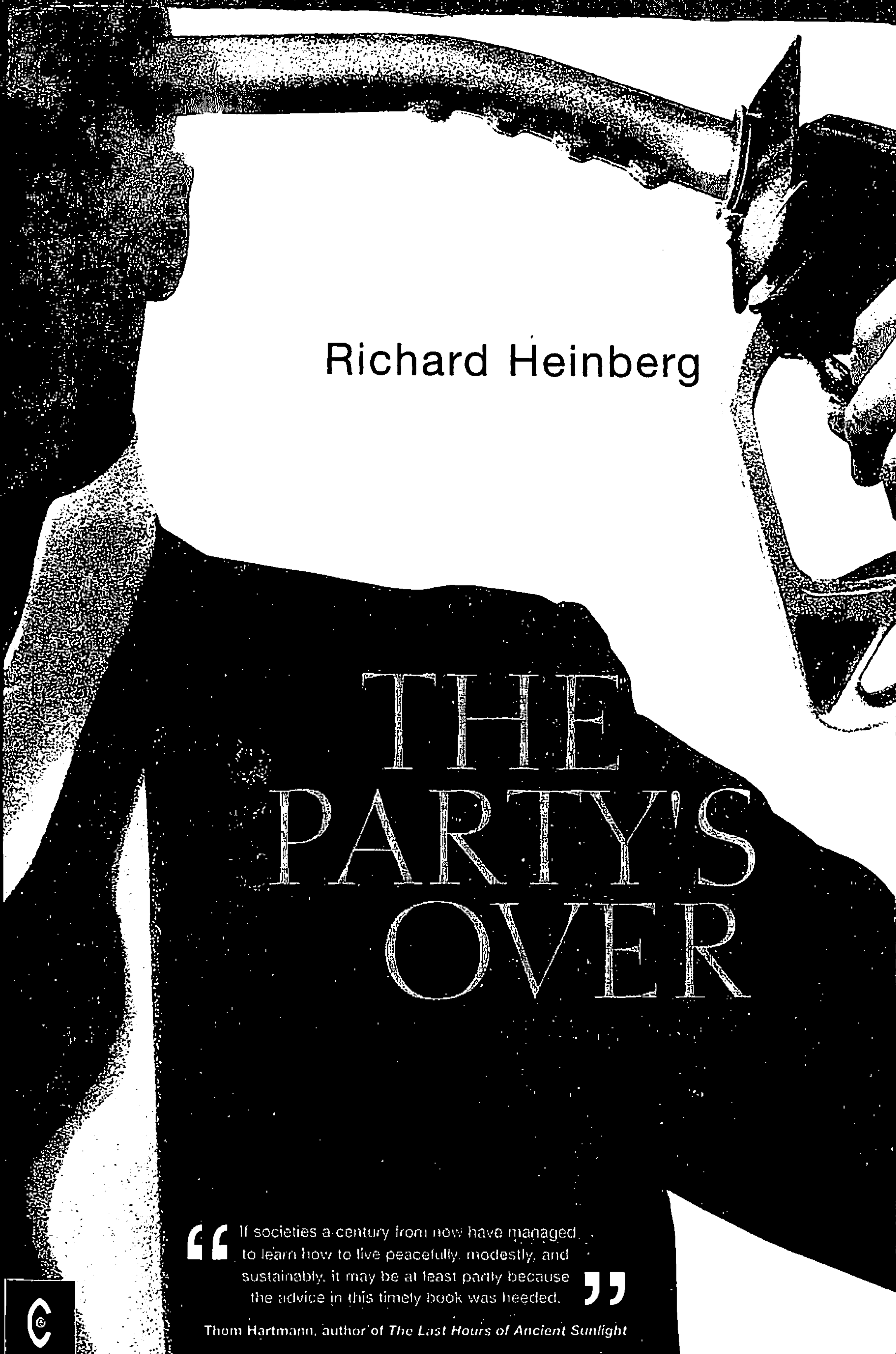

Richard Heinberg

THE PARTY'S OVER

"If societies a century from now have managed to learn how to live peacefully, modestly, and sustainably, it may be at least partly because the advice in this timely book was heeded."

Thom Hartmann, author of *The Last Hours of Ancient Sunlight*

The Party's Over begins with a commanding review of world history, where past and current developments including war, empire, and population growth are interpreted as functions of cheap or increasingly scarce and expensive energy. The discussion of substitutes for fast-depleting fossil fuels, and the formidable impediments to making the transition that would allow industrial civilization to continue, are important to every investor and citizen.

— Virginia Deane Abernethy, Ph.D., author of *Population Politics*

Richard Heinberg's *The Party's Over* is outstanding. I hope that the U.S. President and Congress read this book. The world and the U.S. populations are projected to double in 50 and 70 years, respectively, and global oil supplies are projected to be mostly depleted in 50 years! I agree with Heinberg that society is headed for serious trouble in the near future.

— David Pimentel, Professor, Department of Entomology, Systematics and Ecology, Cornell University

THE PARTY'S OVER

OIL, WAR AND THE FATE OF INDUSTRIAL SOCIETIES

RICHARD HEINBERG

IRVI

Clairview Books
An imprint of Temple Lodge Publishing
Hillside House, The Square
Forest Row, East Sussex
RH18 5ES

www.clairviewbooks.com

Published by Clairview 2003
Reprinted 2004

First published in Canada by New Society Publishers, Gabriola Island, 2003

A catalogue record for this book is available from the British Library

ISBN 1 902636 45 7

Cover by Andrew Morgan Design
Typeset in Canada
Printed and bound by Cromwell Press Limited, Trowbridge, Wiltshire

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ACKNOWLEDGMENTS

I AM DEEPLY INDEBTED to three geologists who read parts of the manuscript and offered invaluable corrections, additions, and advice: C. J. Campbell, who read the entire manuscript and offered editorial as well as technical suggestions; Jean Laherrère, who read Chapter 3 and offered detailed criticisms and suggestions; and Walter Youngquist, who read an early version of Chapter 3 and supplied helpful resource materials.

I am also indebted to Ron Swenson, an expert on renewable energies, who offered immensely valuable insights and suggestions for Chapter 4.

For the past three years my students at New College of California have heard me develop the ideas for this book in lectures; during the same period my colleagues on staff and faculty have engaged me in frequent conversations about issues related to the book. I would like to thank all of these wonderful people, both for their comments and for their patience with me as I doggedly pursued this topic.

Readers of my monthly *MuseLetter* read early drafts of chapters and also offered helpful suggestions. I thank them for their loyalty and interest.

Thanks to Chris Plant and the rest of the staff at New Society Publishers for taking on a controversial topic, for understanding the timeliness of the book, and for thus working to get it out so quickly. Thanks to Michael Mundhenk for his meticulous copy editing. And thanks also to Chellis Glendinning for putting me in touch with New Society in the first place.

I must mention my debt of gratitude to Jay Hanson, whose research and documentation of this topic on his web site <www.dieoff.org> provided much of the original inspiration for this book.

For their kind permission to quote from their work, my appreciation goes out to Michael C. Lynch, Bjørn Lomborg, C. J. Campbell, and Richard C. Duncan.

Finally, I would like to thank my wife, Janet Barocco, for her constant support and encouragement.

FOREWORD

It is well said that oil and politics are never far apart. Even during the First World War, when the oil industry was in its infancy, there was a certain focus on oil in, for instance, the German pressure in the Middle East. The French premier of the day commented, "A drop of oil is worth a drop of blood." Japan came into the Second World War in order to control Indonesian oil. Hitler aimed at Baku on the Caspian with a desperate need for oil to support his war machine, which still relied heavily on horse drawn transport. The invasion of Kuwait in the second Gulf War had its origins in Kuwait's action in producing above its agreed OPEC quota, which depressed the price of oil and therefore seriously reduced Iraq's legitimate revenue. The United States, its own indigenous production having been in terminal decline for more than thirty years, has long explicitly stated that access to foreign oil is a vital national interest justifying military intervention. By the time these words come into print, such a policy may have been implemented with apocalyptic consequences; at best it will have been only narrowly averted by world opinion.

This remarkable book therefore comes at an opportune time.

It is indeed a remarkable book, bringing deep insight into the state of a world that has come to rely on cheap oil-based energy, the fundamental driver of its prosperity and economic growth. Yet, as the author points out, oil is a fossil fuel, which means that it was formed in the geological past and is consequently subject to depletion. Accordingly, we started running out of oil when we produced the first barrel. But running out is not the main issue, as the tail end of production can drag on for a very long time. What matters much more are the date of the peak and the onset of the decline, which are likely to constitute a historic discontinuity as the growth of the past gives way. It will affect all aspects of life as we know it since oil is critical for transport, trade and agriculture. The world's population has expanded six-fold during the first half of the Oil Age. What will it do during the second half?

The book opens with a discussion of energy in general, explaining in lucid terms, its characteristics and physical laws. It cannot be created or destroyed, merely transformed. Thus, plants grow by using the energy from the sun to convert nutrients and minerals in the soil into stalks and leaves, which in turn provide food for animals. The Laws of Entropy cover the essential balances that determine the success or failure of every environmental niche. That perception in turn has led to the discipline of ecology where scientists study the viability of the life systems of the very finite planet on which we live. As the early dustbowls of America confirmed, every system has its limits: plants can't grow if the soil has been blown away or the natural aquifers drained dry.

This is, however, sensitive territory, as understandably people prefer not to hear about natural constraints that intrude on their belief in Man as Master of His Environment. These limitations even touch on religious doctrine, which elevates Man to a special status in the eyes of God. The passions of the eco-warrior may be rightfully raised but ironically prove self-defeating if he is stereotyped as a crank with sandals and beard. It is refreshing, therefore, to find the author of this book presenting such a level-headed account, free from any extreme opinion or bias. He makes a very compelling argument that should appeal as much to the boardroom as to the passionate environmentalist.

Speaking of the boardroom, we learn how relatively recent the corporate world in which we live actually is. It arose out of the Industrial Revolution of the 18th century, when we learned to harness energy, first from mill streams and then later from coal, oil, and gas to manufacture goods and products. This in turn led to surplus capital that stimulated growth and created new markets. The saturation of home markets led to overseas empires by Britain, France and Russia, followed today by US economic hegemony and globalism, driven by the dollar and backed by unprecedented military might. Capitalism itself has evolved through the development of unseen financial instruments dominated by debt and usury, as commercial banks lend money they neither have nor own in an almost virtual system built on confidence in perpetual growth. All of this has been achieved in the span of only a few generations: my father was born before the advent of the automobile and long before the first tractor ploughed its furrows.

But, as the book explains, empires fall as well as rise, and do so quickly, with collapse often being triggered by some ecological event. The Roman Empire crashed when the silver mines in Spain flooded upon reaching the water table, so there was no money to pay the mercenary troops to defend the realm. The Rhine froze in 410 AD allowing Aleric the Goth to march south and sack Rome, bringing to an end an empire that had lasted a thousand years.

Whether we like it or not, we live within a natural environment — and we ignore its impacts at our peril. Did Darwin get it right when he proclaimed that evolution was achieved by the survival of the fittest? In fact, the record of life

on Earth over 500 million years shows how species thrived when they adapted to environmental niches, but died out when the environment changed, leaving simpler forms to survive and later branch out to exploit new environments, only to die out in their turn.

The prime questions posed by this book are precisely these: Will we be the first species to use our claimed intelligence to reverse our course when we discover that we have taken a wrong turn in the road? And can we recover simplicity and an equitable balance with the resources at our disposal? These questions touch on human diversity and migration. Some communities may learn to adapt better than others. Will they be able to exploit their advantage? Or will they rather be swamped by migrants from less adapted places?

Just how close are we to these fundamental changes of direction? Economists can readily chart trends, but they are hopeless when it comes to anticipating discontinuities. The unexpected can happen. September 11th may have been just such a catalyst. As the days pass more questions are asked about who exactly was responsible and what motive did they have. Was it the work of an isolated group, or were there sinister forces operating even in the United States itself as some of the evidence suggests? The jury is out, but these events may have been symptomatic of unseen deeper tensions, tensions that are not unrelated to Middle East oil.

The jury is not out however on the issue of our declining oil supply. Even the CEO of Exxon-Mobil confirms that less than half the oil needed to meet demand by 2010 can be supplied by present fields, and that as much as a trillion dollars would be needed to secure it. This is an oblique way of saying that demand cannot be met. In an equally oblique reference to the depletion of its principal asset, British Petroleum says that BP now stands for Beyond Petroleum.

The authorities and powers-that-be are reluctant to grasp the nettle and come out to say it the way it is, but this book rightly takes the imminent peak of oil supply as a given, before exploring the other sources of energy that may come in. It concludes that there are useful substitutes, although none will be as cheap or convenient as was oil.

In a final chapter, the author makes some eminently sensible recommendations about how to face the social, economic, political, and individual lifestyle changes that will be imposed upon us. The strength of these recommendations is that they aim at what people may do at a personal level in their own lives, especially in the United States. This seems eminently sensible because however corrupted the democratic system has become, the politicians do ultimately have to depend on popular support. As personal attitudes change, so eventually will government policies have to change to meet them.

The key word here is *eventually*, as there is much truth in the adage that generals always plan to fight the previous war, as they are the last ones to perceive the changed circumstances.

The enormous contribution that the author has made in writing this book is that he gives us the ammunition with which to identify the new challenges and wrestle victory from defeat. It should be standard reading for governments everywhere — and is nowhere more desperately needed than in the White House. It also deserves a place on every household bookshelf and in schools and colleges. If it captures the interest and imagination of the youth, as it deserves to, perhaps, after all, we will have a good future. The United States is known for the initiative, individuality, ingenuity and enthusiasm of its people. They can rise to the challenge once they know what it is. This book will tell them, and tell them in a very clear, unambiguous, well-argued and unemotional fashion.

C. J. Campbell
Former oil executive (FINA)
Founder of the Association for the Study of Peak Oil (ASPO)
County Cork, Ireland
August 2002

INTRODUCTION

The skylines lit up at dead of night, the air-conditioning systems cooling empty hotels in the desert, and artificial light in the middle of the day all have something both demented and admirable about them: the mindless luxury of a rich civilization, and yet of a civilization perhaps as scared to see the lights go out as was the hunter in his primitive night.

— Jean Baudrillard (1989)

It is evident that the fortunes of the world's human population, for better or for worse, are inextricably interrelated with the use that is made of energy resources.

— M. King Hubbert (1969)

There is no substitute for energy. The whole edifice of modern society is built upon it ... It is not "just another commodity" but the precondition of all commodities, a basic factor equal with air, water, and earth.

— E. F. Schumacher (1973)

THE WORLD IS CHANGING before our eyes — dramatically, inevitably, and irreversibly. The change we are seeing is affecting more people, and more profoundly, than any that human beings have ever witnessed. I am not referring to a war or terrorist incident, a stock market crash, or global warming, but to a more fundamental reality that is driving terrorism, war, economic swings, climate change, and more: the discovery and exhaustion of fossil energy resources.

The core message of this book is that industrial civilization is based on the consumption of energy resources that are inherently limited in quantity, and that are about to become scarce. When they do, competition for what remains will trigger dramatic economic and geopolitical events; in the end, it may be impossible for even a single nation to sustain industrialism as we have known it during the twentieth century.

What comes after industrialism? It could be a world of lower consumption, lower population, and reduced stress on ecosystems. But the process of getting there from here will not be easy, even if the world's leaders adopt intelligent and cooperative strategies — which they have so far shown little willingness to do. Nevertheless, the end of industrial civilization need not be the end of the world.

This is a message with such vast implications — and one that so contradicts the reassurances we receive daily from politicians and other cultural authorities — that it appears, on first hearing, to be absurd. However, in the chapters that follow I hope to show

- the complete and utter *dependency* of modern industrial societies on fossil fuel energy resources as well as the inability of alternatives to fully substitute for the concentrated, convenient energy source that fossil fuels provide;
- the *vulnerability* of industrial societies to economic and political disruption as a result of even minor reductions in energy resource availability;
- the *inevitability* of fossil fuel depletion;
- the *immediacy* of a peak in fossil fuel production, meaning that soon less will be available with each passing year regardless of how many wild lands are explored or how many wells are drilled;
- the *role of oil* in US foreign policy, terrorism and war, and the geopolitics of the 21st century;
- and hence the necessity of our responding to the coming oil production peak cooperatively, with compassion and intelligence, in a way that minimizes human suffering over the short term while, over the long term, enabling future generations to develop sustainable, materially modest societies that affirm the highest and best qualities of human nature.

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I came to the subject of energy resources out of a passion for ecology and a decades-long effort to understand what makes human cultures change — an attempt, that is, to answer the question, *What causes one group of people to live in air-conditioned skyscrapers and shop at supermarkets, while another genetically similar group lives in bark huts and gathers wild foods?*

This is a complex problem. There is no single explanation for the process of cultural change; reasons vary considerably from situation to situation. However, as many students of the subject eventually conclude, there is one element in the process that is surprisingly consistent — and that is the role of energy.

Life itself requires energy. Food is stored energy. Ecosystems organize themselves to use energy as efficiently as possible. And human societies expand or contract, invent new technologies or remain static, in response to available energy supplies. Pay attention to energy, and you can go a long way toward understanding both ecological systems and human social systems, including many of the complexities of economic and political history.

Once I realized this, I began to focus my attention on our society's current energy situation. Clearly, over the past century or so we have created a way of life based on mining and consuming fossil energy resources in vast and increasing quantities. Our food and transportation systems have become utterly dependent on growing supplies of oil, natural gas, and coal. Control of those supplies can therefore determine the economic health and even the survival of nations. Hence I tried to find answers to the following questions: *How much petroleum is left? How much coal, natural gas, and uranium? Will we ever run out? When? What will happen when we do? How can we best prepare? Will renewable substitutes — such as wind and solar power — enable industrialism to continue in a recognizable form indefinitely?*

Important questions, these. But a quick initial survey of available answers proved to be confusing and frustrating. There are at least four sets of voices spouting mutually contradictory opinions:

- The loudest and most confident voice belongs to conventional free-market economists, who view energy as merely one priced commodity among many. Like other commodities, energy resources are subject to market forces: temporary shortages serve to raise prices, which in turn stimulates more production or the discovery of substitutes. Thus the more energy we use, the more we'll have! Economics Nobel laureate Robert Solow has gone so far as to say that, ultimately, " ... the world can, in effect, get along without natural resources."[1] Economists like him have a happy, cornucopian view of our energy future. If an energy crisis appears, it will be a temporary one caused by "market imperfections" resulting from government regulation. Solutions will come from the market's natural response to price signals if those signals do not get obscured by price caps and other forms of regulatory interference.

