumulation.

Capitalism, to meet the coming realities, will have to evolve into an economic system embodying the concept of the preservation of natural capital for a sustainable future. In this economic form a much smaller and stable population would enhance the individual's identity and dignity, and yet continue to build on the talents of entrepreneurial individuals.

Jared Diamond in his book, *Collapse: How Societies Choose to Fail or Succeed*, (2005) concludes that collapse is the fate of societies that do not integrate themselves with ecological limits and the limitations of their available resources.

The world is entering a huge momentous transition in countless ways. The illusions of mainstream economists and politicians who want to continue "growth" indefinitely, are going to conflict with the reality that Earth's resources are ultimately in control. The scale of our demands on these resources cannot now sustainably be met by that finite pale blue dot. Colonizing other worlds to maintain the scale of our population or to pursue growth in any form are futile illusions advocated by the Mars Society and a few others.

Columnist and bestselling author, Thomas Friedman (2009), in an article in the *New*

York Times titled "Inflection is near," made the following comment on the worldwide financial crisis:

> What it is telling us is that the whole growth model we created over the last 50 years is simply unsustainable economically and ecologically and that 2008 was when we hit the wall — when Mother Nature and the market both said 'No more.' We created a way of raising standards of living we can't possibly pass on to our children.... We have been getting rich by depleting all our natural stocks, water, hydrocarbons, forests, rivers, fish and arable land — and not by generating renewable flows. But it had to collapse unless adults stand up and say, 'This is a Ponzi scheme. We have not generated real wealth....' Real wealth is something you can pass on in a way that others can enjoy it.

Friedman quotes Glenn Prickett, Senior Vice President at Conservation International, "Just as a few lonely economists warned us we were living beyond our financial means and overdrawing our financial assets, scientists are warning us that we're living beyond our ecological means and overdrawing our natural assets." Environmentalists have pointed out that "Mother Nature doesn't do bailouts."

In ancient times, the ability of a community to survive depended on how much life-sustaining resources within walking distance could be collected daily (including some for storage in winter, or to guard against crop failure). When those resources could not be obtained, communities either starved or migrated. Now, with the aid of fossil fuels, chiefly oil, providing worldwide transport with no seasonal constraints, industrialized countries and those seeking to become industrialized, are able to plunder the resources of the entire world. But even there we are encountering limits, as aptly observed by Krugman (2008), "We are running out of planet to exploit."

Less materialism

Commenting on the importance of smaller communities as an essential viable part of the future, Murphy (2008) wrote, "When the cheap and easy fossil fuels became available, the value system of affluent humanity moved from an orientation of community relationships toward the acquisition and consumption of material goods. We no longer became citizens — we became consumers. Plan C brings us back to a focus on community."

In the future, there will be more localized economies, as international trade in Earth resources and energy supplies (petroleum and coal), in particular, shrink or no longer exists and communities have to depend on local resources.

This view is also expressed by Australian academic, Ted Trainer (2007), in a chapter titled "The Simpler Way," in which he enumerates as some of the principles:

> Material living standards must be far less affluent. A very different economic system must be developed, one that is geared to needs of people and ecosystems, therefore not driven by market forces or the profit motive (although it might have a place for them). It must be an economy operating with the minimal levels of production and consumption necessary for a high quality of life, with a much lower GDP than the present economy, and without any growth. There must be mostly small scale highly self-sufficient local economies. We must shift to some very different values...and toward possible frugality.

If Murphy and Trainer's visions of future survival through means of smaller communities becomes a reality, one has to wonder about the viability and fate of major population centers, such as New York, Los Angeles, London, Tokyo, Shanghai, Mexico City, and others. In the post-petroleum paradigm, these centers may be the first impacted.

As Trainer points out, alternative energy sources, which will be the norm in the future, cannot sustain the affluent society as we know it now in its size and massive consumption of resources. Murphy (2008) adds "The hope for a renewable-energy future in which Americans can live just as profligately as they have in recent decades is simply the blissful fantasy of children."

Chapter 30

True Wealth, GDP, Encouraging Trends, and Education

The strains that developed in major economic systems around the world in the early part of this century made it more evident that Earth resources are the base from which all wealth must come. Increasingly paper-based economies began to falter, and in the case of Greece, to essentially collapse.

Printed "money" and the illusion of wealth

In the worldwide "recession" that started in 2007, governments printed large quantities of paper "money," promoting the illusion of security and wealth. But it is not possible to print more copper, zinc, oil, soil, water, and other Earth resources. "Money" in any form simply allows the holders to acquire Earth resources, which are the only true form of physical wealth. People can buy food, but in fact, they are drawing on fertile soil and freshwater. Without these, there would be no food, and money would be worthless. Whether there is more food in the future does not depend on how much money is printed, but how much food fertile soil and freshwater — the basic wealth of any nation — can produce.

Printed "money" is simply a claim on true wealth. Printing more "money" increasing "financial assets" on corporate and personal balance sheets creates an illusion that more wealth is being created. But increasing the amount of "money" only means that the resource pie is divided into smaller pieces. The size of the pie remains the same. And unfortunately, the pie to be divided is actually getting smaller.