- A more strident voice issues from environmental activists, who are worried about the buildup of greenhouse gases in the atmosphere and about various forms of hydrocarbon-based pollution in air, water, and soil. For the most part, ecologists and eco-activists are relatively unconcerned with high energy prices and petroleum resource depletion — which, they assume, will occur too late to prevent serious environmental damage from global warming. Their message: Conserve and switch to renewables for the sake of the environment and our children's and grandchildren's welfare.
- A third and even more sobering collective voice belongs to an informal group of retired and independent petroleum geologists. This is a voice that is so attenuated in the public debate about energy that I was completely unaware of its existence until I began systematically to research the issues. The petroleum geologists have nothing but contempt for economists who, by reducing all resources to dollar prices, effectively obscure real and important physical distinctions. According to the petroleum geologists, this is arrant and dangerous nonsense. Petroleum will run out. Moreover, it will do so much sooner than the economists assume — and substitutes will not be easy to find. The environmentalists, who for the most part accept economists' estimates of petroleum reserves, are, according to the geologists, both right and wrong: we should indeed be switching to renewable alternatives, but because the renewables cannot fully replicate the energy characteristics of fossil fuels and because decades will be required for their full development, a Golden Age of plentiful energy from renewable sources is simply not in the cards. Society must engage in a crash program of truly radical conservation if we are to avoid economic and humanitarian catastrophe as industrialism comes to its inevitable end.
- Finally, there is the voice that really matters: that of politicians, who actually set energy policy. Most politicians tend to believe the economists because the latter's cornucopian message is the most agreeable one — after all, no politician wants to be the bearer of the awful news that our energy-guzzling way of life is waning. However, unlike economists, politicians cannot simply explain immediate or projected energy constraints away as a temporary inconvenience. They have to deal with constituents — voters — who want good news and quick solutions. When office holders are forced to acknowledge the reality of an impending energy crisis, they naturally tend to propose solutions appropriate to their constituency and their political philosophy, and they predictably tend to blame on their political opponents whatever symptoms of the crisis cannot be ignored. Those on the political Left usually favor price caps on energy and subsidies to low-income rate payers; they blame price-gouging corporations for blackouts and high prices. Those on the political Right favor "free-market" solutions (which often entail subsidies to oil companies and privately owned utilities) and say that shortages are due to environmental regulations that prevent companies from further exploration and drilling.

Personally, I have long supported the program of renewable energy alternatives that eco-activists advocate. I still believe in that program, now more than ever. However, after studying the data and interviewing experts, I have concluded that, of the four groups described above, the retired and independent petroleum geologists are probably giving us the most useful factual information. Theirs is a long-range view based on physical reality. But their voice is the hardest to hear because, while they have undeniable expertise, there are no powerful institutions helping them spread their message. In this book, the reader will find the geologists' voices prominently represented.

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As should be obvious from the title of this book, I am choosing to emphasize the bad news that we are approaching the first stages of an energy crisis that will not easily be solved and that will have a profound and permanent impact on our way of life. There is also good news to be conveyed: it is possible that, in the post-petroleum world, humankind will discover a way of living that is more psychologically fulfilling as well as more ecologically sustainable than the one we have known during the industrial age. However, unless we are willing to hear and accept the bad news first, the good news may never materialize.

Many books published during the past few decades have pleaded with us to reduce our non-renewable energy usage for a variety of reasons — to lessen the greenhouse effect and environmental pollution, to halt the destruction of local communities and cultures, or to preserve human health and sanity. Though I agree with those prescriptions, this is not another such book. Until now, humankind has at least theoretically had a choice regarding the use of fossil fuels — whether to use constantly more and suffer the long-term consequences or to conserve and thus forgo immediate profits and industrial growth. The message here is that we are about to enter *a new era in which each year, less net energy will be available to humankind, regardless of our efforts or choices*. The only significant choice we will have will be how to adjust to this new regime. That choice — not *whether*, but *how* to reduce energy usage and make a transition to renewable alternatives — will have profound ethical and political implications. But we will not be in a position to navigate wisely through these rapids of cultural change if we are still living with the mistaken belief that we are somehow entitled to endless energy and that, if there is suddenly less to go around, it must be because "they" (the Arabs, the Venezuelans, the Canadians, the environmentalists, the oil companies, the politicians, take your pick) are keeping it from us.

Industrial societies have been flourishing for roughly 150 years now, using fossil energy resources to build far-flung trade empires, to fuel the invention of spectacular new technologies, and to fund a way of life that is opulent and fast-paced. It is as if part of the human race has been given a sudden windfall of wealth and decided to spend that wealth by throwing an extravagant party. The party has not been without its discontents or costs. From time to time, a lone voice issuing from here or there has called for the party to quiet down or cease altogether. The partiers have paid no attention. But soon the party itself will be a fading memory — not because anyone decided to heed the voice of moderation, but because the wine and food are gone and the harsh light of morning has come.

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Here is a brief tour of the book's contents:

Chapter 1 is a general discussion of energy in nature and human societies. In it we see just how central a role energy has played in the past and why it will shape the fates of nations in the decades ahead. This chapter is a brief guided trip through the fields of ecology, cultural anthropology, and history, with energy as our tour guide.

Chapter 2 traces the history of the industrial era — the historic interval of cheap energy — from the Europeans' first use of coal in the 12th century to the 20th-century miracles of petroleum and electricity with their cascading streams of inventions and conveniences.

Chapter 3 is in many respects the informational core of the book. In it we will learn to assess oil resources and review estimates of current reserves and extraction rates. Many readers may find the information in this chapter unfamiliar and disturbing since it conflicts with what we frequently hear from economists and politicians. Among other things, we will explore the question, *Why do the petroleum-reserve estimates of independent geologists diverge so far from those of governmental agencies like the US Geological Survey?*

Chapter 4 explores the available alternatives to oil: from coal and natural gas to solar power, wind, and hydrogen, including cold fusion and "fringe" free-energy devices.

Chapter 5 discusses the meaning and the implications of the approaching peak in fossil-fuel production. We will explore the connections between petroleum dependence, world food systems, and the global economy. We will also examine the global strategic competition for dwindling petroleum resources and attempt to predict the flashpoints for possible resource wars.

Finally, Chapter 6 addresses the vital question: *What can we do?* — individually, as communities, as a nation, and globally. In this chapter we will explore solutions, from the simple practical steps any of us can take to policy recommendations for world leaders. As we will see, humankind now must decide whether to respond to resource shortages with bitter competition or with a spirit of cooperation. We will face this decision at all levels of society — from the family and neighborhood to the global arena of nations and cultures.

Chapter 1

Energy, Nature and Society

The life contest is primarily a competition for available energy.
— Ludwig Boltzman (1886)

Other factors remaining constant, culture evolves as the amount of energy harnessed per capita per year is increased, or as the efficiency of the instrumental means of putting the energy to work is increased. We may now sketch the history of cultural development from this standpoint.
— Leslie White (1949)

[T]he ability to control energy, whether it be making wood fires or building power plants, is a prerequisite for civilization.
— Isaac Asimov (1991)

We live in a universe pulsing with energy; however, only a limited amount of that energy is available for our use. We humans have recently discovered a temporary energy subsidy in the forms of coal, oil, and natural gas, and that momentary energy bonanza has fueled the creation of modern industrial societies. We tend to take that subsidy for granted, but can no longer afford to do so. Emerging circumstances will require us to think much more clearly, critically, and contextually about energy than we have ever done before.

In this chapter we will first review some basic facts about energy and the ways in which nature and human societies function in relation to it. We will follow this discussion of principles with an exploration of the history of the

United States' rise to global power, showing the central role of energy resources in that process.

The first section below includes information that may already be familiar to many readers from high-school or college courses in physics, chemistry, and biology. I begin with this material because it is absolutely essential to the understanding of all that follows throughout the book. Have patience. We will soon arrive in new (and disturbing) intellectual territory.

Energy and Earth: The Rules of the Game

Few understand exactly what energy is. And yet we know that it exists; indeed, without it, *nothing* would exist.

We commonly use the word *energy* in at least two ways. A literary or music critic might say that a particular poem or performance has energy, meaning that it has a dynamic quality. Similarly, we might remark that a puppy or a toddler has a lot of energy. In those cases we would be using the term intuitively, impressionistically, even mystically — though not incorrectly. Physicists and engineers use the word to more practical effect. They have found ways to measure energy quite precisely in terms of ergs, watts, calories, and joules. Still, physicists have no more insight into energy's ultimate essence than do poets or philosophers. They therefore define energy not in terms of what it is, but by what it does: as "the ability to do work" or "the capacity to move or change matter." It is this quantifiable meaning of the term *energy* that concerns us in this book. Though we are considering something inherently elusive (we cannot, after all, hold a jar of pure energy in our hands or describe its shape or color), energy is nevertheless a demonstrable reality. Without energy, nothing happens.

In the 19th century, physicists formulated two fundamental laws of energy that appear to be true for all times and places. These are commonly known as the First and Second Laws of Thermodynamics. The first, known as the Conservation Law, states that energy cannot be created or destroyed, only transformed. However, energy is never actually "transformed" in the sense that its fundamental nature is changed. It is more accurate to think of energy as a singular reality that manifests itself in various forms — nuclear, mechanical, chemical, thermal, electromagnetic, and gravitational — which can be converted from one to another.

The Second Law of Thermodynamics states that whenever energy is converted from one form to another, at least some of it is dissipated, typically as heat. Though that dissipated energy still exists, it is now diffuse and scattered.

and thus less available. If we could gather it up and re-concentrate it, it could still work for us; but the act of re-concentrating it would itself require more energy. Thus, in effect, available energy is always being lost. The Second Law is known as the law of entropy — a term coined by the German physicist Rudolf Clausius in 1868 as a measure of the amount of energy no longer practically capable of conversion into work. The Second Law tells us that the entropy within an isolated system inevitably increases over time. Since it takes work to create and maintain order within a system, the entropy law tells us that, in the battle between order and chaos, it is chaos that ultimately will win.

It is easy to think of examples of entropy. Anyone who makes the effort to keep a house clean or who tries keeping an old car repaired and on the road knows about entropy. It takes work — thus energy — to keep chaos at bay. However, it is also easy to think of examples in which order seems naturally to increase. Living things are incredibly complex, and they manage not only to maintain themselves but to produce offspring as well; technological gadgets (such as computers) are always becoming more sophisticated and capable; and human societies seem to become larger, more complex, and more powerful over time. These phenomena all appear to violate the law of entropy. The key to seeing why they actually don't lies in the study of systems.

The Second Law states that it is the entropy in an *isolated system* that will always increase. An isolated system is one that exchanges no energy or matter with its environment. The only truly isolated system that we know of is the universe. But there are two other possible types of energy systems: *closed systems* (they exchange energy with their environment, but not matter) and *open systems* (they exchange both energy and matter with their environment). The Earth is, for the most part, a closed system: it receives energy from the Sun and re-radiates much of that energy back out into space; however, aside from the absorption of an occasional asteroid or comet fragment, the Earth exchanges comparatively little matter with its cosmic environment. Living organisms, on the other hand, are examples of open systems: they constantly receive both energy and matter from their environment, and also give off both energy and matter.

It is because living things are open systems, with energy and matter continually flowing through them, that they can afford to create and sustain order. Take away their sources of usable energy or matter, and they soon die and begin to disintegrate. This is also true of human societies and technologies: they are open systems that depend upon the flow of energy and matter to create temporary islands of order. Take away a society's energy sources, and "progress" — advances in technology and the growth of complex institutions — quickly ceases. Living systems can increase their level of order and complexity by increasing their energy flow-through; but by doing so, they also inevitably increase the entropy within the larger system of which they are a part.

Matter is capable of storing energy through its chemical order and complexity. This stored energy can be released through chemical processes, such as combustion or, in the case of living things, digestion. Materials that store energy are called *fuels*.

The law of entropy holds true for matter as well as for energy. When energy is dissipated, the result is called *heat death*. When matter is eroded or degraded, the result is called *matter chaos*. In both cases, the result is a randomization that makes both matter and energy less available and useful.

In past decades, a simplistic understanding of entropy led many scientists to conclude that order is an anomaly in the universe — a belief that made it difficult to explain how biological evolution has proceeded from the simple to the complex, from bacteria to baleen whales. In recent years, more sophisticated understandings have developed, centered mostly around chaos theory and Ilya Prigogine's theory of dissipative structures. Now it is known that, even within apparently chaotic systems, deeper forms of order may lurk. However, none of these advances in the understanding of living systems and the nature of entropy circumvents the First or Second Laws of Thermodynamics. Order always has an energy cost.

Because the Earth is a closed system, its matter is subject to entropy and is thus continually being degraded. Even though the planet constantly receives energy from its environment, and even though the ecosystems within it recycle materials as efficiently as they can, useful concentrations of matter (such as metal ores) are always being dispersed and made unusable.

On Earth, nearly all the energy available to fuel life comes from the Sun. There are a very few exceptions; for example, oceanographers have discovered organisms living deep in ocean trenches, thriving on heat emanating from the Earth's core. But when we consider the energy flows that support the biosphere as a whole, sources originating within the planet itself are trivial.

The Sun continually gives off an almost unimaginable amount of energy — the equivalent of roughly 100 billion hydrogen bombs going off each second — radiating it in all directions into space. The Earth, 93 million miles away, is a comparatively tiny target for that energy, receiving only an infinitesimal fraction of what our local star radiates. Still, in terms that concern us, that's plenty: our planet is constantly bathed in 1,372 watts of sunlight energy per square meter. The total influx of solar energy to the Earth is more than 10,000 times the total amount of energy humankind presently derives from fossil fuels, hydro power, and nuclear power combined. The relative vastness

of this solar-energy influx as compared with society's energy needs might suggest that humans will never face a true energy shortage. But only some of this solar energy is actually available for our use: much is re-radiated into space (30 percent are immediately reflected from clouds and ice), and nearly all of the rest is already doing important work, such as driving the weather by heating the atmosphere and oceans and fueling life throughout the biosphere.

Some organisms — green plants, including algae and phytoplankton — are able to take in energy directly from sunlight. Biologists call these organisms *producers*, or *autotrophs* ("self-feeders"), because they make their own food from inorganic compounds in their environments.[1] Producers trap solar energy through photosynthesis, a process in which chlorophyll molecules convert sunlight into chemical energy. Most of us tend to assume that green plants are mostly made up of materials from the soil drawn up through the plants' roots. This is only partly true: plants do require minerals from the soil, but most of their mass is actually derived from air, water and sunlight, via photosynthesis. Hundreds of chemical changes are involved in this process, the results of which can be summarized as follows:

carbon dioxide	+	water	+	solar energy	→	glucose	+	oxygen
$6CO_2$	+	$6H_2O$	+	solar energy	→	$C_6H_{12}O_6$	+	$6O_2$

Glucose — a sugar, or carbohydrate — serves as food for plants and can be converted into materials from which the plants build their tissues. Plants absorb only about half of the solar energy that falls on them; of that, they are able to convert only about one to five percent into chemical energy. Still, even at this low level of efficiency, photosynthetic organisms each year capture a little more than twice the total amount of energy used annually by human beings. (Interestingly, however, within the US, the total amount of energy captured in photosynthesis amounts to only about half of the energy used by humans.)

All nonproducing organisms are classifiable as *consumers*, or *heterotrophs* ("other-feeders"). By digesting glucose and other complex organic compounds that were produced through photosynthesis, consumers absorb the energy previously locked into chemical order by green plants. In the process, they produce waste — less-ordered material — which they excrete into the environment. In effect, consumers feed on order and excrete chaos in order to survive. All animals are consumers.

There are several categories of consumers: *herbivores*, which eat plants; *carnivores*, which eat other consumers (primary carnivores eat herbivores, secondary carnivores eat other carnivores, and tertiary carnivores eat carnivores that eat carnivores); *scavengers*, which eat dead organisms that were killed by other organisms or died naturally; *detritovores*, which eat cast-off fragments and wastes of living organisms; and *decomposers*, consisting mostly of certain kinds of bacteria and fungi, which complete the final breakdown and recycling of the remains and wastes of all organisms. Human beings — like foxes, bears, rats, pigs, and cockroaches — are *omnivores*, eating both plants and animals.[2]

Both producers and consumers use the chemical energy stored in glucose and other organic compounds to fuel their life processes. In most cells, this is accomplished through aerobic respiration, a process with a net chemical change opposite that of photosynthesis:

$$\text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water} + \text{energy}$$

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

Some decomposers get energy through anaerobic respiration, or fermentation. Instead of carbon dioxide and water, the end products are compounds such as methane gas (a simple hydrocarbon) and ethyl alcohol. Normally, in the decay of organic materials, a chemical process based on aerobic respiration occurs, with carbon-based organic material combining with oxygen to yield carbon dioxide and water. However, if there is no additional oxygen available because of an anaerobic environment — such as exists if organic matter is buried under sediment or stagnant water — then anaerobic decomposers go to work. Plant and animal remains are transformed into hydrocarbons as oxygen atoms are removed from the carbohydrate organic matter. This is the chemical basis for the formation of fossil fuels. It is now believed that most oil comes from a few brief epochs of extreme global warming over quite short spans of geological time. The process began long ago and today yields fuels — chemically stored sunlight — that are energy-dense and highly usable.

Energy in Ecosystems: Eating and Being Eaten

Just as individual organisms use energy, so do complex systems made up of thousands or millions of organisms. The understanding of how they do so has been one of the central projects of the science of ecology.

The term *ecology* was coined in 1869 by German biologist Ernst Haeckel from the Greek roots *oikos* ("house" or "dwelling") and *logos* ("word" or "study of"). However, the discipline of ecology — which is the study of how organisms interact with one another and their surroundings — did not really flourish until the beginning of the 20th century.

At first, ecologists studied food chains — big fish eating little fish. Quickly, however, they realized that since big fish die and are subsequently eaten by scavengers and microbes that are then eaten by still other organisms, it is more appropriate to speak of food *cycles* or *webs*. Further analysis yielded the insight that all of nature is continually engaged in the cycling and recycling of matter and energy. There are carbon cycles, nitrogen cycles, phosphorus cycles, sulfur cycles, and water cycles. Of fundamental importance, however, are *energy flows* — which tend to drive matter cycles and which, as we have seen, begin in nearly all cases with sunlight.

Energy is the basic currency of ecosystems, passing from green plants to herbivores to carnivores, with decomposers participating along the way. With each transfer of energy, some is lost to the environment as low-quality heat. Typically, when a caterpillar eats a leaf, when a thrush eats the caterpillar, or when a hawk eats the thrush, only 5 to 20 percent of usable energy are transferred from one level to the next. Thus, if green plants in a given area capture, for example, 10,000 units of solar energy, then roughly 1,000 units will be available to support herbivores, even if they eat all of the plants; only 100 units will be available to support primary carnivores; only 10 to support secondary carnivores; and only one to support tertiary carnivores. The more energy-transfer levels there are in the system, the greater the cumulative energy losses. In every ecosystem, most of the chemically bound energy is contained among the producers, which also account for most of the *biomass*. The herbivores present will account for a much smaller fraction of the biomass, and the carnivores for yet a still smaller fraction. Thus the energy flow in ecosystems is typically represented by a pyramid, with producers on the bottom and tertiary carnivores at the top.

The energy available in an ecosystem is one of the most important factors in determining its *carrying capacity*, that is the maximum population load of any given species that is able to be supported by its environment on an ongoing basis. Energy is not the only factor, however; the operative principle in determining carrying capacity is known as Liebig's Law (after the 19th-century German scientist Justus von Liebig), which states that whatever necessity is least abundant, relative to per-capita requirements, sets the environment's limit for the population of any given species. For a plant, the limiting factor may be heat, sunlight, water, nitrogen, or phosphorus. Sometimes too much of a limiting factor restricts the carrying capacity, as when plants are killed by too much water or too much soil acidity. The limiting factor for any population may change over time. For herbivores and carnivores, the most common limiting factor is food-energy. This is why ecologists pay so much attention to food webs: when we understand the energy flows within an ecosystem, the dynamics of the system as a whole become clear.

These days the term *ecology* is often understood to be used merely in a scientific critique of human society's negative impact on nature. There are two reasons for this. The first is that early ecologists soon realized that, since humans are organisms, ecology should include the study of the relationship between people and the rest of the biosphere. The second is that, as early ecologists cataloged and monitored various natural systems, they found that it was becoming increasingly difficult to study such systems in an undisturbed state; everywhere, nature was being impacted by the human presence.

This impact itself became a focus of investigation, and soon ecologists realized that disturbed and undisturbed systems differ in clear ways. Ecosystems that have not been disturbed significantly for long periods of time (whether by humans or by natural disasters) tend to reach a state of dynamic equilibrium which ecologists call a *climax phase*, meaning that organisms have adapted themselves to one another in such a way as to maintain relatively constant population levels, to avoid direct competition, to keep energy flow-through to a minimum, and to recycle available energy and nutrients as completely as possible. They have formed, to use an anthropomorphic term, a *community*.

Biological communities are kept in equilibrium through *balancing feedback loops*. A useful technological example of a balancing feedback loop is a thermostat: if a room gets too cold, the thermostat triggers the furnace to turn on; when the room achieves the set temperature, the thermostat turns the furnace off. The temperature of the room varies, but only narrowly. Similarly, feedback loops in ecosystems — such as predator-prey relationships — tend to keep varying population levels within narrow ranges. If the vole population increases, fox and hawk populations will soon expand to take advantage of this food-energy surplus. The increase in the hawk and fox populations will then reduce the vole population, whose diminution will eventually lead to a reduction in the numbers of hawks and foxes as well.

The more mature the ecosystem, the more thoroughly the organisms in it use the available energy. Waste from one organism becomes food for another. Moreover, in order not to expend energy unnecessarily, organisms will tend to avoid direct competition through any of several strategies: by dividing the habitat into niches, by specializing (for example, if two species depend upon the same food source, they may evolve to feed at different times of day), or by periodic migration. Territorial animals avoid wasting energy in fights by learning to predict one another's behavior from signals like posture, vocalizations, and scent marks.[3] As a result, climax ecosystems give the appearance of cooperation and harmony among member species. The degree of mutual interdependence achieved can be astounding, with differing species relying on

one another for food, shelter, transportation, warnings of danger, cleaning, or protection from predators. As biologist Lewis Thomas once put it, "The urge to form partnerships, to link up in collaborative arrangements, is perhaps the oldest, strongest, and most fundamental force in Nature. There are no solitary, free-living creatures, every form of life is dependent on other forms."[4]

In climax ecosystems, population levels are kept relatively in check not only through predators culling prey species, but also through species acting on their own to limit their numbers via internal feedback mechanisms. These internal mechanisms are seen in elephants, for example, which regulate their population densities through delays in the onset of maturity as well as among smaller animals such as mice, where females typically ovulate more slowly or cease ovulation altogether if populations become too dense. In many bird species, much of the adult population simply does not breed when there is no food-energy available to support population growth.

All of this contrasts with ecosystems that have recently been seriously disturbed, or whose balances have been upset by the arrival of a new species.

Fires, floods, and earthquakes are high-energy events that can overwhelm the energy balances of climax ecosystems. Disturbed ecosystems are characterized by disequilibrium and change. First, *pioneer species* appear — and proliferate wildly. They then give way to various secondary species. The environment passes through a series of phases, known collectively as *ecological succession*, until it arrives again at a climax phase. During these successive phases, earlier organisms transform the environment so that conditions are favorable for organisms that appear later. For example, after a forest fire, tough, annual, weedy, ground-cover plants spring up first. During the second or third season, perennial shrubs begin to dominate; a few years later, young trees will have grown tall enough to shade out the shrubs. In some cases, this first generation of trees may eventually be replaced by other tree species that grow taller. It may take many decades or even centuries for the land to again become a climax forest ecosystem. If we accept the view that the Earth can itself be treated as a living being, as has been proposed by biologists James Lovelock and Lynn Margulis[5], then it might be appropriate to think of succession as the Earth's method of healing its wounded surface.

In other instances, balances in ecosystems can be upset as a result of the appearance of *exotic species*. These days, the arrival of most exotic species is due to the actions of humans importing plants and animals for food, decoration, or as pets. But sometimes new arrivals appear on a freak wind current or a piece of flotsam. Most newcomers, having evolved in other environments, are unfit for life in their new surroundings and quickly perish; but occasionally, an exotic species finds itself in an environment with plenty of available food and with no predators to limit its numbers. In such instances, the species becomes an *invader* or *colonizer* and can compete directly with indigenous species. Most Americans are familiar with Scotch broom, starlings, and kudzu vine — all of which are successful, persistent, and profuse colonizers.

Many colonizing species are parasites or disease-causing organisms: bacteria, protozoa, or viruses. When such organisms initially invade a host species, they are often especially virulent because the host has not yet developed the proper antibodies to ward off infection. But the death of the host is no more in the interest of the microbe than it is in the interest of the host itself since the former is dependent on the latter for food and habitat. Thus, over time, disease organisms and their hosts typically co-evolve, so that diseases which initially were fatal eventually become relatively innocuous childhood diseases like measles, mumps, or chickenpox.

Not all feedback loops create balance, however; in *reinforcing feedback loops*, change in one direction causes more change in the same direction. A technological example would be a microphone held too close to the speaker of the amplifier to which it is attached. The microphone picks up sound coming from the speaker, then feeds it back to the amplifier, which amplifies the sound and sends it back through the speaker, and so on. The result is a loud, unpleasant squeal.

Colonizing species sometimes create reinforcing feedback loops within natural systems. While population levels among species in climax ecosystems are relatively balanced and stable, populations in disturbed or colonized ecosystems go through dramatic swings. When there is lots of food-energy available to the colonizing species, its population *blooms*. Suppose the organism in question is the rabbit, and the environment is Australia — a place previously devoid of rabbits, where there is plenty of food and no natural predator capable of restraining rabbit population growth. Each rabbit adds (on average) ten new baby rabbits to the population. This means that if we began with ten rabbits, we will soon have 110. Each of these adds ten more, and before we know it, we have 1,210 rabbits. More rabbits cause more babies, which cause more rabbits, which cause more babies.

Obviously, this cannot go on forever. The food supply for the rabbits is ultimately limited, and eventually there will be more rabbits than there is food to support them. Over the long term, a balance will be struck between rabbits and food. However, that balance may take a while to be achieved. The momentum of population increase may lead the rabbits to *overshoot* their carrying capacity. The likelihood of overshoot is increased by the fact that the environment's carrying capacity for rabbits is not static. Since the proliferating rabbits may eat available vegetation at a faster rate than it can naturally be regenerated, the rabbits may actually reduce their environment's rabbit-carrying capacity even as their numbers are still increasing. If this occurs, the rabbit population will not simply gradually diminish until balance is achieved; instead, it will rapidly *crash* — that is, the rabbits will *die off*.

At this point, depending on how seriously the rabbits have altered their environment's carrying capacity, they will either adapt or die out altogether. If they have not eaten available food plants to the point that those plants can no longer survive and reproduce, the rabbit population will stabilize at a lower level. For a time, population levels will undergo more seasonal swings of bloom, overshoot, and die-off as food plants recover and are again eaten back. Typically, those swings will slowly diminish as a balance is achieved and as the rabbits become incorporated into the ecosystem. This is, in fact, what has begun to happen in Australia since the introduction of rabbits by Europeans in 1859. However, if the rabbits were ever to eat food plants to the point of total elimination, they would reduce the rabbit-carrying capacity of their environment to zero. At that point, the rabbits would die out altogether.

Since successful invaders change their environments, usually overpopulating their surroundings and overshooting their ecosystem's carrying capacity, colonized ecosystems are typically characterized by reduced diversity and increased energy flow-through. As colonizers proliferate, energy that would ordinarily be intercepted by other organisms and passed on through the food web goes unused. But this is always a temporary state of affairs: living systems don't like to see energy go to waste, and sooner or later some species will evolve or arrive on the scene to use whatever energy is available.

These are the rules of the game with regard to energy and life: energy supplies are always limited; there is no free ride. In the long run, it is in every species' interest to learn to use energy frugally. Competition, though it certainly exists in Nature, is temporary and limited; Nature prefers stable arrangements that entail self-limitation, recycling, and cooperation. Energy subsidies (resulting from the disturbance of existing environments or the colonization of new ones) and the ensuing population blooms provide giddy moments of extravagance for some species, but crashes and die-offs usually follow. Balance eventually returns.

Social Leveraging Strategies: How to Gain an Energy Subsidy

We don't often tend to think about the social sciences (history, economics, and politics) as subcategories of ecology. But since people are organisms, it is apparent that we must first understand the principles of ecology if we are to make sense of events in the human world.

Anthropological data confirm that humans are capable of living in balance and harmony as long-term members of climax ecosystems. For most of our existence as a species, we survived by gathering wild plants and hunting wild animals. We lived within the energy balance of climax ecosystems — altering our environment (as every species does), yet maintaining homeostatic, reciprocally limiting relationships with both our prey and our predators.

However, humans are also capable of acting as colonizers, dominating and disrupting the ecosystems they encounter. And there is evidence that we began to do this many millennia ago, long before Europeans set out deliberately to colonize the rest of the world.

Like all organisms, humans seek to capture solar energy. Humans have certain disadvantages as well as advantages in this regard. Our disadvantages include our lack of thick fur, which would allow us to live in a wide range of climates, and our upright posture, which hampers our ability to outrun bears and lions. Our advantages include our adaptability, our flexible and grasping hands, and our ability to communicate abstract ideas by means of complex vocalizations — that is, by language.

We have made the most of our advantages. By exploiting them in ever more ingenious ways, we have developed five important strategies for gaining energy subsidies and thereby expanding the human carrying capacity of our environments:

- *takeover,*
- *tool use,*
- *specialization,*
- *scope enlargement, and*
- *drawdown.*[6]

While other creatures have adopted some of these strategies to a limited degree, modern industrial humans have become masters of all of them, combining and leveraging their advantages. Through an examination of these strategies we can begin to understand how and why *Homo sapiens* — one species among millions — has come to dominate the planetary biosphere.

Takeover

The first and most basic strategy that we have used to increase the human carrying capacity of our environments is one that William Catton, in his pathbreaking book *Overshoot* (1980), called *takeover.* It consists, in his words,

> ... of *diverting* some fraction of the earth's life-supporting capacity from supporting other kinds of life to supporting our kind. Our pre-*Sapiens* ancestors, with their simple stone tools and fire, took over for human use organic materials that would otherwise have been consumed by insects, carnivores, or bacteria. From about 10,000 years ago, our earliest horticulturalist ancestors began taking over *land* upon which to grow crops for human consumption. That land would otherwise have supported trees, shrubs, or wild grasses, and all the animals dependent thereon — but fewer humans. As the expanding generations replaced each other, *Homo sapiens* took over more and more of the surface of this planet, essentially at the expense of its other inhabitants.[7]

Takeover is a strategy composed of substrategies. The most basic of these entailed simply moving to new habitats. *Homo sapiens* presumably evolved in Africa; probably because of population pressure (which, in turn, may have been due to natural disasters or climate change), early humans left their African homeland and gradually began to fan out around the globe — first to Asia and Europe, and then to Australia, the Pacific Islands, and the Americas. As humans arrived in new habitats, they inevitably took over food-energy from other organisms, as all successful colonizing species do. They hunted for wild game that might otherwise have been prey for wolves, lions, or bears; and they foraged for roots, berries, seeds, and tubers that were already nourishment to a host of herbivores.

Meanwhile, humans were themselves prey to large carnivores. Hence, humans and the existing members of their newfound ecosystem communities went through a process of mutual adjustment. The archaeological evidence suggests that the adjustment was sometimes a painful one: humans often upset local balances dramatically, appropriating so much of the food supply that they caused or hastened the extinction of many animal species.[8]

Humans facilitated the takeover process by the use of fire — a rapid release of chemically stored energy. This constituted a second substrategy of takeover. In addition to keeping people warm at night, fire also served to increase their food supply. Early humans often carried fire sticks with them, deliberately igniting underbrush both to flush out game and to encourage the growth of edible shoots and grasses. The Native Americans and Aborignals of Australia were still using fire this way when European colonists first arrived. It is interesting to note that at least one nonhuman animal has adopted the same tactic: the black kite of India is known as the "fire hawk" because of its habit of picking up smoldering sticks from fires, dropping them on dry grass, and then waiting to catch small animals that flee.[9]

When humans arrived in Australia roughly 60,000 years ago, their use of fire so disrupted the normal growth cycles of shrubs and trees that large indigenous birds and mammals, including giant kangaroos and flightless ostrich-like birds, were deprived of food. According to recent paleontological research, roughly 85 percent of the Australian animals weighing more than 100 pounds disappeared within a few millennia of the first human appearance on the scene.[10]

The first humans to arrive in the Americas and the Pacific Islands provide similar examples: there, too, animal extinctions closely followed human arrival. In North America, the mammoth, mastodon, native horse, four-pronged antelope, native camel, giant beaver, ground sloth, mountain deer, and giant peccary all succumbed about 12,000 to 10,000 years ago, at a time when humans were migrating rapidly from Asia through present-day Alaska and southward into vast territories opened up by retreating ice sheets. Similarly, the Polynesian peoples extinguished the large, flightless moa bird soon after arriving in New Zealand.

But it is important to note what happened next in many of these places. In ancient Australia, over a period of tens of thousands of years, human beings and their adopted environment achieved a relative balance. The Aboriginals developed myths, rites, and taboos: overhunting was forbidden, and burning was permitted only in certain seasons of the year. Meanwhile, native species adjusted themselves to the presence of humans. All of the surviving species — humans, animals, and plants — co-evolved. By the time European colonizers arrived, once again upsetting the balance, Australia — people and all — had the characteristics of a climax ecosystem. Many native Australian trees and shrubs had so adjusted themselves to the Aboriginals' "fire-farming" practices that they could no longer reproduce properly in the absence of deliberate burning. Moreover, the Aboriginals had learned the necessity of limiting their own population levels through extended lactation, the use of contraceptive herbs, or, if necessary, infanticide.

In North America, native peoples had come to regard as sacred the animals and plants they used as food. According to Luther Standing Bear in his 1928 book *My People the Sioux*, Native Americans recognized a human responsibility to the rest of nature and regarded "the four-leggeds, the wingeds, the star people of the heavens, and all things as relatives."[11] Overhunting or the wanton destruction of ecosystems had come to be viewed by these people as an act with negative moral as well as practical implications.

In addition to the colonization of new territories and the use of fire, humans have pursued takeover through yet another substrategy: the appropriation of ever greater amounts of the total food web to human use, first through

horticulture (gardening with a hoe or digging stick), then through agriculture (growing monocrops using plows and draft animals). The deliberate planting and tending of food plants probably began gradually and somewhat inadvertently at a time when humans had already populated many habitable areas of the world as densely as they could. When people live by hunting and gathering, they require large territories; in this case, the human carrying capacity of a typical environment may be considerably less than one person per square mile. Horticulture yielded more food from a given land area, permitting population densities of several individuals per square mile.

Agriculture was yet more productive, permitting even greater population densities, though it also resulted in a reduction in the variety and nutritional quality of the human food supply: paleoanthropologists have found that the skeletons of early agriculturalists are usually smaller and show more evidence of degenerative diseases than those of earlier hunter-gatherers.

Agriculture entailed the deliberate simplification of ecosystems. Humans learned to grow only a few domesticated food crops while discouraging competitors to their food plants (*weeds*) and killing any organisms that competed with humans for access to those food plants (*pests*).

The domestication of animals constituted yet another variation on the takeover strategy. Animals could be useful for extracting energy from ecosystems in two ways: first, by concentrating and making available food energy from otherwise inedible fibrous plants; and second, by providing traction to pull plows, carts, and carriages. By helping to intensify agricultural production and assisting in overland transportation, domesticated animals facilitated the conquest of ecosystems and continents.

Though the takeover strategy was applied at first to other species, soon some humans began to use it in relation to other humans. Typically, societies with denser populations and more powerful weapons took over the territories of, or enslaved, groups with less intensive demands on the environment. This last substrategy achieved its apotheosis in the European takeover of most of the rest of the planet throughout the past 500 years.

Tool Use

Over the millennia, we humans facilitated our takeover of new ecosystems and other societies with an expanding kit of tools — from fire-drills, spears, knives, baskets, and pots to plows, carts, sailboats, machine guns, steam shovels, and computers.

This second basic strategy — the design, making, and use of tools — has ancient roots: archaeological evidence suggests that humans have been using tools for at least a hundred thousand years, perhaps much longer. Moreover, tool use is not absent among other animals: captive birds of the corvid family (which includes crows, ravens, and jays) have been reliably observed spontaneously constructing rakes out of available sticks or newspaper strips for pulling grain from outside their cage; placing stones in a drinking dish to raise the water to a drinkable level; or using a plastic cup to fetch and pour water on too-dry food.[12] Thus, the spectacular tools invented and used by modern industrial humans represent the development of a long-existing biological potential.

Nearly all tools assist in the harvesting of ever-greater amounts of energy from the environment. The only notable exceptions are tools used purely for entertainment — which are also ancient, dating back at least to the oldest-recovered bone flute, made about 60,000 years ago.

It is often said that humans use tools to adapt and change their environments, and this is certainly true (recall the use of fire to thin out brush and thus clear space for the growth of food-yielding plants). However, it is just as accurate to say that we use tools to adapt *ourselves* to a variety of habitats. For example, we use shoes to adapt our feet to walking on rocky or uneven terrain.