Walter Hickel, former secretary of the Department of the Interior, which includes the U.S. Geological Survey and the former Minerals Management Service, once said, "There is no wealth without production. Someone has to dig a hole (mine or drill), catch a fish, or grow a bushel of grain. Manipulation of money does not increase the wealth of a nation. Money is not secure wealth."

An illustration of the difference between true wealth based on Earth resources, and paper "wealth," is the contrasting circumstances in 2010 between two of the United Arab

Emirates. Dubai based its future on selling financial services. The financial structure called Dubai World, with debt financed by Dubai, built towering office structures to house these financial operations. But Dubai had very little oil, arable land, or water, and, therefore, no true wealth to back its finances. In contrast, Abu Dhabi had large amounts of oil to sell, and from previous oil sales, had accumulated a Sovereign Wealth Fund worth more than $70 billion. When real estate values fell 50 percent, Dubai World and Dubai suffered a financial meltdown. Abu Dhabi was essentially unfazed. In 2009, Abu Dhabi, with its resource-based wealth, agreed to loan Dubai five billion dollars to aid the recovery of its paper-based economy.

Printing, distributing, and shuffling financial investments of various kinds are not true wealth-producing activities. Farming, fishing, mining, and sustainable forestry are. Saudi Arabia would surely prefer abundant fertile soil and freshwater supplies more than money from the U.S. or any other country. This puts money, especially paper money, in proper perspective. No amount of it can assure a sustainable future for humanity, similar to properly managed fertile soil and freshwater supplies. In many countries this reality is already apparent. As populations increase, it will be apparent to many more. Libya, with only 1.03 percent arable (farmable) land and a 54 percent increase in population expected by 2050, surely would like more fertile soil and freshwater. Oil-rich Kuwait has only 0.84 percent arable land. The thriving principality of Monaco has zero percent arable land, and is entirely dependent on arable land elsewhere. Without the "elsewhere" fertile soil and freshwater, Monaco's residents would starve in spite of all the money in their casinos.

The reality that real wealth resides in Earth resources will become clear this century. In "a letter from the future," Richard Heinberg (2007) writes, "With the exhaustion of fossil fuels *no* technology could have maintained the way of life that people had gotten used to."

Putting a perspective on wealth

To provide a perspective, one only has to contrast the money-managers of financial centers with the farmer in the adjacent countryside. For all the "wealth" handled during each day, in the evening of each day the money-managers must go home for supper. The farmer, from his fields, does likewise. If it weren't for the farmer the money moguls would have nothing to eat, and would starve. The farmer would still be fed. In the end, the money managers cannot eat the paper "wealth" they shuffle each day. Money managers may buy and sell commodities such as metals, oil, natural gas, coal, lumber, grains, cattle, hogs, and orange juice. But the geologist must find and the engineers must extract the minerals from the Earth, and the farmer and forester must produce and then harvest the biological wealth produced from water and soil. Without these, money managers would be out of business. Earth resources have final control, and those who find and produce these resources are the true wealth creators. Those making huge profits in the world's financial systems should keep this humbly in mind.

Various economies and cultures operate at different levels of consumption of Earth resources. Low-productive economic systems may draw mostly from local or regional resources, and support a relatively low standard of living. Highly productive economies such as those in the developed world draw from resources they have, together with more and more resources from other parts of the world, and support a high standard of living. Debt is a claim on the ability of economies to generate wealth in the future, and this in turn depends on the ability of future economies to obtain the energy and other Earth resources needed to keep their economic machines running.

If these resources cannot be produced to meet the debt demands, the debt instruments (government and privately issued bonds, for example)~~,~~ will become worthless, or else simply "paid" by printing paper called "money," backed by nothing tangible and~~,~~ therefore~~,~~ also likely to become worthless. Debt assumes that wealth will be produced later to pay the debt.

The G20 program to increase demand and continue to "grow" economies eventually will meet with the reality of rapidly depleting Earth resources, but apparently this has not yet been considered. It is doubtful that developed world economies will ever again be in the same condition that we have seen them up to now. Whether recognized by political and industrial leaders or not, a new economic order is emerging incrementally from the control that limited Earth resources have over nations and individuals.

Need for a new view of "growth" and a corresponding index

The "economic crisis" that spurred the meeting of the G20 group of nations was caused by a drop in the Gross National Product (GNP) of the various nations. The GNP; also called the Gross Domestic Product (GDP), is now the common measurement of national economic health. GNP always has to go up, and only a slight downturn in that trend is an "economic crisis" to be dealt with at all costs, such as simply printing money, despite the resulting inflation and depreciation of the currency. Suzuki (2000) notes "Governments will turn somersaults to try to keep the GNP going up."

The GDP is widely considered an index of the overall health of a nation's economy and society's well-being. But this index has only enhanced the illusion of wealth, which in turn, has misdirected public policy as well as individual actions. For example, if we could cut down all our forests and catch all the fish in the oceans in one year, and then sell the product, this would greatly increase the GDP. Presumably this would make governments (political leaders) and their economists very pleased, and no doubt would be happily announced by the politicians in power. But the environmental costs would dwarf the brief bump in the GDP figure.