Looked at this way, tools can be considered as functionally equivalent to detachable organs.[13] Another way of saying this is that tools are *prosthetic devices* we add to ourselves to replace or supplement our senses, limbs, or muscles. Usually the term *prosthesis* is used to describe a mechanical replacement for an absent organ or a supplement for a poorly functioning one (examples include artificial limbs, false teeth, iron lungs, and eyeglasses); however, it is possible to broaden the concept to include mechanical enhancements of perfectly healthy organs: wheels enhancing the mobility of legs and feet, bows and arrows effectively extending the reach of arms and hands, and so on. William Catton calls *Homo sapiens* "the prosthetic animal" and notes wryly that "when an airline pilot with thirty-three years of flying experience refers to the familiar act of buckling his cockpit seatbelt as 'strapping a DC-8 to my waist,' it is clear that even a modern jetliner can be seen as an elaborate prosthetic device."[14] Catton also notes that the "evolutionary and ecological significance of such prosthetic devices has been to facilitate the spread of mankind over a more extensive range than we could have occupied with only the equipment of our own bodies."[15]

Because tools are extensions of ourselves, they change us. The human-tool complex is effectively a different organism from a toolless human. We unconsciously tend to adapt ourselves to our tools in a myriad of ways — witness how industrial societies have adapted themselves to the automobile. Tool use also alters the mentality of entire societies. For example, the use of

the technology of money tends to move whole cultures in the direction of an increased emphasis on calculation and quantification, powerfully intensifying any existing utilitarian attitudes toward natural resources and other humans by facilitating the accumulation of wealth. Similarly, as Marshall McLuhan and others have documented, the technology of writing reduces people's reliance upon memory while intensifying their use of abstract reasoning.[16] More recently, computers have sped up our lives while seeding our language with new metaphors: we now "process" experiences the way our computers process information; we get together with friends to "download" gossip; we complain that talkative individuals take up too much "bandwidth"; we go on vacations so that we can have "down time." Gone are the days of barnyard metaphors (chickens coming home to roost, foxes guarding the henhouse, grown children leaving the nest). As metaphors based on experiences of the natural world disappear from language and are replaced by mechanical or electronic referents, human consciousness may be subtly disengaging itself from its biological roots.

One way to better understand the evolution of technology through the millennia is to examine the relationship between tools and energy. All tools require energy for their use or manufacture — but that energy may come from human muscle power or some source external to the human body, such as animal muscle, wood fire, coal fire, or hydro-generated electricity. Some tools harness externally produced energy, making it available to other tools that then do work for us. Using energy source as a criterion, we can identify four basic categories of tools. These categories also correspond very roughly to four major watersheds in social evolution:

A. *Tools that require only human energy for their manufacture and use.* Examples include stone spearheads and arrowheads, grinding tools, baskets, and animal-skin clothing. These sorts of tools are found in all hunter-gatherer societies.

B. *Tools that require an external power source for their manufacture, but human power for their use.* Examples: all basic metal tools, such as knives, metal armor, and coins. These tools were the basis of the early agricultural civilizations centered in Mesopotamia, China, Egypt, and Rome.

C. *Tools that require only human energy for their manufacture, but harness an external energy source.* Examples: the wooden plow drawn by draft animals, the sailboat, the firedrill, the windmill, the water mill. The firedrill was used by hunter-gatherers, and the wooden plow and sailboat were developed in early agricultural societies; the windmill and water mill appeared at later stages of social evolution.

D. *Tools that require an external energy source for their manufacture and also harness or use an external energy source.* Examples: the steel plow, the gun, the steam engine, the internal combustion engine, the jet engine, the nuclear reactor, the hydroelectric turbine, the photovoltaic panel, the wind turbine, and all electrical devices. These tools and tool systems are the foundation of modern industrial societies — in fact, they define them.

This scheme of classification emphasizes the cumulative nature of technological and social development. Some Class A tools still persist in horticultural, agricultural, and even industrial societies (flint blades, for example, are, because of their extreme sharpness, today often used by brain and eye surgeons for the most delicate operations), but Class D tools by and large did not exist in hunter-gatherer societies. However, the categories do overlap somewhat, and there are exceptions and anomalies: hunter-gatherers used fire to make some tools (for example, by cooking glues), thus turning them into Class C tools; the use of the metal plow (Class D) predated industrialism by three millennia; and a simple steam engine (Class D) was invented by the ancient Greeks, though they did not put it to practical use. Still, even if we allow these inconsistencies, the scheme shows a clear trend: over time, tools and the societies that use them have increasingly captured energy from sources external to the human body and used that captured energy to fashion even more sophisticated energy-capturing and energy-reliant tools and tool systems.

Specialization

This third strategy is closely related to the second. Since a human-tool complex is effectively a different organism from a toolless human, humans using different tool complexes can become, in effect, different species from one another. As a society becomes composed of people working in different occupations, using different sets of tools, it becomes more complex; it develops its own technological-economic "ecosystem" that exists within, yet apart from, the larger biotic ecosystem.

We noted earlier that humans first applied the takeover strategy to other species and then to other humans; something similar happened with the tool-using strategy. At first, humans made tools out of stones and sticks, but eventually their increasingly utilitarian frame of mind led them to begin treating other human beings as tools. This scheme at first took the form of slavery. Some humans could capture the energy of others who had been seized in war, putting them to work at tasks too dangerous, dreary, or physically taxing for any free person to undertake voluntarily — tasks such as mining metal ores

from beneath the Earth's surface. Those ores were, in turn, the raw materials from which were fashioned the chains and weapons that kept the slaves themselves in bondage. Eventually, metals also came to be used as money, a tool that would become the basis for a more subtle form of energy capture: wage labor. Through the payment of money, humans could be persuaded to give their energies to tasks organized by — and primarily benefiting — others. Some humans would become members of a permanent soldier class, which, through its conquests, could capture human slave-energy; others would become part of a peasant class, capturing solar energy through the growing of plants and animals for food for others. Compared to the raw energy of fire, human energy is of extremely high quality because it is intelligently directed. Only with the computer revolution of the late 20th century could inventors envision automatons capable of capturing and using energy in comparably sophisticated ways.

Just as the use of tools has affected our collective psychology, so has specialization. With a lifelong division of labor, many members of society became cut off from basic subsistence activities and processes; rather than enjoying a direct relationship with the natural world, they became, for their material existence, dependent upon the society's economic distribution system. This subtly fostered attitudes of conformity and subordination while undermining feelings of personal confidence and competence.

Scope Enlargement

To understand the nature of this fourth strategy for enlarging the human carrying capacity of environments, we must return to Liebig's Law, which states that for any given organism the carrying capacity of a region is limited by whatever indispensable substance or circumstance is in shortest supply.

Tools provided ways of getting around many limiting factors. For example, clothing permitted humans to live in climates that were otherwise too cold whereas irrigation enabled humans to produce an abundance of food in regions that would otherwise have supported far fewer inhabitants. However, some limiting factors could be mitigated simply by transporting resources from one region to another. This sharing of resources among geographically circumscribed regions typically took the form of trade.

If one region had plenty of minerals but poor soil and another had good soil but no minerals, trade allowed both regions to prosper so that the total population of the two regions working together could far exceed what would be possible if they remained in isolation. William Catton calls this strategy *scope enlargement* and argues that

> a good many of the events of human history can be seen as efforts to implement [this principle] .... Progress in transport technology, together with advancements in the organization of commerce, often achieved only after conquest or political consolidation, have had the effect of enlarging the world's human carrying capacity by enabling more and more local populations (or their lifestyles) to be limited not by local scarcity, but by abundance at a distance.[17]

Local or regional catastrophes — famines, earthquakes, floods, droughts, plagues, etc. — have always been part of the human experience. With scope enlargement, their effects can be somewhat mitigated, as when aid is trucked or flown into a region experiencing famine. However, local populations then tend to become increasingly dependent on the system of trade and transport that connects them. If that system were itself ever to be threatened, many or all of the regions it encompasses would suddenly be put at risk.

In the past few decades, the strategy of scope enlargement has reached its logical culmination in a world system of trade and transport known as *globalization*. We who today live in industrialized countries are the ultimate heirs of the millennia-long process of scope enlargement. We have become globalized humans, daily eating foods grown hundreds or thousands of miles away, filling our cars with gasoline that may have originated in oil wells on the other side of the planet.

Drawdown

The fifth and final strategy that humans have used to increase their environment's carrying capacity is to find and draw down nature's stocks of nonrenewable energy resources: coal, oil, natural gas, and uranium. This strategy can only be pursued once societies are near the point of being able to invent, and produce in quantity, sophisticated Class D tools.

Drawdown dramatically improved the rates of return from the previous four strategies. It permitted

- the intensification of agriculture, with chemical fertilizers, pesticides, and herbicides increasing yields per acre, and with acreages devoted to the growing of food for humans increasing as a result of draft animals being replaced by tractors;
- the invention and utilization of a vast array of new tools that use energy more intensively;
- the development of more social roles and occupations based on specialized tool usage; and

- the rapid acceleration of transportation and trade.

Drawdown has been by far the most successful of the five strategies at increasing the human carrying capacity of the planet, and the degree of that success can be gauged in a single statistic, namely that of the world population growth since the beginning of the industrial revolution. The human population did not reach one billion until about 1820; in the less than two centuries since then, it has increased six-fold. This is a rate of growth unprecedented in human history.

The exploitation of energy-bearing minerals created so much new carrying capacity, and so quickly, that much of that new capacity could be translated into increased wealth and a higher standard of living for a small but significant portion of the world's population. Previously, a parasitic increase of the standard of living for a wealthy few (kings, nobles, and lords) nearly always entailed a lessening of the standard of living of far more numerous serfs and peasants. Now, with power being liberated from fossil fuels, so much energy was available that the standard of living could be improved for large numbers of people, at least to a certain extent. Even though the majority of the world's population shared but little in this bonanza and continued to be exploited for cheap labor via takeover and specialization, virtually everyone shared in the expectation that the benefits of fuel-fed industrialism could eventually be spread to all. This expectation led in turn to a partial relaxation of the class-based social tensions that had plagued complex societies since their beginnings.

Americans, more than the people of any other region, have learned to take high-energy living standards for granted. In order to gain some perspective on this accustomed standard, it might be helpful to perform a little experiment. Try running up three flights of stairs in twenty seconds. If you weigh 150 pounds and the three flights go up forty feet, you will have done 6,000 foot-pounds of work in twenty seconds, or 300 foot-pounds per second. One horsepower equals 550 foot-pounds per second; therefore, you will have just generated a little over half a horsepower. But no one could sustain such a burst of muscle-energy all day long. The average sustained human power output is roughly one-twentieth of a horsepower.

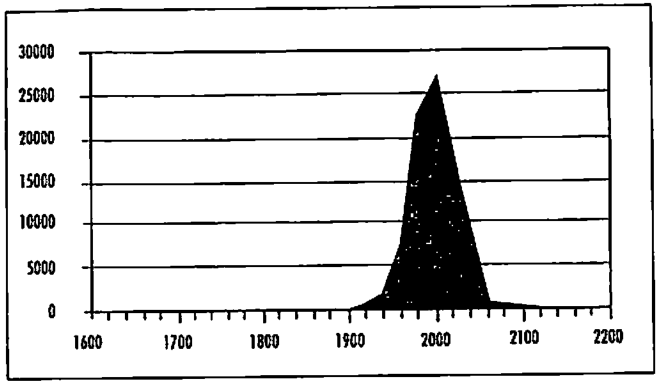

Figure 1. World oil production from 1600 to 2200, history and projection, in millions of barrels per year (Source: C. J. Campbell)

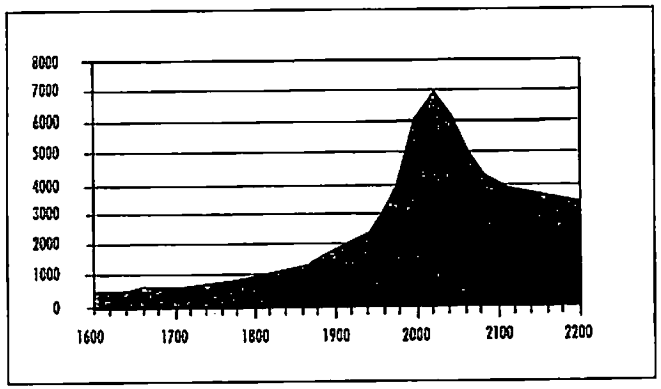

Figure 2. World population from 1600 to 2200, history and projection, assuming impacts from oil depletion, in millions (Source: C. J. Campbell)

This exercise is useful (even if performed only in imagination) in comparing human power with the power of the machines that maintain our modern way of life. Suppose human beings were powering a generator connected to one 150-watt light bulb. It would take five people's continuous work to keep the light burning. A 100-horsepower automobile cruising down the highway does the work of 2000 people. If we were to add together the power of all of the fuel-fed machines that we rely on to light and heat our homes, transport us, and otherwise keep us in the style to which we have become accustomed, and then compare that total with the amount of power that can be

generated by the human body, we would find that each of us Americans has the equivalent of over 50 "energy slaves" working for us 24 hours each day. In energy terms, each middle-class American is living a lifestyle so lavish as to make nearly any sultan or potentate in history swoon with envy.[18]

But if the payoffs of the drawdown strategy are spectacular, so are its dangers and liabilities. The latter can be grouped into three broad categories: environmental degradation, climate change, and increasing human dependency on a "phantom" carrying capacity.

Pollution was the first drawback of fossil fuel use to make itself apparent. Of course, pollution was hardly unknown before fossil fuels —it was apparent in the smoke of wood fires blackening winter skies over medieval cities, the horse manure clogging the streets of 19th-century London and New York, and the tailings from mines ruining surrounding land and water throughout most of the civilized world since the dawn of civilization itself. But with the advent of the petrochemical industry, the toxic load on the environment has increased dramatically and quickly. Over the course of a few decades, chemical engineers synthesized tens of thousands of new, complex organic compounds for a wide variety of purposes. Few of these chemicals were safety-tested; of those that were, many turned out to have toxic effects on humans or other organisms. The undesirable consequences of the spread of these chemicals into the environment were sometimes dramatic, with rates of respiratory ailments and cancers soaring, and at other times more subtle, with estrogen-mimicking chemicals disrupting reproductive processes in fish, birds, amphibians, and mammals, including humans.[19]

The second danger of the drawdown method, which has more recently begun to make itself known, is climate change resulting from the global accumulation of greenhouse gases. The world's oil and coal fields represent vast stores of carbon that have been sequestered under the Earth's surface for hundreds of millions of years. With the advent of the industrial revolution, as these stores of carbon began to be mined and burned at an increasing rate, that carbon was released into the atmosphere as carbon dioxide (CO_2). There is strong evidence to suggest that elevated levels of carbon dioxide trap heat in the global atmosphere, creating a greenhouse effect that gradually warms the planet. Climate records derived from Greenland ice cores indicate a very close correlation between atmospheric carbon dioxide concentrations and global temperatures. Around the beginning of the 20th century, both CO_2 concentrations and global temperature began perceptibly to rise. For the previous 10,000 years, the amount of carbon in our atmosphere had remained constant at 280 parts per million. By 1998, that amount had increased to 360 ppm and was projected to increase to 560 ppm by the middle of the current century. Climate scientists have projected a consequent increase in the average global temperature of 3 to 7 degrees Fahrenheit (2 to 5 degrees Celsius).

Thus we have, unintentionally, begun to disturb massive planetary systems that have kept much of the world climate relatively hospitable to civilization for the last 10,000 years. We are heating the deep oceans, which leads to more frequent and intense El Niño weather patterns. The timing of the seasons is noticeably altered and most of Earth's glaciers are retreating at accelerating rates. The potential effects are catastrophic. They include the drowning of coastal cities and whole island nations as a result of rising sea levels and intensified storms; the proliferation of disease-spreading insects into new regions, resulting in cases of malaria perhaps doubling in tropical regions and increasing 100-fold elsewhere; and the loss of forests and wildlife that depend upon a stable climate, leading to vastly increased extinction rates and the collapse of whole ecosystems.[20] The Earth's climate is so finely balanced that global warming could result in a rapid flip in weather regimes. For example, cold, fresh water from the melting of the arctic ice pack could halt the Gulf Stream, plunging Europe and North America into a new Ice Age.

The third danger of the drawdown strategy is one that is discussed less frequently than either pollution or global warming, though its ultimate implications for humankind may be even more dire. This is our increasing dependency on energy resources that are depleting within historically narrow time frames. There are now somewhere between two and five billion humans alive who probably would not exist but for fossil fuels. Thus if the availability of these fuels were to decline significantly without our having found effective replacements to maintain all their life-sustaining benefits, then the global human carrying capacity would plummet — perhaps even below its pre-industrial levels. When the flow of fuels begins to diminish, everyone might actually be worse off than they would have been had those fuels never been discovered because our pre-industrial survival skills will have been lost and there will be an intense competition for food and water among members of the now-unsupportable population (Chapter 5 provides a closer look at the likely consequences of the anticipated petroleum depletion.).

Complexity and Collapse: Societies in Energy Deficit

The five strategies humans have adopted for capturing increasing amounts of energy (takeover, tool use, specialization, scope enlargement, and drawdown) have permitted societies to grow in size, scope, and complexity. However, it is important to note that the ramp of history, rising upward from the simplest Paleolithic hunter-gatherer bands to the heights of globalized industrial civilization, has not been a smooth one. Many civilizations have expanded their scope and complexity dramatically, only to dissolve back into simpler forms of social organization.

Archaeologists have understandably given much attention to the study of collapsed complex societies since the ruins left by the ancient Egyptians, Romans, Mayas, Greeks, Minoans, Mesopotamians, Harappans, and Chacoans provide a wealth of material for investigation. Why would a group of people intelligent enough to have built impressive temples, roads, and cities suddenly lose the ability to maintain them? Why would a society capable of organizing itself into a far-flung empire, with communications networks and distribution systems, suddenly lose its ability to continue? Such questions — as much as the ruins left behind — contribute to a widespread and perennial fascination with lost civilizations.

The literature on the subject is voluminous and includes speculation on the causes of collapse ranging from class conflict to mismanagement. Undoubtedly, the best modern research on this subject was done by archaeologist Joseph Tainter, whose book *The Collapse of Complex Societies* (1988) is now widely recognized as the standard work on the topic. In his book and related essays, Tainter takes an ecological view of society as an energy-processing structure and concludes that complex societies tend to collapse because *their strategies for energy capture are subject to the law of diminishing returns.*

Tainter describes complexity as a problem-solving strategy used by civilizations and empires. "For the past 12,000 years," he writes, these societies "have seemed almost inexorably to grow more complex. For the most part this has been successful: complexity confers advantages, and one of the reasons for our success as a species has been our ability to increase rapidly the complexity of our behavior."[21]

When Tainter uses the term "complexity," he is referring to "such things as the size of a society, the number and distinctiveness of its parts, the variety of specialized roles that it incorporates, the number of distinct social personalities present, and the variety of mechanisms for organizing these into a coherent, functioning whole."[22] Hunter-gatherer societies, for example, may have no more than a few dozen distinct social personalities whereas a modern census recognizes many thousands of occupational roles. More complex societies, Tainter notes,

> are more costly to maintain than simpler ones, requiring greater support levels per capita. As societies increase in complexity, more networks are created among individuals, more hierarchical controls are created to

regulate these networks, more information is processed, there is more centralization of information flow, there is increasing need to support specialists not directly involved in resource production, and the like. All of this complexity is dependent upon energy flow at a scale vastly greater than that characterizing small groups of self-sufficient foragers or agriculturalists. The result is that as a society evolves toward greater complexity, the support costs levied on each individual will also rise, so that the population as a whole must allocate increasing portions of its energy budget to maintaining organizational institutions. This is an immutable fact of societal evolution, and is not mitigated by type of energy source.[23]

Tainter offers the following diagram (Fig.3) as a schematic representation of the trajectory of a typical complex society. At first, incremental investments in social complexity, new technologies, and expanding scope yield impressive returns. Agricultural production increases, and wealth captured from conquest flows freely as the society's increasingly formidable army invades surrounding states. But gradually the rates of return tend to diminish, even as requirements for further investments in institutional support (including investments in legitimization and coercion) are still increasing. This eventually makes the strategy of complexity itself less palatable to the population. According to Tainter, a

> society that has reached this point cannot simply rest on its accomplishments, that is, attempt to maintain its marginal return at the status quo, without further deterioration. Complexity is a problem-solving strategy. The problems with which the universe can confront any society are, for practical purposes, infinite in number and endless in variety. As stresses necessarily arise, new organizational and economic solutions must be developed, typically at increasing cost and declining marginal return. The marginal return on investment in complexity accordingly deteriorates, at first gradually, then with accelerating force. At this point, a complex society reaches the phase where it becomes increasingly vulnerable to collapse.[24]

From the perspective of the average citizen, the burden of taxes and other costs is increasing while at the local level there are fewer benefits. The idea of being independent thus becomes more and more attractive. "Collapse," then, may simply entail the decomposition of society, as individuals or groups decide to pursue their own immediate needs rather than the long-term goals of the leadership. In other situations, collapse may entail the takeover of a society that is stressed because of declining marginal returns by another society that is still enjoying higher rates of return on its investments in strategic leveraging.

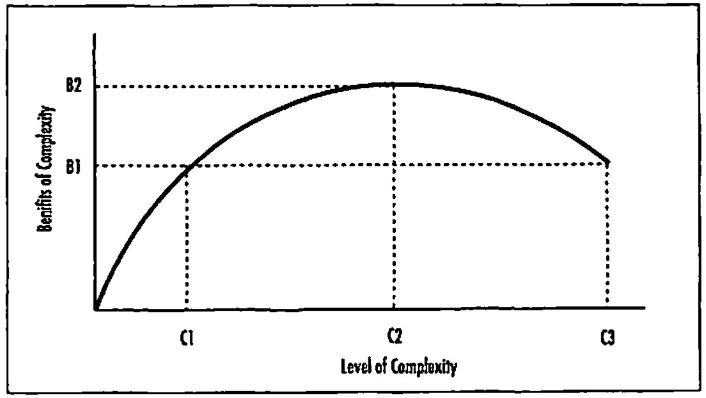

Figure 3: Benefits to a society from investments in complexity over time. Prior to point C1/B1, benefits are abundant; between points B1/C1 and B2/C2, returns on investments in complexity gradually diminish. After a society passes point B2/C2, its returns on investment become negative and it becomes vulnerable to collapse. (Source: Joseph Tainter, "Complexity, Problem Solving, and Sustainable Societies")

Tainter discusses this theory in relation to the well-documented collapse of 17 different civilizations. Regarding the Roman Empire, he writes:

> The establishment of the Roman Empire produced an extraordinary return on investment, as the accumulated surpluses of the Mediterranean and adjacent lands were appropriated by the conquerors. Yet as the booty of new conquests ceased, Rome had to undertake administrative and garrisoning costs that lasted centuries. As the marginal return on investment in empire declined, major stress surges appeared that could scarcely be contained with yearly Imperial budgets. The Roman Empire made itself attractive to barbarian incursions merely by the fact of its existence. Dealing with stress surges required taxation and economic malfeasance so heavy that the productive capacity of the support population deteriorated. Weakening of the support base gave rise to further barbarian successes, so that very high investment in complexity yielded few benefits superior to collapse. In the later Empire the marginal return on investment in complexity was so low that the barbarian kingdoms began to seem preferable.[25]

This process of collapse is somewhat analogous to the phenomenon of population overshoot and die-off within a colonized ecosystem; indeed, the population of the city of Rome declined from over a million inhabitants in 100 AD to about 40,000 in 1100 AD.

Tainter's discussion of the Western Chou Empire, the Harappan Civilization, Mesopotamia, the Egyptian Old Kingdom, the Hittite Empire, the Classic Mayan civilization, and others yields a similarly tight fit between theory and historical data.

Western civilization from the Middle Ages to the present illustrates the theory in a somewhat different way. Rather than growing and declining in a simple curve, Western civilization has recovered and undergone at least two even greater growth surges due to its ability to find and exploit new energy subsidies at critical moments. The takeover of the Americas, Africa, India, and the Pacific Islands offered subsidies ranging from slave labor to new sources of metal ores and timber. The expansion of the Euro-American cultural and political influence that these new resources enabled, while impressive, probably could not have been sustained through the 20th century in the face of rising costs (e.g., for the maintenance of colonial administrations) and declining returns, had it not been for the discovery of fossil fuels, the greatest energy subsidy ever known. This discovery, as we have already seen, enabled the transformation of civilization itself into a form never before seen: industrialism.

The returns on early investments in drawdown and industrial production were staggering. Costs were extraordinary as well, but they could easily be borne. As Tainter puts it,

> with subsidies of inexpensive fossil fuels, for a long time many consequences of industrialism effectively did not matter. Industrial societies could afford them. When energy costs are met easily and painlessly, the benefit/cost ratio of social investments can be substantially ignored (as it has been in contemporary industrial agriculture). Fossil fuels made industrialism, and all that flowed from it (such as science, transportation, medicine, employment, consumerism, high-technology war, and contemporary political organization) a system of problem solving that was sustainable for several generations.[26]

This does not mean, however, that industrial civilization is immune to the law of diminishing returns. Tainter cites statistics indicating that already there have been steep reductions in returns on increasing US investments in education, military hardware, information processing, and scientific research. As we will see in more detail in Chapter 3, the drawdown of fossil fuels is itself subject to the law of diminishing returns. Early investments in drilling for oil yielded fabulous returns. But most of the largest and most productive oil fields were discovered within a century of the drilling of the first commercial well: rates of discovery peaked in the 1960s. And so, over time, the amount of

energy that must be expended to find and extract each barrel of oil, or to mine each ton of coal, increases.

Tainter ends his book by drawing the following sobering conclusion: "However much we like to think of ourselves as something special in world history, in fact industrial societies are subject to the same principles that caused earlier societies to collapse."[27]

Applied Socio-Ecohistory: Explaining the American Success Story

So far in this chapter we have explored some of the basic energy principles at work in natural systems and human societies. In order to better illustrate these principles (and especially those discussed in the last two sections), let us use what we have learned to address a specific question that could add importantly to our understanding of global energy resource usage over the past two centuries: *Why is the United States of America currently the wealthiest and most powerful nation in the history of the world?*

Often this question is addressed through a discussion of ideas, personalities, and unique historical occurrences. We have all learned the names of early explorers, inventors, and politicians; we have been taught the importance of the American system of government, with its guarantees of freedoms and rights; and we have memorized the dates of important wars and other political events in US history. These are all of course essential to any explanation of US ascendancy. However, let us take an approach that focuses on energy and tackle the following question: To what extent does America owe its prominent position in the world to energy resources and its people's ability to exploit them?

Such a discussion must begin with geology and geography. The North American continent, which Europeans began to explore and claim in the early 16th century, was a place of extraordinary biotic and mineral abundance. Early Spanish conquistadors found vast forests, animals for food and fur, fertile farmland, fresh water, iron, copper, silver, and gold — all in far greater quantities than existed in Europe. Eventually, the colonists' descendants also found an abundance of coal and petroleum. These energy resources proved to be especially valuable because they enabled the more intensive extraction and use of all other resources.

When Europeans first arrived in the New World, there were already other humans present. Why hadn't Native Americans taken more advantage of all these resources? Why was it not they who became world conquerors, sailing to Europe to claim it as a possession of the Iroquois, the Seminole, or the Lakota?

As Jared Diamond explains in his Pulitzer Prize-winning book *Guns, Germs, and Steel: The Fates of Human Societies*, Eurasia had been blessed with indigenous domesticable cereal grains and traction animals nonexistent in the Americas.[28] These permitted — perhaps even encouraged — the development of large-scale agriculture and stratified societies. The Europeans thus had a head start in applying the leveraging strategies discussed above. Their successes in expanding the carrying capacity of their environment meant that Europe, by the 16th century, was comparatively crowded and resource-depleted. Europeans were therefore highly motivated to expand their application of the takeover and scope-enlargement strategies by conquering and exploiting new lands. Most Europeans who came to America were not so much searching for freedom as escaping population pressure and resource depletion.

Still, things might have turned out differently: in the early 15th century, squadrons of large Chinese junks made several amazing voyages that carried them as far as Hormuz; had these expeditions continued, the Chinese might have become the first to circumnavigate Africa and sail the Atlantic and the Pacific. However, political troubles back home in China called a halt to the entire project; thus newly claimed territories in America acquired names like New Spain and New England, rather than New Beijing or New Canton.

As it turned out, the Europeans who arrived in North America regarded the land as essentially empty and saw the native peoples — who were making far fewer demands on resources than the Europeans themselves were accustomed to making — as unproductive savages. Europeans at first sought to enslave the natives, thus taking over the human muscle-energy of the continent in addition to its other resources. But many of the natives — millions, in fact; in some regions over 90 percent of the population — quickly succumbed to colonists' diseases, such as smallpox, measles, and influenza. These diseases were caused by microorganisms that had become integrated into the internal bodily ecosystems of Europeans through centuries of contact with domesticated animals; for the natives of the Americas, however, these microorganisms were exotic invasive species whose impact was utterly devastating.[29] In any case, the natives made poor slaves because most were accustomed to living in a more easy-going and egalitarian — namely less specialized and complex — social environment than were the Europeans, and often preferred death to lifelong servitude.

Nevertheless, it was clear that great wealth could be extracted from the continent if only there were sufficient energy available to farm the land and mine the ores. Quickly, Europeans seized upon the strategy of importing Africans as slaves. With the latter's intelligently directed muscle-power as motive force, the machinery of extraction went to work and produced great

fortunes for thousands of colonists and their families — those, that is, who could afford to buy into this wealth-producing system. Because the Africans were typically kidnapped from kingdoms — complex societies — and then ripped from their cultural matrix (not only by transplanting them geographically but by preventing them from speaking their own languages and engaging in their own customs), they were somewhat more easily enslaved than were most Native Americans.

This discussion of "where" and "who" helps account for America's meteoric rise from colonial backwater to global superpower in a mere two centuries, but it is still not sufficient. We must also take into account the "when" of the US appearance on the world scene. Europeans had in fact arrived in North America several centuries before Columbus: the Norse and possibly the Irish made the voyage repeatedly between approximately 1000 and 1350 AD. However, all that ultimately resulted was the leaving behind of a few enigmatic stone inscriptions for future historians to puzzle over. As every musician knows, timing is of the essence. Jared Diamond notes that the

> second Eurasian attempt to colonize the Americas [in the 15th century] succeeded because it involved a source, target, latitude, and time that allowed Europe's potential advantages to be exerted. Spain, unlike Norway, was rich and populous enough to support exploration and subsidize colonies. Spanish landfalls in the Americas were at subtropical latitudes highly suitable for food production, based at first mostly on Native American crops but also on Eurasian domestic animals, especially cattle and horses. Spain's transatlantic colonial enterprise began in 1492, at the end of a century of rapid development of European oceangoing [Class C] ship technology, which by then incorporated advances in navigation, sails, and ship design developed by Old World societies (Islam, India, China, and Indonesia) in the Indian Ocean.[30]

Resources are of little benefit without the ability to exploit them. Imagine having several barrels of gasoline but no car or other motorized equipment with which to put that gasoline to use. This was essentially the situation not only of the Native Americans, but also, at first, of the invading Europeans with regard to America's energy minerals. Though the continent was rich in coal and petroleum, few people, if any, yet realized that fact.

However, the Europeans had spent many centuries making prior investments in tool making, and so the breakthrough to the production of Class D tools was for them merely the next step in a long evolution of strategic leveraging. As we have already noted, the entire process of industrialization was based on using fossil fuels (initially coal, later petroleum) to mechanize production and transport. Soon after the Industrial Revolution began in England, it became clear that North America in fact had a much greater natural abundance of energy minerals than did Europe. If the US had remained a colony, its energy resources would likely have been siphoned off to promote the production of still more wealth in the Old World. However, the American Revolutionary War had dissolved the former Crown Corporations of Virginia, Delaware, Massachusetts, etc., so that the people of the new nation of the United States of America were free to shape their own economic destiny by exploiting the continent's resources for their own benefit. Thus within a few decades the situation changed from being one in which Europe was taking resources from North America to one in which North America was taking industrial technology from Europe and putting it to more effective use due to its richer resource base. The US did not start the Industrial Revolution, but was poised to capitalize on it.

The history of the 19th century in America is a tale of snowballing invention, exploration, and extraction, each feeding the others. Political events were largely shaped by resource disputes. For example, the realization (by the industrial northern states) that America's future wealth lay far more in the extraction and use of concentrated fuels than in the continued reliance (by the agrarian southern states) on kidnapped African muscle-power may have played a role in the freeing of the slaves.

Overall, the US made the most of its energy-resource advantage. At first, wood fueled the mills and factories of the Northeast; soon it also fueled the railroads that brought raw materials to the factories and manufactured goods to the frontier. In the latter decades of the 19th century, coal took the place of dwindling wood supplies; and then in the 20th, oil — flowing initially from Pennsylvania and Ohio, then from southern California, then Texas and Oklahoma, and finally the Gulf of Mexico and Alaska — in turn fueled the automobile industry, modern agriculture, and the modern chemical industry. While European nations had to colonize far-off places like Indonesia in order to fill their increasing appetite for energy resources, the US could extract all it needed from within its borders. Its energy-resource base was so great that, until 1943, it remained a net petroleum exporter.

In the 20th century, while the old colonial powers (such as England, Spain, and Portugal) were reaping diminishing returns from their investments in conquest and while other aspiring colonial powers (Germany, Japan, and Italy) were thwarted in gaining access to energy resources in other lands, the US found itself in the rare and enviable position of having both abundant indigenous resources and the expertise, technology, and freedom to exploit

them for its own benefit. It invested the wealth from these resources both in further technological development and in the production of by far the most powerful and sophisticated weapons systems the world has ever seen. Thus by the end of the Second World War the US was, from both an economic and a military point of view, the most powerful nation in the history of the world.

This is not to say that the promise of political and religious freedom had played no role in drawing millions of skilled and highly motivated immigrants from Europe — though many were simply driven out by overcrowding at home. Nor can one deny the role of extraordinary personalities: inventors, politicians, military leaders, and explorers whose names and accomplishments fill history books. However, it is also indisputable that without its wealth of minerals and energy resources, the US could never have achieved its current position of global dominance.

But American resources, however vast, were nevertheless limited. Throughout the 20th century, geologists combed the North American continent for oil, coal, and natural gas reserves. The US quickly became the most explored region of the planet. Americans were encouraged through advertising to buy private automobiles in order to take advantage of these energy resources, and they did so at a rate unparalleled in the industrialized world. By mid-century, however, older oil wells were running dry and newer wells were proving to be less productive. The rate of discovery of new petroleum resources in the continental US peaked in the 1930s; the rate of extraction of those resources peaked in 1970. But the energy-based "American Way of Life" had to be maintained in order to avoid political and economic disaster; therefore, further energy resources had to come from elsewhere.

Understandably, industrial and political leaders adopted a time-tested strategy — scope enlargement, or trade and transport — in order to make up the difference. The US began to buy oil at first, and soon natural gas, from other nations. Its balance of trade — historically positive — soon became overwhelmingly negative. Formerly the world's foremost lender and investor, the US soon became the world's foremost debtor nation. Meanwhile it continued to develop its already awesome military capability with which to enforce its priorities on the rest of the world, more blatantly so following the demise of its only competitor for global hegemony: the Soviet Union, itself geologically blessed with energy resources but handicapped by early barriers in exploiting those resources and by an economic-social system that discouraged individual initiative.

Soon after US petroleum production had peaked, official policy began emphasizing "free trade" as a global panacea for unemployment, underdevelopment, despotism, and virtually every other economic or political ill.

Through its manipulation of the rules of global trade, the US sought to maintain and increase its access to natural resources worldwide. Those rules — written primarily by US-based corporations and encoded in policies of the International Monetary Fund (IMF), the World Bank, and the World Trade Organization (WTO) as well as in treaties like the North American Free Trade Agreement (NAFTA) — essentially said that wherever resources lie, they must be available for sale to the highest bidder. In other words, whoever has the money to buy those resources has a legally defensible right to them. According to those rules, the oil of Venezuela belongs to the US every bit as much as if it lay under the soil of Texas or Missouri. Meanwhile technology, or "intellectual property," was regarded as proprietary; thus nations with prior investments in this strategy were at an advantage while "underdeveloped" nations were systematically discouraged from adopting it.

In the early 21st century, growing opposition to globalization — peaceful and otherwise — began to emerge in mass public demonstrations as well as in terrorist attacks. Most Americans, however, informed only by commercial media outlets owned by corporations with energy-resource interests, remained utterly in the dark as to what globalization was really about and why anyone would object to it.

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In this first chapter, we have focused on energy principles in physics, chemistry, ecology, and sociology. We have noted how important energy is for the functioning of ecosystems and societies, and have traced its role in the history of the US rise to global dominance.

As we have just seen, America became the preeminent world power in the 20th century not just because of its professed ideals of freedom and democracy, its ingenuity, and the hard work of its people, but more importantly because of its immense wealth of natural energy resources and its ability to exploit them. For the past three decades, the depletion of those resources has been propelling US economic, political, and military policy in a certain definable direction, which we will explore further in Chapter 5.

In order to better understand these developments and their likely consequences, we need to examine more thoroughly the recent history of energy resources and their impact on societies around the globe. It is to this subject that we turn next.

Chapter 2

Party Time: The Historic Interval of Cheap, Abundant Energy

In 1859 the human race discovered a huge treasure chest in its basement. This was oil and gas, a fantastically cheap and easily available source of energy. We did, or at least some of us did, what anybody does who discovers a treasure in the basement — live it up, and we have been spending this treasure with great enjoyment.

— Kenneth E. Boulding (1978)

Oil has literally made foreign and security policy for decades. Just since the turn of this century, it has provoked the division of the Middle East after World War I; aroused Germany and Japan to extend their tentacles beyond their borders; the Arab Oil Embargo; Iran versus Iraq; the Gulf War. This is all clear.

— Bill Richardson, Secretary of Energy (1999)

Whether we are talking of an individual citizen or a whole community, "cataclysmic wealth" can have disastrous consequences ... Its use rises sharply to create new habits and expectations. These habits are accompanied by an irrational lack of care about usefulness or waste. The process develops habits in individual people, and institutions in whole societies, which accustom them to operating on the basis of excess and wastefulness; and, although different episodes have different endings, one prospect sees the affected groups, long after the cloudburst of wealth has passed, trying every kind of expedient — borrowing, sponging, speculating — to try to ensure that the private habits or public institutions of excess and waste are maintained. The result is at best a measure of social disintegration; at worst, collapse.

— Barbara Ward (1977)

Forests to precede civilizations, deserts to follow.