Reinforcing the view that the GDP index is neither a very useful nor accurate measure of the general *welfare of a nation*, Warner (2009), observes:

> The basic problem is that gross domestic product measures activity, not benefit…. Common sense tells us that if we want an accurate accounting of change in our economic well-being, we need to subtract costs from benefits including those of ecosystem services when they are lost to development. These include storm and flood protection, water purification and delivery, maintenance of soil fertility, pollination of plants, and regulation of our climate on a global and local scale. One recent estimate puts the minimum market value of all such natural capital services (globally) at $33 trillion annually. GDP represents gross domestic transactions and few people would mistake a measurement of gross transactions for a measurement of general welfare. We need a new measurement. 'Call it net economic welfare.' GDP…is a miserable failure at representing our economic reality.

Using GDP (selling more, buying more, consuming more) as an index of progress is illusionary, and leads us into unsustainable short-term behaviors detrimental to a sustainable long-term future.

Grant (2007) writes, "There is no necessary connection between rising GNP and rising well-being…. On the other hand, GNP includes many things that offer no pleasure in themselves but are necessary in complex societies — things such as urban infrastructure costs, parking meters, superhighways, and security systems." Costs of all these become part of GDP. Cost of irrigation systems become part of GDP, but no value is assigned to rain, which can replace irrigation systems and, therefore, would be beneficial. Grant continues, "If China's GNP accounting follows these rules, its remarkable recent GNP growth is thus in part an artifact. It documents what is happening to the modern sector, but not to the resource base (rapidly being diminished by soil erosion and drop in water tables), or to the majority of Chinese who are down on the farm, except as they send young people to work in factories."

GDP largely measures what is produced today and winds up in the landfill tomorrow, to be replaced by the GDP of the following year, measuring the same thing.

If the G20 is wedded to the concept of "growth" and wants to continue using it as a happy word, then a different measure of growth should be used. It should include the health of the environment, its sustainability, the health of individuals, the degree of social stability — or unrest — and the happiness of a population in its current circumstances. Are we gaining or losing from these perspectives, with a view toward what human life will be like in the future?

France made a noteworthy move toward considering something beyond the commonly used GDP measure in 2009. President Sarkozy urged other countries to adopt gauges of well-being in addition to GDP. Sarkozy said that new measures were needed in the wake of the financial crisis triggered by an over-reliance on the free-market, and declared: "If the market was the solution to all problems and was never wrong, then why are we in such a situation? We need to change criteria."

The commission convened by President Sarkozy said that in the longer term, governments must pay more attention to sustainability to determine what level of well-being can be maintained for future generations. President Sarkozy urged the G20 to take up the commission's recommendations. Commission member and Nobel Prize winner in economics Joseph Stiglitz observed: "What we measure (by the GDP) affects what we do. If we have the wrong measures, we will strive for the wrong things." In his 1968 Presidential Campaign, Robert Kennedy complained that the GDP "counts napalm and nuclear warheads." It also counts bombs, fighter and bomber planes, tanks and artillery pieces as part of GDP. Whether these contribute to human welfare might be debated. As such, the GDP does not reflect very well the total health and welfare of the citizenry, only the value of what is produced regardless of its ultimate use.

The commission convened by President Sarkozy did not propose a single composite indicator to replace GDP, but suggested that each country design its own basket of indicators. At the same time the group met in France, an organization of the world's largest banks urged the G20 to maintain economic-stimulus programs. Presumably, this would enhance global GDP, produce more "stuff," and make everyone happy.

Genuine Progress Index/Global Progress Index

A different index of well-being to replace GDP has been suggested by a few forward-thinking people, who call it the GPI (Genuine Progress Index). This index could be used by individual nations and then the world as a whole, and the name changed to the *Global* Progress Index. It would be a truly revealing measure about whether humanity is gaining or losing on prospects for a successful future. The existing GDP index actually measures just the opposite, the unsustainable rate at which we are consuming Earth's resources. The enhancement of natural capital or just its preservation in the form of the environment should be considered in the Global Progress Index. The value of natural capital can hardly be overestimated. Along with examples cited elsewhere in this volume should be added such things as the more than 300 disease-fighting drugs potentially available from the world's flowering plants, more than half of which live in tropical rainforests (Mendelsohn et al. 1996). Instead, we are destroying the world's rainforests to temporarily increase the GDP of the nations, which are custodians of these riches.

"People derive an extraordinary range of material benefits from the healthy ecological function of diverse plants, animals, and associated habitats … . Agriculture especially depends on the ecological services of many wild creatures including bees, wasps, butterflies, and other invertebrates. Some 130 agricultural crops in the United States depend on the pollinating activities of wild species" (Kellert, 1997). All these and many other values could and should be included in a Global Progress Index, giving us a measure of a sustainable economy, which GNP does not provide.

Kellert (1997) writes:

> The capacity of many creatures to survive has declined precipitously as a consequence of the large increase in human population including technological advance, excessive resource exploitation and escalating consumption of space and material…. Destruction of natural habitat constitutes by far the most important factor. Particularly damaging activities include large-scale agriculture and forestry, excessive livestock herding and grazing, various water impoundments and diversions, extravagant mining and energy production, spreading urbanization and industrialization — and underlying all of these, rapid human population growth.