— François René Chateaubriand (ca. 1840)

FOSSIL FUELS HAVE PROVIDED HUMANKIND with a source of energy so abundant and cheap that, in our rush to take advantage of them, we have utterly transformed our societies and our personal lives. This transformation has been so profound as to compare with the agricultural revolution of ten thousand years ago. However, that earlier development was, by comparison, an event in slow motion, requiring centuries to unfold in the areas where it originated, and millennia to reach most other inhabited regions of the planet. By contrast, fossil-fueled industrialism has swept the world in a mere two hundred years.

Historians are accustomed to speaking of the "Old Stone Age," the "New Stone Age," the "Bronze Age," or the "Iron Age" as a way of denoting certain periods by their characteristic technological regimes. An "age" in this sense may last tens of thousands of years, as did the Old Stone Age, or, in the case of the Bronze Age, only a millennium or so. The period of time during which humans will have discovered petroleum, reshaped their societies to make use of it, and then exhausted nature's supply promises to last little more than two centuries in total. This period of overwhelming transformative change has sometimes been called the "Petroleum Era" or the "Industrial Age," but, in view of its relative brevity, it may be more appropriate to call it the "Petroleum Interval" or the "Industrial Bubble."

This recent fossil-fuel-based explosion of human population and invention, though in many ways unprecedented in history, shares some basic characteristics with previous socio-technic transformations. Most great socio-technic revolutions begin out of necessity. When circumstances are comfortable, people tend to prefer doing things in old, familiar ways. It is when things aren't going well — that is, during times of an energy deficit, in any of its multitude of forms — that humans are most willing to experiment. But, having solved their immediate problems through some technical or social innovation, people often find that their new strategy has liberated more energy than was actually needed. Then, in developing ways to fully implement the new strategy and to take advantage of a sudden and unexpected energy abundance, they reshape their society, which typically grows in size and complexity.

The agricultural revolution illustrates this principle. Much evidence suggests that humans took up horticulture and then agriculture at least partly out of necessity; as anthropologist Marvin Harris has put it, "it seems clear that the extinction of the Pleistocene megafauna triggered the shift to an agricultural mode of production in both the Old and New Worlds."[1] But agriculture did not merely make up for the caloric loss resulting from hunting large prey animals to extinction (in fact, it did this only poorly); rather, it opened up an entirely new way of life — one that would eventually both enable far more humans to survive in closer proximity to each other than ever before and encourage the building of permanent and expanding settlements in which division of labor and class distinctions would emerge and proliferate.

As we are about to see, this same principle has been powerfully at work throughout the duration of the Industrial Bubble. Necessity led to invention, which led to growth and transformation.

In this chapter, we will trace the history of this fateful period from its beginnings to the present.

Energy in Medieval Europe

If we could somehow carry ourselves back in time to central and western Europe in the year 400 AD and fly a few hundred feet above that continent, our bird's-eye view would reveal a land covered from horizon to horizon by dense forest, with only occasional clearings. In each of those clearings we might see a cluster of thatched huts, with smoke rising from one or more wood fires.

The Europeans of 400 AD relied on an energy regime based mostly on wood. They built their houses and furniture with wood; they made tools from it, including plows, pumps, spinning wheels, and wine-presses; they made transportation devices (carts and boats) from it; and they used it as fuel to cook with and to heat their homes. Whatever bits of metal they used — blades, coins, jewelry, horseshoes, nails — came from wood or charcoal-fired hearths.

If wood was supremely useful, it was also abundant. A vast forest lay within sight of virtually every town or village. In addition to its immediate benefit of supplying fuel, the temperate oak forest of Europe also supported a profusion of wild game animals, including deer, boar, and numerous bird species, such as pheasant and quail. Human settlements were small, seldom numbering more than a few hundred people; the total population of Europe probably — exact figures are not known — did not exceed 25 million (compared to 600 million today, if European Russia is included).

That the ancient Europeans revered the forest is evidenced by their traditions concerning the sacredness of certain groves, by their customs of making sacrifices and offerings to trees, and by their extensive lore regarding tree-spirits. But, with the coming of Christianity, these early pagan attitudes (the Latin *paganus* means "peasant") were gradually replaced by the idea that the wilderness is inherently fallen and corrupt, to be reclaimed only by pious human work. Far from fearing the overcutting of forests, later medieval Europeans saw the clearing of land as their Christian duty. Cutting the forest meant pushing back chaos, taming Nature, and making space for civilization.

While wood was the principal fuel in medieval Europe, it was far from being the only available energy source. Generally, civilized humans have two broad categories of energy needs: for lighting and heating on the one hand, and for motive power for agriculture and transportation on the other. Until recent times, these two categories of needs were usually served by two separate categories of energy sources.

Lighting and heating required fuel. In medieval Europe, the burning of wood (though occasionally straw or dried animal dung was used) provided heating fuel for virtually everyone. Fuel for lighting came from the burning of wax, tallow, rushes, or olive oil — but was considered too costly for any but the wealthy, except on special occasions.

Motive power at first came primarily either from human labor or animal muscle, though these would later be supplemented by power from water and wind. Despite the fact that the human engine is capable of generating comparatively little power, much of the land in Europe — as well as in China — was tilled directly by humans using a hoe or spade, without the help of an animal-drawn plow. Because people typically eat less than draft animals do and because their efforts are intelligently directed, they often provide a more economical source of power than do oxen, horses, or mules.

In medieval Europe, as in the great civilizations of China, Rome, and the Near East, forced human labor was common. While in Germany and eastern England a substantial portion of the peasantry was made up of free persons who held and worked lands in common, most communities elsewhere came to be organized around manors controlled by lords whose right to land could be defended, when necessary, by full-time specialists in violence (soldiers, vassals, knights, and sheriffs). Agricultural tenants, in order to gain the right to cultivate a plot of land for themselves, were required to work a certain portion of each year on their landlord's estate. Serfs were bound to the land as quasi-slaves; and though they retained certain economic and legal rights, many existed perpetually on the verge of starvation. Ironically, however, it is also true that, in view of the many holidays and festivals celebrated in medieval societies, the typical serf back then actually enjoyed considerably more free time on a yearly basis than does today's typical American salaried worker.

In the early medieval period, most of the power for pulling plows and carts was provided by oxen. Only during the 12th century did horses come to be used as draft animals in any great numbers, this shift being due to the invention and widespread adoption of the horse-collar. Both before and after this time, horses were widely used for military purposes, a mounted cavalryman being both more mobile and more formidable than a footsoldier. In Spain and

southern France, mules provided motive power for agriculture and transportation. Mules would later also become the primary source of animal power in regions of the Americas dominated by Spain — namely Mexico and most of South America. In addition to pulling plows and carts, oxen, horses, and mules also provided power for machinery: at first, for grain mills; later, for pumps to drain mines and for textile looms.

A significant implication of the use of large ruminant animals for traction was the necessity of growing food for them. Oxen, which can live on grass stubble and straw, were cheaper to maintain than horses, which also need grain. A horse typically requires between four and five acres of land for its food production; thus the use of traction animals on the one hand reduced the human carrying capacity of the land while at the same time adding to it by enabling the plowing of larger fields. The net result varied. Animals were costly, and only a prosperous individual could afford to keep a horse. However, until the beginning of the 20th century, the trend was toward the increasing use of animal power. By 1900, Britain had a horse population of 3.5 million, consuming four million tons of oats and hay each year, thus necessitating the importation of grain for both animals and humans. In the US during the same period, the growing of horse feed required one quarter of the total available cropland (90 million acres).

Throughout the medieval period, human and animal power was increasingly supplemented by power from watermills and windmills. Watermills had been known from the time of ancient Greece; the Romans, Chinese, and Japanese employed them as well. The Romans had contributed the significant innovation of gears, which permitted the wheel to be moved to a vertical position and enabled the millstone to turn up to five times faster than the propelling wheel. Toward the latter days of their Empire, the Romans appear to have been taking increasing advantage of such equipment, perhaps because of a scarcity of slave labor, though such incipient industrial efforts subsided with the collapse of their civilization in the fifth century. However, in the 12th and 13th centuries, Europeans, led by the Cistercian monks, began using water wheels more extensively, and for a greater variety of purposes, than in any time or place previously. Windmills were costlier to operate than watermills, but could be built away from streams and could be used, for example, to drain water from the soil and to pour it into canals — hence the windmill's significant role in the reclamation of land in the Low Countries.

Originally, both windmills and watermills were primarily used for grinding grain, an otherwise arduous process. A first-century verse by Antipater of Thessalonica describes the perceived benefits of the water wheel in both mythic and human terms:

> Cease from grinding, ye women of the mill; sleep late even if the crowing cock announces the dawn. For Demeter has ordered the Nymphs to perform the work of your hands, and they, leaping down on top of the wheel, turn its axle, which with its revolving spokes, turns the heavy concave Nysirian millstones. We taste again the joys of primitive life, learning to feast on products of Demeter, without labor. [2]

Gradually, ingenious though anonymous inventors worked to develop and extend the use of windmills and watermills. One of the most important of these refinements consisted in the use of gears both to harness the machine's motive power to operate tools, such as saws and looms, and to operate several implements simultaneously. Eventually, mills would be used to pump water from mines, crush ores, make paper, and forge iron, among other tasks.

It should be noted that Europeans also harnessed wind power for transportation by means of sails. Sailing ships already had a long history throughout the Mediterranean as well as in China; during the medieval period their use gradually increased with improvements in shipbuilding and navigational technology, so that, by the latter part of the 16th century, European ships were conveying an estimated 600,000 tons of cargo annually. Many countries additionally maintained large fleets of sail-propelled warships.

The development of watermills and wind power in the Middle Ages could be said to have constituted the first industrial revolution. It was a period of sometimes explosive invention and development of Class B and C tools (including the printing press); but perhaps more importantly, it was the time when the very first Class D tools appeared, consisting of iron components for windmills and watermills, such as the heavy tilt-hammers used in iron forging.

Iron played no small part in this first industrial revolution. The use of iron can be traced back to the 15th century BC in the Caucasus, and cast iron and coal firing were known in China as early as the fifth century BC — developments not seen in Europe until the 14th century. Moreover, in China and India a high-quality carbonized steel (known in Europe as Damascus or damask steel) was being made as early as the second century — Europeans would not produce steel of equal quality until the 19th century.

However, despite being somewhat late on the scene with regard to such improvements, Europeans increasingly made use of iron during the medieval period, with demand for it often being stimulated by a long-simmering arms race. With crusades, wars, invasions, and peasant rebellions recurring throughout the period, there was constant need for more and better swords and pikes and, subsequently (following the introduction of gunpowder — another Chinese invention — in the 14th century), for arquebuses, canons, and iron bullets — all in addition to the cooking utensils, cauldrons, horseshoes, nails, and plowshares that were the day-to-day products of local smiths. Between the 11th and the 15th century, significant developments included the replacement of hand bellows by a hydraulic blowing machine and the invention of the blast furnace, permitting the production of cast iron and low-grade steel.

Demand for other metals — copper, bronze, gold, and silver — was also on the rise during this period. While the manors of the early medieval period were almost entirely self-sufficient, so that money was required only for the purchase of imported luxury goods, a gradually increasing trade required larger and larger quantities of copper, silver, and gold coins.

The production of all these metal goods required fuel. Smelting necessitated high temperatures achievable only by the burning of charcoal, which is made by charring wood in a kiln from which air is excluded. The quantities of charcoal — and therefore of wood — that were required were far from negligible: the production of each ton of iron required roughly 1,000 tons of wood.

Altogether, the medieval energy economy — based on wood, water, and wind as well as on human and animal power — relied on resources that were renewable but not inexhaustible. Oak forests could regenerate themselves, though that took time. But trees were being cut faster than they could regrow, and the result was a rapid depletion of medieval Europe's primary fuel source.

While the construction of more and larger ships and the invention of the blast furnace contributed to the accelerated felling of trees, the ultimate cause was simply the increase in human population: many forests were cut merely to make way for more crops to feed people and domesticated animals. Prior to the Industrial Revolution of the late 18th century, there were two prolonged population surges in Europe: between 1100 and 1350 and between 1450 and 1650. Following the first surge, there was a sharp recession due to the Black Death; following the second, population growth tapered off partly due to recurring famines. From an ecological point of view, Europe had become saturated with humans, whose demands upon the environment were resulting in a rapid destruction of their temperate-forest ecosystem. Any further population growth would have to be based upon the acquisition of a new energy source.

Much of the southeast of England had been deforested by the end of the 11th century, and by 1200 most of the best soils of Europe had been cleared for agriculture. Wood shortages became commonplace in the 12th and 13th century. Between 400 and 1600 AD, the amount of forest cover in Europe was reduced from 95 percent to 20 percent. As scarcities appeared, wood began to be transported for ever further distances by cart and by water. By the 18th century, blast furnaces were able to operate only one year in every two or three, or even only one in five or ten. Wood shortages led to higher prices for a variety of goods; according to Sully, in his *Oeconomies Royales*, "the price of all the commodities necessary for life would constantly increase and the growing scarcity of firewood would be the cause."[3]

In sum, the medieval period in Europe was a time of technological innovation, population growth, and energy-resource depletion within a region that, compared with China and the Islamic world, must be considered a cultural backwater. But this was the cultural, demographic, and geographic crucible for two immense developments, of which only one seemed profound at the time. The first, whose significance was almost immediately recognized, was the commencement of the European age of exploration and colonization, which would eventually transfer vast wealth from the New World to the Old. The second was the gradually increasing use of a new kind of fuel.

The Coal Revolution

According to the report of an early missionary to China, coal was already being burned there for heating and cooking, and had been so employed for up to four thousand years.[4] Likewise in early medieval Europe, the existence of coal was no secret, but the "black stone" was regarded as an inferior fuel because it produced so much soot and smoke. Also, it occurred only in certain regions and had to be mined and transported. Thus, until the 13th century, it was largely ignored in favor of wood.

As wood shortages first began to appear, poor people began heating their homes by burning coal — most of which came from shallow seams and was a soft and sulfrous type that produced an irritating, choking smoke. Much was "sea-coal," which consisted of lumps collected from beaches and derived from cliff outcrops. By the late 13th century, London — a town of a few thousand inhabitants — was already cloaked in smog during the winter months. By the 16th and 17th century, even the rich were forced to make do with this inferior fuel. In the words of Edmund Howes, writing in 1631, "the inhabitants in general are constrained to make their fires of sea-coal or pit-coal, even in the chambers of honourable personages."[5]

However, coal was soon found to have advantages for some purposes — especially for metal working, since the higher temperatures possible with coal-fed fires facilitated the smelting of iron and other ores. Moreover, experimenters soon discovered that the roasting process used to make

charcoal could be adapted to coal, the result being an extremely hot-burning fuel called coke. The use of coke in iron and steel production, beginning in England in the early 17th century, would so transform those industries as to constitute one of the key developments paving the way for the Industrial Revolution.

By the 17th century coal had revolutionized far more than metallurgy and home heating: its use had become essential for manufacturing glass, bricks, tiles, and salt (through the evaporation of sea water) as well as for refining sugar, brewing beer, and baking bread.

Meanwhile, the extraction of coal — a dreary, dangerous, and environmentally destructive activity at best — led by necessity to a series of important mechanical inventions, including the mechanical lift and the underground tunnel with artificial lighting and ventilation. As mines were sunk ever deeper, sometimes to a depth of 200 feet or more, water tended to accumulate in the bottoms of the shafts. Workmen drained the water either with hand pumps or bucket brigades. In 1698, Thomas Savery devised a pumping engine that condensed steam to create a vacuum to suck water from mineshafts. The engine was extremely inefficient, requiring enormous amounts of energy to lift modest quantities of water. Just ten years later, Samuel Newcomen introduced a self-acting atmospheric engine operating on different principles; and though it constituted the first crude steam engine, it was used solely for pumping water from coal mines — at that time, no one apparently envisioned its possible employment in manufacturing and transportation.

In addition to water seepage, coal miners faced another problem: that of transporting the coal from the depths of mines to rivers or ports. Typically, balks of wood were thrown down to facilitate the movement of coal-bearing wagons. In 1767, Richard Reynolds constructed a track of cast-iron rails, running from Coalbrookdale to the Severn, to hold the wagon wheels on track. Scores of similar tramways were constructed during the following two decades; in all cases, traction was supplied by horses.

Toward the end of the 18th century, inventors began toying with the idea of using the new steam engine (by now greatly improved through the efforts of James Watt) for locomotive power. After the expiration of Watt's patent, a Cornish engineer named Richard Trevithick devised a new high-pressure engine and, in 1803, installed it on a carriage in which he made several journeys through the streets of London. But public highways were too rough to accommodate the steam carriage, and so the idea languished for another two decades until George Stephenson hit upon the idea of putting the steam locomotive on rails like those used in the tramways of coal mines. When hired by a group of Quaker investors to construct a railway from Stockton to

Darlington in 1821, Stephenson built the first steam railroad; and eight years later his locomotive, named the *Rocket*, won a competition on the newly constructed Liverpool and Manchester Railway, demonstrating once and for all the superiority of the new technology over horse-drawn rail carriages.

Until the mid-19th century, all ships had traveled by renewable human or wind power. Beginning in the 1840s, steam power began to be applied to shipping; by the 1860s, new developments, such as the steel high-pressure boiler and the steel hull, enabled a typical steamship to transport three times as much cargo from China to Europe as a typical sailing ship, and in half the time.

The effects of these innovations on the economic life of Europe were dramatic. Trade was facilitated, both within nations (between the countryside and the city as well as between cities) and among nations and continents. More trade meant the extraction of more ores and other resources. The steam engine also greatly accelerated the transformation of those resources by industrial processes, as inventors devised a variety of steam-powered machines — including powered looms, cotton gins, lathes, die presses, and printing presses — to supplement or replace human labor.

Coal also had important chemical by-products. Of these, the earliest to have a significant social impact was manufactured (or artificial) gas. The first gaslights appeared in England in the 1790s, when William Murdock, an engineer and inventor, lit his own factory and then a large cotton mill in Manchester. The first gas street lighting was installed in London in 1807. In the United States, Baltimore was the first city to light its streets with gas, in 1816. Paris adopted gas street lighting in 1820. Soon nearly every town with a population of over 10,000 had a gas works, and the discharge of coal tars from the production of manufactured gas was being blamed for drinking-water pollution and the contamination of crops. In 1877, inventor T. S. C. Lowe discovered a way to make "fuel gas" from steam enriched by light oils recovered from gas-making residual tars. Fuel gas (also known as "carburetted water gas") was seen by the gas industry as a means of combating the inroads being made by electricity on gas lighting.

With the discovery of coal-tar dyes in 1854, coal byproducts also gave rise to the establishment of the chemical industry. The new synthetic dyes revolutionized the textile industry and led to the growth of the German chemical and pharmaceutical companies Hoechst and I.G. Farben.

Coal was thus central to the pattern we call industrialism. Even wage labor seems to have originated in the mining industry, and, as Lewis Mumford once noted, the "eight-hour day and the twenty-four-hour triple shift had their beginning in [the coal mines of] Saxony."[6] By the late 19th century, the factory, with its powered machines, had revolutionized human labor, the economy, and society as a whole. First in England, and then in America, Germany, and a growing roster of other nations, settled cultivators and craftspersons became managers, wage-earning employees, or unemployed urban paupers; and economies that previously had been based on local production for local consumption became increasingly dependent on the long-distance trade of raw materials and finished goods.