From Kellert's study and numerous others, it is clear that consumption and population must be reduced if social and economic chaos are to be avoided and life-sustaining ecosystems preserved. This is exactly the opposite of what the G20 proposes to solve the world's economic problems. The G20 remedy of "more growth" may have been a successful policy in the nineteenth and early decades of the twentieth century. But today, it is an economic paradigm that can no longer be accommodated with the huge rise in world population, and the related massive depletion of both nonrenewable and renewable Earth resources. Nevertheless, the G20 continues to pursue what is now an artifact of history.

Denial

One of the things Americans want from government is to keep things as they are. They want to maintain their relatively pleasant lifestyle without major changes. The inevitability of change is not part of the public consciousness. The public is in a state of denial in this regard. Congress spends most of its time on current issues. The most fundamental relationship, that of resources and population, and the continuing destruction of the environment that is the basis for human existence, are low on the agenda. They are not pleasant topics to discuss, because resolving these problems ultimately requires a change in current levels of consumption. It would disturb the voters, and, therefore, these basic trends are ignored. Only when public awareness of the importance of these matters rises and is conveyed to Congress, will the agenda be revised.

Fortunately, there is some evidence this is beginning to happen. Various groups are becoming aware of the finite nature of fossil fuels, that world production of our single most important current energy source, oil, may have peaked, and that peak production of both natural gas and coal is certain to occur this century. Other groups are concerned with the environment. The important value of wetlands is finally being recognized, and there is growing opposition to converting them to subdivisions. Some wetlands are being restored. Still other groups are concerned with the impact of a rising population on the environment. We have organizations such as Population Connection (formerly Zero Population Growth), Population/Environment Balance, Negative Population Growth, and World Population Balance, all of whom recognize the fact that there is a limit to the carrying capacity of the Earth. There is hope that these organizations and others yet to form, will collectively become a significant voice in the affairs of this nation (as well as others) and be heard by the policymakers. Much of the support for these goals, however, must come on an individual basis.

Unfortunately, it is hard to convince the public to adopt different lifestyles and make other difficult and inconvenient choices that have no discernible immediate effect, but which, however, have long-term value. Thus in legislative forums and political agendas, the "tyranny of the moment" prevails. In 2008, when the world was concerned with an economic recession, Dickinson (2008) commented:

> Panic over a turbulent world economy has overshadowed strategic issues, that in the long run, will determine quality of life on Earth. Few people are willing to concentrate now on such transcendent matters as unsustainable population growth, dwindling water supplies, loss of biodiversity. Yet they amount to slow motion disasters in waiting…. In the year just now ending, world population grew about 80 million. Political leaders worry about more immediate concerns because, after all, overpopulation is a long-range problem. Except that it isn't. One-third of Africa's overloaded countries are trapped in civil wars or cycles of violent unrest. Egypt's poverty-stricken masses are near revolt. China's urbanization is depleting its reservoirs. And so on. There are simply too many people for Earth's finite resources.

The Mars Society notwithstanding, we are stuck on this planet. We can make it better and work toward a stable world population at a size that will allow generations ahead to live on renewable resources harmoniously with the environment and each other. We should spend our natural wealth not on arms and destruction, but on ways to make things better not bigger — quality not quantity (Fodor, 2001).

To survive at any reasonable standard of living, humans must move to a compatible coexistence within natural systems. As Weisman (2007) observed, the world could get along very well without us, probably even better, given what we have been doing to it. Nature is neutral on the question of whether the human race survives or not. We must design our lifestyles and economies to fit with nature, or we will not survive.

Throwaway societies and economies

The current paradigm of the developed world is to buy, consume, and discard. Some appliances are intentionally designed for a limited life. Portland, Oregon, sends 9,000 tons of waste a day to sparsely inhabited Gilliam County (population 1,800 in 2009), where the waste disposal area now occupies more than five square miles. Ironically, the landfill and related transport operations are Gilliam County's single largest source of employment. Waste disposal is a growing problem everywhere. Garrett Hardin has observed that the plight of our throwaway societies is that there is fast becoming no "away" to throw to.

A simple but striking example of our throwaway society, is the fact that *each* day, an estimated 40 million plastic containers are discarded in the United States. One need only to look at the shelves in the supermarket lined with countless plastic containers for a huge variety of products in daily use to understand how the figure of 40 million discards a day is accurate. These plastics are of two kinds, both made from natural gas. Another widely used plastic, PVC (polyvinylchloride), is a molecule that is 60 percent chlorine (from common salt) and 40 percent natural gas. Plastics can survive almost indefinitely, making for a difficult disposal problem. In the U.S., 30 million tons of various plastics are discarded each year. With continued U.S. growth in population, this figure is certain to increase. A small percentage is now being recycled, but in most countries~~,~~ plastic containers are simply discarded. The plastic trash in the streets of many cities of the world continues to accumulate.

But to keep the current form of our economies going, the industrialized world must continue to produce a profusion of goods to be absorbed by our high-consuming societies and maintain our material standard of living. The goods produced are used for a time and then discarded as trash. This "ethic" is vigorously promoted to maintain an "ever-growing economy."

A notable "monument" to this "ethic" is now the highest point in all of southern Florida — Mount Miami Trash and Garbage Pile. Having no canyon or even valley in which to dump the waste from the city of Miami, the "solution" has been to pile it UP and UP.

This is the century when a balance must be achieved between population size, renewable resources, and acceptable standards of living in the various cultures that hope to survive~~d~~. The vital relationship between humanity and the natural world is what David Suzuki calls "the sacred balance." I am considerably encouraged by the increasing number of organizations around the world committed to the preservation of the environment. Governments have established sanctuaries for marine and land animals and plants around the world. These are places that can be of great value to maintaining the diversity of life vital to preserving the environment needed for the future. Marine sanctuaries already appear to be quite successful~~,~~ and are being expanded. According to the World Conservation Union, nearly 10 percent of the Earth's land surface is now protected. It's a start. But environmental degradation continues. When people are hungry and need land and biological resources to survive, sanctuaries are invaded and often destroyed. There are examples in many regions such as in Africa and Madagascar. These refuges are repositories of critically important biological diversity that cannot be duplicated elsewhere. The obvious key to success is eliminating the destructive impacts of population growth.

The future is not a spectator sport. It envelopes each of us little by little every day. The continuing increase in resource use (depletion) caused by population growth and the aspirations for a better material life, especially by segments of the world now largely left behind, is bringing the future to us ever more rapidly.

Concern for the basics

In this century, people in the industrialized world will become increasingly concerned with the basic elements of survival, just as many in the rest of the world are already. Adequate supplies of fertile soil and clean freshwater will move up the list of priorities because they are the basics of food supply. For some living at the margin of existence, this is already reality. The leached red lateritic soils of much of Africa and loss of topsoil will make it hard for Africa to meet its food demands. Energy simply to perform cooking will be important. In higher latitudes, energy simply to keep warm will also be important – very important where winter temperatures reach the level of fatal cold. "Earth Day" will take on increasing meaning, as the control of Earth resources over basic human activities becomes more evident.

Beyond these basic survival concerns, how much of the high standard of living in industrial societies can be preserved? "Things" now seem to be essential to how we define "standard of living." Hopefully, libraries, various cultural events, and medical advances will continue to be maintained and improved. These do not depend largely on "things." Growth in knowledge is "growth" we can usefully pursue. Knowledge is a frontier we can still explore, but it depends on committing more resources to education. Not all the "things" that clog our streets and homes are necessary for a happy, pleasant life. There is evidence that a simple life might be a happier one.

The pervasive underlying population factor

Throughout this book, population size has been given a deliberate emphasis. From observations I made in more than 70 countries over a period of more than 50 years while traveling and living and working abroad, I have seen the problems caused by population growth countless times. It is this century's *number one* problem, and the root of many, if not most, of our other problems. Harvard biologist E.O. Wilson calls population growth "the raging monster on the earth." Overpopulation is degrading living standards and the environment, and putting unbearable stress on human relations in many regions. Riots over diminishing supplies of food have already occurred.

Then what is our answer to starving children with flies in their eyes on the nightly TV news? Ethically, we must try to take care of those now living. But we must also confront the problems compounded by added population the world does not need. Even our present population is not sustainable at a decent standard of living.

Comfortable apathy toward the most fundamental problem

In both developed and developing countries, most people tend to avoid thinking about, or else are unaware of the great impact rapid population growth has on quality of life and resource demand. This includes the United States, where increasingly, resources have to be imported to sustain the quality of life we wish to preserve. However, decreased air quality, water supply issues, waste disposal (sewage and landfill) problems, increased traffic congestion, crowded schools and the need for more of them, crowded health facilities, and more and more people needing more land area and resources of every kind are the obvious signs of overpopulation we see nearly everywhere. These are all reasons why the matter of population growth is fundamental to every lifestyle or resource issue. But the tough choices needed to address population issues are mostly ignored by the body politic and the general public. This delays serious progress in solving environmental, lifestyle, or social equity problems.

The problem is apathy and complacency by political bodies and the general public. This facet of human nature was evident centuries ago. Niccolò Machiavelli, advisor to public figures in what is now Italy in the 1500s, wrote in his classic *The Prince*: "When trouble is sensed well in advance it can be easily remedied. If you wait for it to show itself any medicine will be too late. Political disorders can be quickly healed if they are seen well in advance (and only a prudent ruler has such foresight), but when for lack of diagnosis, they are allowed to grow in such a way that everyone can recognize them, remedies are too late."

The best investment

There must be a worldwide commitment. The United Nations Population Fund is one international organization providing family planning information, materials, and active assistance, but its efforts are insufficient compared to the need. They are hindered by racial prejudices, religious dogma, lack of education, and lack of funds. But investment in it would probably be more useful to the future of humankind than any other.

Priorities of resource use

Resources themselves carry no inherent judgments as to how they are used. It is an entirely human decision. Oil is critical to modern economies, and has great beneficial uses in agriculture. But it has also been the basis for conducting warfare, maintaining corrupt governments, supporting a few in luxury at the expense of many, and financing terrorism and religious extremists. It buys armaments and keeps dictators in power. The gold brought to the old world from the new world was largely squandered instead of being the basis for developing healthy economies and widespread prosperity. In the lands which were looted, disease carried by the looters decimated native populations. Cultures and even entire peoples were destroyed.