One way of gauging the pace and extent of this transformation is to chart the quantities of coal being mined and used during the 19th century. In 1800, the annual world coal output stood at 15 million tons; by 1900, it had risen to 700 million tons per year — an increase of over 4,000 percent. In the last two years of the 19th century (1899-1900), the world used more coal than it had in the entire 18th century.

However, this vast expansion in coal usage was not evenly distributed over the globe. It occurred primarily in Europe and North America; and of all countries, Britain used by far the most — between one-half and one-third of the global total throughout the 19th century. (Germany, a rival industrial power, was also a significant user.) The ability of British industry to take advantage of this new energy resource had important geopolitical consequences: British cargo steamers carried raw materials from around the world to British ports, whence they were taken by trains to factories; manufactured goods were then hauled by train from factories to ports, whence they were distributed to colonies thousands of miles away. This system of trade was based both on policies, laws, and treaties that greatly favored the colonizing nation over the colonies and on a highly mobile, industrialized form of military power capable of enforcing those laws and treaties. While colonialism had existed prior to the widespread use of fossil fuels, Britain's industrial version of it greatly intensified its essential practices of extracting wealth and consolidating political power.

Other nations envied Britain's colonial empire but lacked either the energy resources or the geographical prerequisites (such as coastlines and ports) or other historical advantages (including prior colonies and investments in industry).

America's energy path during the early decades of the 19th century differed greatly from that of Britain. Because of its abundant forests and numerous rivers, the United States relied primarily on wood- and water-power for its early industrial development; and during the first half of the century, much of the energy for agricultural production came from African slaves. As late as 1850, half of the iron produced in the US was smelted with charcoal. Locomotives and riverboats continued to burn wood well into the last two decades of the century, when America's forests began to be dramatically depleted. Only in the mid-1880s did a shift to coal begin in earnest; by 1910, coal accounted for three-quarters of the nation's energy supply. Like Britain, the US was favored with abundant indigenous deposits, especially in the mountainous regions of Pennsylvania, West Virginia, Kentucky, and Tennessee.

Global dependence on coal peaked in the early 20th century, when its contribution to the total world energy budget surpassed ninety percent. In the course of a hundred years, coal had transformed much of the world. New forms of production, new inventions and discoveries, new patterns of work, and a new geopolitical balance of power among nations were all due to coal. Cities were lit, and factory-made goods were produced in abundance. In addition, a great surge of population growth began, which was to be by far the most dramatic in world history.

The 13th-century Europeans who had reluctantly begun burning coal to heat their homes would scarcely have understood the ultimate implications of their actions. For them, coal was a sooty black stone with only a few practical uses. Surely, few stopped to think that, while all of their other energy resources were renewable (if exhaustible), coal was both exhaustible and nonrenewable. At the population levels and scales of usage prevailing in the Middle Ages, the limits to coal must hardly have seemed imaginable. Nevertheless, a threshold had been crossed: from then on, an increasing proportion of the world's energy budget would be derived from a source that could not be regrown or reproduced on a timescale meaningful to humans.

The Petroleum Miracle, Part I

In the late 19th and early 20th century, another new source of energy began to come into use: petroleum. As had been the case with coal, few people at first had any inkling of the consequences of the increasing exploitation of this new energy resource. But as coal had so dramatically shaped the economic, political, and social contours of the 19th century, petroleum would shape those of the 20th.

Again, necessity was the mother of invention. As motorized machines proliferated during the 19th century, vegetable oils, whale oil, and animal tallow were typically used for machine lubrication, and whale oil as fuel for lamps. Toward the end of the century, commercial whale species were being hunted to the point of extinction, whale oil was becoming increasingly costly, and tallow and vegetable oils were proving inadequate as lubricants for the ever-larger and more sophisticated machines being designed and built.

Petroleum had been known for centuries, perhaps millennia, and had been used in warfare as early as 670 AD, when Emperor Constantine IV attached flame-throwing siphon devices to the prows of his ships, which spewed burning petroleum on enemy vessels. Oil also had a long history of use for sealing and lubrication, and even for medicinal purposes. However, the exploitation of petroleum was limited to small quantities that seeped to the ground surface in only a few places in the world.

Beginning with the successful drilling of the first commercial oil well by "colonel" Edwin L. Drake in northwest Pennsylvania in 1859, petroleum became more widely available as a cheap and superior lubricant and, when refined into kerosene, as lamp fuel. The problems of whale-oil depletion and machine lubrication had been solved. But, of course, oil soon would prove to be useful for many other purposes as well.

Fortunes were quickly made and lost by dozens of drillers and refiners, as a rapidly expanding supply of petroleum fed the nascent demand. By 1866, Drake himself was bankrupt; meanwhile, an extraordinarily business-savvy early oil man named John D. Rockefeller had begun purchasing crude in Pennsylvania, Ohio, and West Virginia and refining it under the name Standard Oil. Soon he had the largest refining operation in the country and was absorbing his competitors, using selective price-cutting strategies and obtaining kickbacks from the railroads that transported both his and his competitors' crude.

Rather than buying up the other refiners and producers outright, Rockefeller set up a trust by which stockholders in Standard Oil controlled the stock in dozens of other oil companies as well. Rockefeller's business strategy was simple and consistent: to be the low-cost producer, to offer a reliable product, and to ruthlessly undercut and assimilate any competitor. In addition to its refineries, Standard developed its own production and distribution systems, building pipelines and the first oil tankers. By 1880, Standard controlled ninety percent of the oil business in the US — and that of the rest of the world as well.

Rockefeller used Standard's domestic business tactics of predatory pricing, secrecy, and industrial espionage to absorb foreign oil companies — especially those in Europe, where industrialization and urbanization were stimulating an ever-increasing demand for kerosene and lubricating oil. Kerosene quickly became the foremost US-manufactured export; and Standard, with its European subsidiaries, became perhaps the first modern transnational corporation. In a mere decade and a half since founding Standard in 1865, Rockefeller had nearly achieved the goal he envisioned from the start: a worldwide monopoly on petroleum.

However, that monopoly hinged at least in part on the control of global production, a control that was soon threatened by the discovery of major reserves outside the American northeast. The first such threat emerged from the Russian empire, where oil was discovered in 1871 in Baku, a region on the Aspheron Penninsula in the Caspian Sea. Ludwig Nobel, known as the "Russian Rockefeller" — and brother of Alfred Nobel, the discoverer of dynamite and donor of the Nobel Prize — arrived in Baku at the beginning of the oil rush there and quickly established commercial dominance in production and refining. By 1885, Russian crude production was at about one-third of the American production levels. But since demand within Russia itself could not absorb such an amount, the Nobels sought foreign markets. Help came from the French branch of the Rothschild banking family, which, over the previous century, had financed wars, governments, and industries, and now owned a refinery at Fiume on the Adriatic. The Rothschilds bankrolled a railroad from Baku to Batum, a port on the Black Sea, enabling the Nobels' oil to flow to European markets.

The Rothschilds soon bought their own oil wells and refineries in Baku, entering into competition with the Nobels. They also expanded the distribution of Russian oil to Britain, prompting Standard to set up its own affiliate in London, the Anglo-American Oil Company. The Rothschilds then looked further afield, namely to Asia, seeking still more markets for the ever-growing supply of Baku crude. In the early 1890s, they contracted with international trader Marcus Samuel to build a system of distribution throughout South and East Asia. Samuel began by embarking on an Asian tour; soon he was supervising the construction of storage tanks throughout Asia, undertaking major improvements in tanker design, and obtaining the right of passage through the Suez canal, which had previously been denied to oil shipping. Samuel's objective was nothing less than to beat Standard Oil at its own game, offering exported Russian oil throughout the Far East at prices Rockefeller could not match. Samuel's company — at first called the M. Samuel Company, later Shell Transport and Trading — achieved a coup that could hardly escape Standard's notice.

During the 1890s, Rockefeller, the Nobels, the Rothschilds, and Samuel engaged in what became known as the Oil Wars. Periods of price-cutting were punctuated with attempts at takeovers or grand alliances.

At the same time, oil production in the Dutch East Indies (now Indonesia) was growing at a furious pace under the commercial control of the Royal Dutch Company, which offered still another challenge to Standard's international dominance.

Further, while all of this global competition was intensifying, the oil business was changing in fundamental ways. With Thomas Edison's promotion of electric lighting in the 1880s, demand for kerosene peaked and began to recede. However, new uses for petroleum more than took up the slack. Oil-burning furnaces appeared toward the end of the century, as well as oil boilers for factories, trains, and ships — all promoted by Standard. By 1909, half of all petroleum extracted was being sold as fuel oil. But by far the most important new use of petroleum was as fuel for the internal combustion engine, developed in the 1870s by German engineer Nikolaus Otto. Gasoline, when first discovered, had, because of its extreme volatility, been regarded as a dangerous refinery waste product; when used in lamps, it caused explosions. Initially, it was simply discarded or sold for three or four cents per gallon as a solvent. Now it was seen as the ideal fuel for the new explosion-driven internal combustion engine.

Another important development was the appearance of a market for natural gas. The latter had frequently been found together with oil (most oil fields have gas deposits). Gas was also often found in coal deposits, and many early coal miners had died from asphyxiation from deadly "coal gas" or from gas explosions. Natural gas is mostly methane, but it also contains small amounts of ethane and heavier hydrocarbon gases, such as butane, propane, and pentane. During the first few decades of oil drilling, natural gas was often regarded as having no value and was simply flared (burned off). However, as prices for manufactured gas for street lighting rose and as environmental hazards from its production became more apparent, natural gas was seen as a cheap and environmentally more benign substitute. In 1883, Pittsburgh became the first city to replace manufactured gas with the cheaper natural gas. Three years later, Standard Oil formed the Standard Natural Gas Trust. But within a few years, electric street lighting and home lighting appeared as commercially viable options. As gas lights were gradually replaced with electric lights, local gas works were sold and consolidated, their infrastructure of pipes converted to the distribution of natural gas for cooking and heating.

Even though petroleum production, refining, and distribution had become huge and quickly growing commercial enterprises, the 19th century was the century of coal to its very end: only after the turn of the 20th would the world witness the true dawning of the petroleum era.

Electrifying the World

Before we continue with the story of petroleum, it is necessary to survey another energy development that would shape the 20th century in nearly as profound a way as would oil: electrification. Unlike petroleum or coal, electricity is not a source of energy, but rather a carrier of energy, a means by which energy can conveniently be transmitted and used. Electrification enabled the development and wide diffusion of home conveniences, business machines, and communication and entertainment devices — all connected by miles of wire to a variety of energy sources ranging from coal or oil boilers to hydroturbines to nuclear fission reactors. By making energy easy to access and use, electricity stimulated the use of energy for ever more tasks until, by the 20th century's end, most people in industrialized cities were spending virtually every moment of a typical day using one or another electrically powered device.

The first electric generator was invented in London in 1834, but decades elapsed before electricity saw commercial applications. Thomas Edison (1847-1931), a former railroad telegrapher, began his career as an inventor by devising improvements to the telegraph and telephone. His laboratory was described as an "invention factory": Edison was the first to apply industrial methods to the process of invention, hiring teams of engineers to work systematically to devise new commercial technologies. This was a strategy widely adopted throughout corporate America in the following century. In 1878 Edison turned his attention to the electric light; in 1879 he lit his factory with electricity; and three years later, his workers installed carbon-filament electric lamps in the financial district of lower Manhattan. Edison, ever the astute businessman, supplied the entire system of generators, transmission lines, and lights, taking care to price electricity at exactly the equivalent of the price of piped gas.

Edison's system for generating and distributing electric power used current flowing in one direction only — direct current, or DC. This had the disadvantage of requiring neighborhood generating stations, since direct current was rapidly dissipated by resistance along transmission lines, given the technology then available (today high-voltage direct current can be transmitted long distances with relatively little line loss). Indeed, most of the factories and homes lit by early DC systems maintained dynamos on-site — which were both expensive and annoying: the generator in the basement of J. P. Morgan's mansion in New York made so much noise that his neighbors frequently complained. At that time, virtually no one envisioned the regional, centralized electric distribution systems we now take for granted.

Engineers of the time knew that alternating current, or AC —where electricity flows back and forth along transmitting wires, alternating its direction many times per second — was a theoretical possibility and could overcome the transmission limitations of direct current. However, no one had yet solved the basic technical problems, and no practical AC motor yet existed.

In 1884, a Serbian-American inventor named Nikola Tesla (1854-1943) approached Edison with his designs for an AC induction motor. Though Edison recognized the younger man's exceptional intelligence and immediately hired him to improve existing DC dynamos, Tesla's plans were ignored. The two men were utterly dissimilar in their approaches to invention: while Edison was a tinkerer with little understanding of theoretical principles, Tesla was a supreme theoretician comfortable with advanced mathematics. Tesla would later write:

> If Edison had a needle to find in a haystack, he would proceed at once with the diligence of the bee to examine straw after straw until he found the object of his search. I was the sorry witness of such doings, knowing that a little theory and calculation would have saved him ninety percent of his labor.[7]

Tesla broke with Edison after a financial dispute (the latter offered a $50,000 bonus for a job he thought impossible, then refused to pay when Tesla accomplished the task), obtained financing, equipped his own laboratory, and proceeded to design, build, and patent the first AC motors. A Pittsburgh industrialist named George Westinghouse heard of Tesla's work, purchased rights to his patents, and went into competition with Edison.

By 1893, the financier J. P. Morgan had engineered a takeover of Edison's company and several other electrical device manufacturers; the resulting General Electric Corporation then settled into a "War of the Currents" with the Westinghouse company over the future of electrification. GE publicists made absurd claims about the dangers of AC power, while spectators at the Columbian Exposition were awed by the most impressive demonstration of electric lighting yet seen — provided under contract by Westinghouse. Flags fluttered, a chorus sang Händel's *Hallelujah Chorus*, and electric fountains shot jets of water high into the air. Twenty-seven million people attended the fair during the following months, all witnessing the practical wonders of alternating current. Tesla's victory was further underscored when the Niagara Falls Power Project, completed in 1896, chose Tesla's advanced AC polyphase designs for its giant dynamos. J. P. Morgan would later comment that his backing of Edison's DC system had constituted the single worst business decision of his career.

Tesla went on to invent or provide the theoretical foundations for radio (while Marconi is still usually given credit for this invention, the US Supreme Court affirmed the priority of Tesla's patents in 1943), robotics, digital gates, and even particle-beam weapons. While other scientists gleaned much of the credit for many of these developments and corporations made fortunes from them, Tesla preferred the role of lone visionary, giving yearly press interviews in which he articulated colorfully his plans for worldwide broadcast power, communication with other planets, and cosmic-ray motors. Tesla died nearly penniless at the height of World War II; his papers were immediately seized and sequestered by the Office of Alien Property. Though mostly forgotten for decades, Tesla is now widely regarded as the true father of 20th-century electrical technology.

At the turn of the century, as the War of the Currents was cooling off, the Utilities Wars were just heating up. Cities wanted electric street and home lighting, but controversy raged over the question of whether the utilities responsible for delivering the electricity should be privately or publicly owned. Financiers like J. P. Morgan and Samuel Insull (of Chicago's Commonwealth Edison) lobbied to make utility monopolies a perpetual "dividend machine" for investors while public-power advocates in hundreds of towns and cities around the country insisted that costs to consumers should be controlled through public ownership. In most cases, the private interests won, resulting in the creation of giant utility corporations like Pacific Gas & Electric (PG&E) and Continental Edison; however, scores of communities succeeded in creating publicly-owned municipal power districts that typically sold electricity to consumers at much lower prices.

During the 1930s, President Franklin D. Roosevelt battled the private utility interests in his campaign for rural electrification. His largest and most successful public-works project, the Tennessee Valley Authority, built dams and distribution systems, making electric power almost universally available throughout the rural East. Today, rural power co-ops and municipal power authorities still control about 20 percent of electrical generation and distribution in the country, and recent developments, such as the bankruptcies of Enron and PG&E — with executives profiting handsomely while customers and employees paid dearly — have revived the public-power movement throughout the nation.

Even before the beginning of the 20th century, electricity already had many many uses in addition to lighting. Electric streetcars and subways began replacing horse-drawn streetcars in the larger cities in the 1890s, and this led to a major change in urban development patterns: the growth of suburbs. In 1850, the edge of the city of Boston lay a mere two miles from the city center; by 1900, electrified mass transit had allowed the city perimeter to spread ten miles from the business district. Previously, city centers had been the most densely populated areas; now, urban cores began emptying as residents moved to the suburbs, leaving the heart of town to financial and commercial activity.

As factories were electrified, opportunities for automation cascaded, further fragmenting production tasks and eliminating the need for skilled labor. A former Edison employee named Henry Ford recognized these possibilities early on, and the electrified assembly line he created for the production of his motor cars stood as an example for other manufacturers of how to cut costs and ensure uniform quality. A Model T Ford sold for $825 in 1908, but by 1916, automated mass production had brought the price down to $345.

As homes were electrified, even domestic work began to be automated, and housewives were bombarded by advertisements informing them of the potential gains in "productivity" and "efficiency" available through the use of gadgets ranging from vacuum cleaners and washing machines to electric toasters, mixers, and irons.

Because of its unique properties, electricity was used in ways that would not have been possible with other forms of energy. The field of electronics — encompassing radio, television, computers, and scores of other devices based first on vacuum tubes and later on semiconductors — would revolutionize communications and entertainment as well as information storage and processing.

While electricity offers extreme convenience to the user, it is an inherently inefficient energy carrier. For example, when coal is burned to drive dynamos, only 35 percent of its energy ultimately becomes electricity. Inefficiencies are also inherent in transmission lines and in end-use motors, lights, and other powered devices. However, as long as primary energy sources remain cheap, such inefficiencies can be easily afforded. At current prices, an amount of electricity equivalent to the energy expended by a person who works all day, thereby burning 1,000 calories worth of food, can be bought for less than 25 cents.

Coal is still the principal primary energy source for the generation of electricity in the US and throughout the world. In 1998, US electric utilities derived 56 percent of their power from coal, 21 percent from nuclear fission, 10 percent from hydro, 10 percent from natural gas, 3 percent from oil, and less than 1 percent from wind, photovoltaics, and other alternative sources.

Electricity's availability for a vast range of tasks has led to a massive increase in total energy usage. Whole industries — such as aluminum production — have arisen that are completely dependent upon electricity. On the whole, during the 20th century electricity consumption increased twice as fast as the overall energy consumption.

The Petroleum Miracle, Part II

In the first half of the 20th century, as electricity was revolutionizing homes and workplaces, the industrialized world's reliance on coal gradually subsided while its use of oil expanded greatly, reshaping nearly all spheres of life.