More thought should be given to the proper priorities for which Earth resources are used. Should Earth's assets be spent for living it up at the moment, or invested for a long-term sustainable future? Decisions we make now will be the blueprint for much of future human existence. In the fable of the ant and the grasshopper, the ant is the one that survived.

The United States cannot consider the population problem as "their" problem. The 314 million population of the U.S. in 2012, because of its high per capita rate of resource consumption, means it has the effect of a much larger population using fewer resources. From this perspective, the United States is the most overpopulated nation in the world. In 2004, three of the world's 10 most populous countries were the United States, Russia, and Japan. By 2050, only the United States is expected to remain in that top 10 list (Population Reference Bureau, 2005). U.S. population is growing at the rate of about three million a year, and its population growth coupled with its high resource consumption, has enormous worldwide impact.

The need and use of borders

One nation can be a model for population control and plan for a decent future, but such efforts must be worldwide. If some countries implement good planning, but others do not, the push of poverty will ensure migration. The countries acting responsibly are likely to be overwhelmed. Whether borders could be enforced in such circumstances is questionable, as vividly portrayed by Jean Raspail (1975) in his prescient novel, *The Camp of the Saints*. The present inability of the United States to control its borders is an example. In the long run, the export of population is not a solution. Every country must realistically assess its resources and determine what combination of population size and standard of living it wants to achieve.

There is an inverse relationship between size of population and quality of life. Are you the happiest in traffic jams, crowded beaches, 40 children in a third-grade classroom, with long lines of people everywhere, and with the growing demand for nearly everything: water, food, fuel? Small families and stable population numbers are two essential ingredients for an acceptable standard of living and quality of life.

Ethics not immutable, but changing with the times

Generally accepted ethics of religious and other humanitarian groups that food aid should be provided unconditionally to needy countries simply supports continued population growth. Inevitably, the expanding human population and the accompanying increased exploitation of the already damaged environment will cause more people to suffer in the future. "Unconditional aid only exacerbates the woes it was intended to redress" (Elliott, 2005). In 1993, Hardin made the same point relative to the overpopulation problems and suffering in Bangladesh. In the case of an overcrowded country, what may have been a moral ethic in earlier times — taking care of the hungry with food aid — becomes immoral in that it only allows the problems to continue and grow larger.

> In a finite world, moral behavior must recognize both physical and biological constraints. Because modern man is rapidly exploiting the natural wealth that took the Earth millions of years to create, the evidence is mounting that a rapid environmental decline is now occurring on a global scale…. Hence it is becoming more and more urgent that ethical theory be grounded in environmental principle…. It will require that the human population be reduced to numbers that the renewable resources of the Earth can support (Elliott, 2005).

Critical matters of sanitation basic to the national health of every nation are much simpler to control in small populations. Rivers have become sewers in India. And untreated sewage is still being dumped into the Mediterranean Sea. Epidemics are more easily spread in densely populated regions, and mass vaccination campaigns are more difficult to carry out. The plagues of the past may not be history. A large variety of pathogenic organisms are ready to do us in, if given the opportunity. The deadly *Ebola* virus is an ongoing concern. The annual new strains of flu also present dangers. Smaller population densities, indeed smaller populations, allow better public health management. Current world population and the more than nine billion people expected by 2050 mean greater potential for deadly pathogens to spread in a more crowded world.

The vulnerability of complex societies

Civilization will continue to evolve and change, as it always has, but in the next several decades probably to a degree never seen before. The complexities of industrial civilization are beyond anything previous, and accordingly are likely to experience the greatest changes. Agrarian economies will not change nearly as much since there isn't that much to change. However, they too will feel the impact of the depletion of Earth resources with still-growing populations in the Third World countries, where adequate food supplies are already a problem.

Encouraging possibilities

An encouraging view of how to cope with changes we can expect came from Johnson (1985) in his book, *The Future Is Not What It Used to Be: Returning to Traditional Values in An Age of Scarcity*:

> The power and the wealth created by modern society overwhelmed traditional ways. Yet few will disagree that something was lost in the process…old supports of extended family, community, and roots in a familiar place.
> As we slowly come to realize that our economic problems are not a temporary setback but are part of a long-term deterioration in the once favorable conditions of industrial society, people will begin to search for more satisfying ways to live than by the values of the market place….
> Scarcity is, after all, the more universal condition of human existence, and because of this the universal values are ones such as loyalty, generosity, and cooperation. As we move toward scarcity, we too will learn to appreciate these values once again, as values that make it easier to live with scarcity and live well. The genius of the best ways of the past is that they permitted much to be done with little. Lives lived on a simpler, less material plane were made rich and full. This will be our challenge, too, as we move toward scarcity.

Some good things are happening

With all the negative trends and problems described in this book — the facts about our current dilemmas — there are also some positive trends and events. The advances in medicine are astounding. Surely the eradication of smallpox, and knowing the cause and largely controlling black plague and malaria, three of centuries-long curses of humankind, are positives. The discovery of the Salk vaccine for polio is another humanitarian milestone.

The movement toward urban produce gardens is growing, along with the slogan "eat locally." This concept may be incorporated in future urban planning and design. Urban garden activities are especially important because they connect city dwellers with the reality that fertile soil and freshwater are basic to life. People may become more concerned with the sustainability of these important resources.

Among the most encouraging trends is the great increase in the awareness of the importance of the environment to present and future generations. As a result, there have been a number of local and regional triumphs such as the establishment of highly successful wildlife and marine reserves. There is growing national and international concern for the preservation of the rainforests with their unparalleled biologic diversity, which we have hardly explored for its potential benefits. The reforestation of South Korea's formerly barren upland regions has been a notable success. Sanitation standards in some countries have been greatly improved, significantly reducing a major cause of disease.

Despite all of these encouraging trends and events, much more remains to be done. Four things stand out:

1. Worldwide reduction of population to a size that can survive at an acceptable standard of living in the arriving, truly sustainable, Earth resources paradigm;
2. Elimination of poverty (largely a function of matching population size to avail-

able renewable natural resources) so the environment can be preserved;
3. Total equality for women so they can plan and be in control of their own lives;
4. Universal access to education for all so that people can more fully understand the basis of civilization and life as we would like it, and can work together united toward achieving that goal.

For the industrialized countries currently enjoying a standard of living based increasingly on importing Earth resources, their standard of living will inevitably decline. Other countries, notably China and India, are coming to the world resource table a bit late, but in seeking at least some share of diminishing resources, they are bidding up the worldwide prices for these resources beyond anything previously seen. Yet their population masses preclude hope of ever achieving a much higher material standard of living for all their citizens. Earth resources simply are not there to provide for it. But greater well-being may be achieved through a wider application of education and knowledge in general, and by medical and sanitation advances in particular.

The exponential growth in affluence in industrialized society is hard to overlook. Fer-guson (2008c) notes, "The number of cars in the world increased from 32 million in 1930 to 775 million by 2000." It is now nearly a billion. Ferguson goes on, "In 1950 there were 25 million international tourists. Fifty years later there were 760 million." Both the increase in the number of cars and the increase in international tourist travel are the expression of a rise in affluent lifestyles for a select portion of the world's population, and have been a large factor in the exponential rise in the demand for oil.

As previously noted, we should clearly distinguish between "development" and "growth." Development means improvement in quality, whereas growth usually means increases in quantity. Development is a laudable human quality, the urge to make things better. But it should not be equated with growth. We might index this by switching from GDP, which perversely measures all economic activity whether good or bad, to a Sustainable Progress Index (SPI) that measures things that are sustainably good.

This volume has recited a host of problems and challenges based on the geologic realities of Earth's limitations. Readers may feel this is a pessimistic view. On the contrary, it is designed to be a hopeful view, as Eyre (1978) said:

> A man is not automatically a pessimist because he feels that our present socioeconomic institutions are unsustainable; indeed if he has convictions that humanity has the latent reserves of resourcefulness and flexibility to change these institutions in time to meet changing circumstances, he should be regarded as an optimist. In a sense, there is no more pessimistic frame of mind than the one which assumes that we have to continue with our present expansionist system because basic human and economic institutions cannot be changed…. Such a conclusion lacks either imagination or honesty…. The responsibility rests on those with knowledge and influence to create the framework in which such a transformation of outlook can take place.

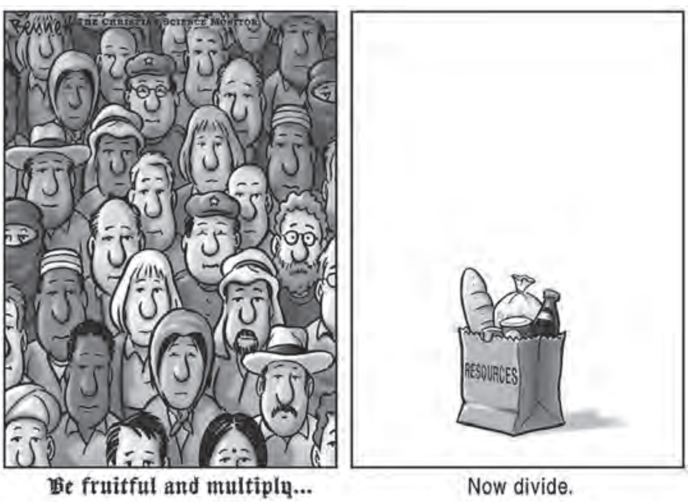
The future of less will arrive for citizens of both the industrial and developing world in small increments, but which, collectively in retrospect, will be seen as a century of profound change in its degree of rapidity and far-reaching consequences. The related problems of resource depletion and unsustainable population growth will become clearly apparent. We have the opportunity to modify these trends, but not without major societal and political commitment.

We urgently need to match population with available resources, stop degrading the renewable resources that must sustain humanity for all future time, and take appropriate actions toward these ends. Brown (2009a) has summarized the challenge in a short but pointed article titled, "When Population Growth and Resource Availability Collide." Much of the discussion and presentation of facts are related to the gravity of this fundamental concern, as it has been summarized graphically in Figure 30-1, a growing population having to exist on a currently decreasing amount of life-sustaining Earth resources.

> If we borrow from Mother Nature, such that her energy and ecosystem services can no longer provide us, there will be no Troubled Earth Relief Program (TERP) to bail us out (King, 2011).

Better technology is the lesser of two important ingredients for a successful future. The more important one is a basic worldwide change of values that replaces growth of the *quantity* of things and of people to buy them, with *quality* of life. Technology and talents must be directed constructively for the long-term good. We have made great progress in technology, but compassion and understanding in human relationships will be required to fairly address coming resource issues. Moving from widespread religious, ethnic, and racial strife to a time of better human relations could do far more for the human species this century than more technology. The path to a useful, fulfilling and pleasant future lies, not in science and technology, but within ourselves. Albert Einstein recognized this truth, saying, "The real problem is in the hearts and minds of men. It is not a problem of physics but of ethics." We have many constructive ways to improve humanity's lot beyond the realm of technology.

Figure 30-1. Population Growth and Earth Resources



By permission: Clay Bennett, *North American Syndicate*

Bhutan, a small remote country in the Himalayas with much less per capita material wealth than the industrial world, chooses to measure its accomplishments for its people by the Gross Happiness Index (GHI). To a large extent, its parameters measuring things other than material goods indicates their GHI is high. The values that are most important in this world are not material things, but the caring and compassionate appreciation of the remarkable thing called "life," especially human life and intellect. Using this intellect, we, unlike all other organisms, can visualize and perhaps even alter for the better the course of the future for ourselves and our posterity. Whether one believes we are put here as a special creation or by the long evolutionary route described so well by Loren Eiseley in his classic book, *The Immense Journey*, life is a gift to be cherished. Regardless of creeds, colors, ethnic, and other divisions, we are one humanity, and we should be united in the common purpose of making life a compassionate and pleasant journey.

Like nature, technology is neutral toward humanity. As Einstein concluded, it is how we use it that is important. But technology used intelligently to solve the problems that lie ahead can be a servant to our future.

Much as I would like to report that my studies found a cheerful, easy solution to our energy problems, providing a base for continued economic growth and sustainably improving living standards for an expanding population, I am unable to do so. A new study by Joseph Tainter and Tad Patzek (2012) reached the same conclusion: "We stated that we would not offer simple solutions. There aren't any. Neither have we discussed the staggering energy-demand problems brought upon us by the growing human population."

U.S. population growth with and without immigration

The 2009 supplemental U.S. Census Bureau projections show a total population of 439 million in 2050, with their baseline immigration assumptions and 322 million without immigration — a difference of 116 million. In other words, immigration will account for over 90 percent of U.S. population growth over the next four decades. In the decade just passed (2000-2010), new legal and illegal immigration combined, including births to immigrants, added about 23 million residents to the United States, equal to about 80 percent of total U.S. population growth in the decade (Camarota, 2012).

Turning points

Human history has witnessed two great turning points. The first was the change from hunter-gathering to settled agriculture, which for many centuries, left the Earth little changed. The second great turning point was the Industrial Revolution, which raised the standard of living for countless millions through the widespread extraction and myriad uses of nonrenewable natural resources.

The Earth's riches accumulated from geological events over millions of years have, in a brief three hundred years, been significantly depleted through mines as deep as 10,000 feet, oil extracted from below 16,000 feet, and gas produced from depths below 20,000 feet. Aquifers are being depleted faster than they can be recharged. Soil is being lost many times faster than nature can replace it.

This has brought us to the brink of a third turning point. Succeeding human populations will cope with a permanently reduced resource base. For the first time, the Earth will provide humanity with a future of less. The human response to this reality could be orderly or it could usher in an age of social and economic chaos.

Natural resources will continue to control the destinies of nations and individuals. This is hardly a profound statement, for what else do we have to live on? It is the irregular distribution of the Earth's resources and how nations have or have not been able to exploit them that cause the great differences we now see in nations' social and economic structures. Simple arithmetic demonstrates that a limited supply of any material cannot meet an unlimited demand for it. Most of the world, including the United States, has failed to recognize the fact that overpopulation devalues life, decreases quality of life, depletes resources, destroys habitats, and overwhelms governmental ability to provide essential services. Resources of food, water, and energy cannot meet infinite demands. As Earth's resources are fixed and finite, world population size is the only variable for achieving an acceptable balance with what the environment can sustainably provide. Where population densities, family size, and population growth are highest, education is the lowest, and the vulnerability to environmental change is the greatest.

Education

The real wealth of societies is knowledge provided chiefly through education. As H.G. Wells said, "Human history becomes more and more a race between education and catas-trophe." Applied knowledge is the critical key to civilized progress. We must be educated to recognize, respect, and preserve the Earth resources that sustain us now, and that will be needed to sustain generations to come. We now know which resources are renewable and which are not. Our destiny as a species will depend on finding a balance between popula-tion size and Earth's ability to sustainably meet its resource demands.

If you plan for a year, sow rice.
If you plan for a decade, plant trees.
If you plan for a century, educate people.
—Chinese proverb

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