The structure of the petroleum industry underwent significant shifts in the early years of the century. In 1902, Samuel was forced to merge his company with Royal Dutch to create Royal Dutch-Shell. And with the discovery of oil in Persia (now Iran), the Anglo-Persian Oil Company (later British Petroleum, or BP) came into being. Persian crude would be the first commercial oil to come from the Middle East.

Meanwhile, in the US, Rockefeller's cutthroat business tactics and near-monopolization of the domestic industry led to an anti-trust suit brought by the Federal government. In 1911, a decision of the Supreme Court forced the breakup of Standard Oil Company into Standard Oil of New Jersey (which later became Exxon), Standard Oil of New York (Mobil), Standard Oil of California (Chevron), Standard Oil of Ohio (Sohio, later acquired by BP), Standard Oil of Indiana (Amoco, now BP), Continental Oil (Conoco), and Atlantic (first Atlantic, then Atlantic Richfield, then ARCO, then Sun, now BP). Rockefeller eventually profited handsomely from the split, and the new companies carefully avoided directly competing with one another.

At the turn of the century, Russia had briefly become the world's largest oil producer. However, political upheavals in that country undermined the further development of the industry. Soon new discoveries in the US — in California, Texas, and Oklahoma — made America again the foremost oil-producing and -exporting nation, a position it would hold for the next half century. In 1901, the Spindletop oil gusher in Texas marked a shift in the center of gravity of American production away from the Northeast and toward the Southwest. Further spectacular Texas and Oklahoma discoveries in the 1930s led to dramatic overproduction and price volatility: for a short time, the price of crude fell to four cents per barrel, making it literally cheaper than drinking water. The Texas and Oklahoma discoveries also engendered several new companies, including Texaco and Gulf Oil.

These developments taken together resulted in the domination of the world petroleum industry throughout the rest of the century by the so-called "Seven Sisters": Exxon, Chevron, Mobil, Gulf, Texaco, BP, and Shell. By 1949, the Seven Sisters owned four-fifths of the known reserves outside of the US and the USSR and controlled nine-tenths of the production, three-quarters of the refining capacity, two-thirds of the oil-tanker fleet, and virtually all of the pipelines.

Throughout the first decades of the century, the US was in a position to control the world oil price. This changed in the second half of the 20th century, as we will see shortly, when US production declined while production in the Middle East increased.

During the first half of the century, as electricity steadily eroded the market for kerosene as a source of illumination, new uses for petroleum products stoked ever greater demand for oil. By 1930, gasoline was the principal refined product of the petroleum industry, and aviation fuel was beginning to account for a noticeable share of oil production. And as the chemical industry switched from coal tar to petroleum as raw material, new synthetic materials — nylon and a wide range of plastics — began to replace traditional materials, such as wood, metal, and cotton, in manufactured consumer products.

It is difficult to overstate the extent of the transformations of the world economy, of industry, and of daily life that can be attributed to the use of petroleum during the 20th century. We can perhaps appreciate these transformations best if we discuss separately the fields of agriculture, transportation, and warfare.

Agriculture

One of the greatest problems for agriculture had always been the tendency of soils to become deficient in nitrogen. The traditional solutions were to plant legumes or to spread animal manures on the soil. But these nitrogen sources were not always adequate. In 1850, explorers of islands off the coast of Chile and Peru had discovered entire cliffs of guano — the nitrogen-rich excreta of sea birds. Over the next two decades, 20 million tons of guano were mined from the Chilean and Peruvian islands and shipped to farms in Europe and North America. Once that supply was exhausted, the search was on for a new source of usable nitrogen.

In 1909, German chemists Fritz Haber and Carl Bosch devised a method for fixing atmospheric nitrogen by combining it with hydrogen to make ammonia. At first, the process used coal to fuel the machinery and as a source of hydrogen; later, coal was replaced by natural gas. As geographer Vaclav Smil has argued in *Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food Production*[8], the Haber-Bosch process probably deserves to be considered the principal invention of the 20th century since today ammonia synthesis provides more than 99 percent of all inorganic nitrogen inputs to farms — an amount that roughly equals the nitrogen tonnage that all of green nature gains each year from natural sources (legumes, lightning strokes, and animal excreta). More than anything else, it is this doubling of available nitrogen in the biosphere that has resulted in a dramatic increase in food production throughout the century, enabling in turn an equally dramatic increase in human population. At the same time, however, the widespread agricultural application of synthetic ammonia has led to nitrogen runoffs into streams and rivers — one of the most significant pollution problems of the last century.

Agriculture was also revolutionized by tractors and other motorized equipment as well as by motorized systems of distribution. Previously, one-quarter to one-third of all agricultural land in North America and Europe had been devoted to producing feed for the animals that pulled plows and wagons; thus the replacement of animals by motorized equipment meant that more land could be freed for human food production. Also, because tractors could cover more ground more quickly than draft animals, fewer farmers were needed to produce an equivalent amount of food; hence larger farms became economically feasible, indeed advantageous. As small subsistence farms were increasingly put at disadvantage, more farmers left the countryside to seek work in the cities.

The development of petrochemical-based herbicides and pesticides after World War II increased yields even further. In the 1960s and '70s, international development agencies promoted the use of motorized farm equipment, synthetic ammonia fertilizers, and chemical herbicides and pesticides throughout the less industrialized nations of the world; known as the "Green Revolution," this program resulted in predictably enhanced yields, but at horrendous environmental and social costs.

Transportation

The transportation revolution of the 20th century had social, economic, and environmental consequences that were nearly as profound as those in agriculture. Central to that revolution were the automobile and the airplane — two inventions dependent on the concentrated energy of fossil fuels.

In its early days, the automobile — invented in 1882 by Carl Benz — was a mere curiosity, a plaything for the wealthy. Nevertheless, the idea of owning a private automobile was widely and irresistibly attractive: the young and the upwardly mobile could not help but be seduced by the motorcar's promise of speed and convenience — even though the reality of journeying any distance in one actually entailed considerable inconvenience in the forms of noise, dust, mud, or mechanical breakdown. Promoters of the automobile claimed that widespread car ownership might relieve the nuisance of horse feces covering urban streets (for cities like New York and Chicago, this posed a serious pollution dilemma), but few gave much thought to the problems that near-universal automobile ownership might itself eventually entail.

One of the principal hindrances to the growth of the early auto industry was the lack of good roads. In order to travel at the speeds of which they were capable, automobiles needed surfaces that were smoothly paved — but few existed. Demand for more public funding for highways was already growing, fed partly by bicyclists, but motorists added dramatically to the public pressure. Beginning at the turn of the century, car owners and manufacturers, together with oil and tire lobbyists, succeeded in persuading all levels of government to, in effect, subsidize the automotive industry — at a rate that would cumulatively amount to hundreds of billions of dollars — through appropriations for road construction.

Henry Ford, America's most prominent automotive industrialist, proposed to make cars so cheap that anyone could own one. Ford made sure to pay his factory workers enough so that they could afford to buy a coupe or sedan for themselves. However, as inexpensive as the Model T was by today's standards, it still represented a cash outlay beyond the means of most American families.

Automated, fuel-fed mass production was proving capable of turning out goods in such high quantity as to overwhelm the existing demand. Until this time, the average family owned few manufactured goods other than small items, such as cutlery, plates, bowls, window glass, and hand tools. Virtually none had motorized machines, which were simply too expensive for the typical family budget. The industrialists' solutions to this problem were advertising and credit. More than any other product, the automobile led to the dramatic expansion, during the 1920s, of both the advertising industry and consumer debt. Car companies nearly tripled their advertising budgets during the decade; they also went into the financing business, making car loans ever easier to obtain. By 1927, three-quarters of all car purchases were made on credit, and there was one car for every 5.3 US residents.

That same year, 1927, was also the first in which more replacement cars were purchased than were bought by first-time owners. As the roaring twenties drew to a close, the market for automobiles became saturated while American families saddled themselves with a record amount of consumer debt. But car companies kept producing more Fords, Buicks, Hupmobiles, and Stutzes, thus setting the stage for a recession. The auto industry was not solely responsible for the full-blown economic catastrophe that followed — overly lenient rules governing stock speculation played a prominent role as well — but it contributed in no small way to the ensuing bankruptcies, bank failures, and layoffs.

By now, the automobile manufacturers together controlled a significant proportion of the national economy: General Motors was the world's largest corporation, with Ford and Chrysler following closely behind. Whatever the

Big Three automakers did sent ripples through the stock market, the banking system, and national labor organizations. The auto industry had united the interests of other giant industries — oil, steel, rubber, glass, and plastics — in the manufacturing, fueling, and marketing of a single product, and in the transformation of the American landscape, lifestyle, and dreamscape to suit that product. Subsidiary businesses sprang up everywhere — from spare parts distributors to local gas stations and repair shops, from fast-food chains to drive-in theaters.

Urban sprawl, which had begun in a few large towns with the installation of electric trolleys, exploded discrete cities into "metropolitan areas" with few clear boundaries, rolling on for mile after mile along major arteries. In New York, urban planner Robert Moses — who himself never drove — put the automobile at the center of his design priorities, creating grand new bridges and freeways for commuters while gutting entire neighborhoods to make way for on-ramps and off-ramps. For over forty years, from the 1930s to the late '70s, Moses rebuilt Manhattan to suit motorists; at the end of the process, traffic and parking problems were worse than they had been at the beginning, and the city had sacrificed much of its charm, neighborhood integrity, and historical interest along the way.

Many European cities responded to the automobile differently by investing more in trains, trolleys, and subways. Partly as a result, per capita auto ownership in Europe for a time remained significantly lower than in the US; meanwhile, the narrowness of old European city streets encouraged the design of smaller cars.

The European approach to mass transit could have taken hold in the US, which maintained excellent inter-urban passenger rail lines and many fine urban streetcar systems until mid-century. However, in 1932 General Motors formed a company called United Cities Motor Transit (UMCT), which bought streetcar lines in town after town, dismantled them, and replaced them with motorized, diesel-burning buses. In 1936, GM, Firestone, and Standard Oil of California formed National City Lines, which expanded the UMCT operation, buying and dismantling the trolley systems in Los Angeles and other major cities. By 1956, 45 cities had been relieved of their electric rail systems. The bus services that replaced them were, in many instances, poorly designed and run, leaving the private auto as the transportation mode of choice or necessity for the great majority of Americans. Public transportation in America reached its broadest per-capita usage in 1945, then fell by two-thirds in the succeeding twenty years.

The American love affair with the auto was also encouraged by what would become the biggest public-works project in history: the Interstate

Highway System. Modeled on Hitler's Autobahn, the Interstate System came into being through the Interstate Highway Act, passed in 1956 partly as a measure for national defense. The bill authorized $25 billion for 38,000 miles of divided roads; by comparison, the entire national budget in 1956 was $71 billion, and the Marshall Plan had cost only $17 billion. It was the Interstates, more than anything else, that would eventually nearly destroy the American passenger rail system: the trains simply could not compete with so highly subsidized an alternative.

Car ownership meant convenience, power, and even romance, as the typical young couple found freedom and privacy in the back seat of the parents' Chevy. Soon they'd be married, the husband commuting to the office, his wife chauffeuring the kids to music lessons and little-league games. The gift or purchase of a first car would become as important a rite of passage for every teenager as graduation from high school. Life would become unimaginable without the Mustang, Camaro, or Barracuda in the driveway, ready and waiting for adventure.

However, the love affair with the car always had its dark side. While in Paris in 1900, novelist Booth Tarkington overheard and recorded the comment, "Within only two or three years, every one of you will have yielded to the horseless craze and be the boastful owner of a metal demon ... Restfulness will have entirely disappeared from your lives; the quiet of the world is ending forever."[9] But noise would prove perhaps the least of the car's noxious effects; air and water pollution, the loss of farmland due to road construction, and global warming constitute far worse damage. Car culture has also resulted in the disappearance of wildlands and poses a constant danger to animals: the toll in roadkill is about a million wild animals per day in the US alone.

Out-of-pocket expenses for car ownership today average about $1,500 per vehicle per year. But if all of the environmental and social losses were factored in, that cost would be closer to $25,000 per car, according to some calculations. One of the greatest of those "external" costs is car crashes: since 1900, more than twice as many Americans have died in auto collisions than have been killed in all of the wars in US history.

If the dollar cost of motoring is burdensome, the energy cost is staggering. The typical North American driver consumes her or his body weight in crude oil each week, and the automobile engines sold this year alone will have more total horsepower than all of the world's electrical powerplants combined. Globally, cars outweigh humans four to one and consume about the same ratio more energy each day in the form of fuel than people do in food. A visitor from Mars might conclude that automobiles, not humans, are the dominant life form on planet Earth.

Like the automobile, the airplane began as an unreliable plaything, but one that evoked the promise of the superhuman power of flight. Its potential ability to speed up travel and to skip over geographic obstacles led to its early use in mail service. The first regularly scheduled passenger service began in the 1920s, though only the wealthy and the adventuresome took advantage of it; everyone else took the train or drove.

In the late 1950s, the first passenger jets entered service. At that time, most long-distance travelers still relied on cars, trains, buses, and ships; only the elite comprised the "jet set." But gradually, as tickets became affordable, more people began to board jet planes; by the 1970s, flying had become a standard mode of long-distance travel, especially for transoceanic journeys, and, at least in the US, airports had taken on the former function of train or bus stations. Air travel's affordability was greatly enhanced by a hidden subsidy: jet fuel is tax-free.

The growth of air transport vastly expanded the tourist industry, from 25 million tourists in 1950 to nearly half a billion by the year 2000. Hotels, travel agencies, and restaurants benefited enormously; today many cities and some nations are largely supported by jet-transport tourism.

Due to significant improvements in jet engine design in the past decades, the typical airline passenger experiences a miles-per-gallon efficiency roughly equivalent to — and, in some instances, better than — that of an automobile driver. Today, roughly ten percent of the extracted oil is refined into kerosene to fuel jets. Americans now fly a total of 764 million trips per year — 2.85 airplane trips per person, averaging 814 miles per trip.

Aviation is the only transport form not significantly regulated to reduce environmental impact. Airports are typically sites of extreme air pollution, and jet aircraft contribute substantially to the destruction of the atmospheric ozone layer.

Warfare

At the beginning of the 20th century, wars were being fought with mounted cavalry, foot soldiers, horse-drawn artillery, and coal-fired warships. In the First World War, military strategists began to appreciate the advantages of applying more sophisticated fossil-fueled technology to the project of killing. Warships, and especially submarines, were converted to oil or diesel power, thus giving them a longer range and greater speed; and tanks and motorized troop carriers (of which the first were simply commandeered Parisian taxicabs) began to revolutionize ground warfare. Meanwhile, airplanes offered the possibility of improved reconnaissance and of raining terror from the skies.

The outcome of World War I was largely determined by oil: the Allies blockaded German supply routes, while Germany sought to cut off shipments to Britain with submarine warfare. The US, the world's largest petroleum producer, was a significant help to the Allies. When the Allies succeeded in denying German access to Romanian oil fields, German industry began to suffer from a shortage of fuels and lubricants. By 1917, civilian trains were no longer in service, and airplanes were running poorly on substitute fuels. On November 11, with its army in possession of only days' worth of essential fuels, Germany surrendered.

The lessons of this defeat were not lost on Adolf Hitler, who promised to reverse disastrous economic and social conditions resulting from the humiliating terms of the Versailles peace treaty. Germany could not fight again without adequate fuel stocks, nor could it allow itself to become bogged down in another war of attrition. Thus when Nazi generals began planning for the invasions that would precipitate World War II, they had two objectives in mind: access to oil supplies and swift and decisive victories through the use of surprise motorized attack — *blitzkrieg*. Among Hitler's principal objectives in Poland and the Soviet Union was control of the oil fields in those regions. When the Allies were eventually able to deny Germany access to those oil fields and to cut off German supply lines, the Nazi war machine simply ran out of gasoline.

In the Pacific, Japan — which had practically no indigenous oil resources — attacked Pearl Harbor after the US cut off oil exports in an effort to thwart Japanese imperial ambitions throughout the Far East. A major Japanese objective in the war was to secure oil fields in the Dutch East Indies. However, American submarines succeeded in sinking enough tankers carrying oil from the East Indies to Japan that, by 1944, Japanese ships and planes were denied adequate fuel. By 1945, Japanese air pilots could no longer be given navigational training and Japanese aircraft carriers could no longer afford to take evasive action — all for lack of fuel.

Thus, by mid-century, oil had established itself both as an increasingly critical fuel for warfare and as an increasingly frequent geopolitical objective of war. Warfare had also become far more deadly, especially for noncombatants. All three trends would accelerate in the second half of the century.

Oil, Geopolitics, and the Global Economy: 1950 - 1980

At of the turn of the 20th century, Russia had begun the process of industrialization only in a few cities; throughout most of its vast territory, peasants worked their fields much as they had for centuries. Following the Bolshevik

Revolution of 1917 and the subsequent period of turmoil and political reorganization, the leaders of the new Union of Soviet Socialist Republics decided to undertake a program of forced industrial development. Subsequently known as Stalinization, the program involved compelling agricultural workers into industry and consolidating peasant land holdings into giant collectives. Between 1927 and 1937, iron output increased by 400 percent, coal extraction by 350 percent, electric power generation by 700 percent, and the production of machine tools by 1,700 percent. However, the human consequences were horrific. Millions of peasants in the countryside died of starvation, and conditions for urban factory workers were abysmal. Political dissent of any kind was brutally crushed.

At the end of World War II, with most of Europe in ruins, the US and USSR emerged as victors. Their alliance against the Axis powers did not persist into peace time as the two superpowers set about dividing much of the world between them. Both had huge petroleum and coal reserves, but their histories and economic systems were fundamentally different. While never directly confronting one another militarily, the US and USSR waged proxy battles over resources and influence throughout the ensuing forty-five years. The Soviet-dominated world was characterized by centralized, government-planned control and distribution whereas US-dominated nations were subsumed under the increasing power of giant multinational corporations.

The United States was the world's largest *consumer* of oil, its economy having been the first to widely exploit the use of petroleum through the mass production of automobiles and the development of a civilian airline industry. Meanwhile, as more Middle Eastern reserves were discovered and tapped, that area became the largest *producer* of oil. This meant a greater abundance of oil abroad than in the United States. Thus, after World War II, the major oil companies began maintaining two price levels: a domestic price for the United States and an international price. The domestic price was always higher, with the difference maintained by an import embargo on foreign oil. The embargo was repealed in the 1960s as oil reserves in the United States diminished.

There was such an excess of supply over demand in the international market that producers found it difficult to keep prices from dropping. Several of the oil-producing nations, of which most were located in the Middle East, formed a cartel known as the Oil Producing Export Countries, or OPEC, in order to restrain competition and avoid excessive price drops. Meanwhile, the "Seven Sisters" also maintained strict limits on oil production in order to stabilize prices. But as the oil industry expanded, many independent oil companies were formed in the US and elsewhere — and those "independents" refused to limit production.

In 1959, a further element of instability entered the mix with the discovery in Libya of rich new reserves of high-quality, easily obtainable oil. Since it was located within easy access of the European market and the northeastern United States, both of which were major consuming areas, Libyan oil threatened the ability of the major oil companies to limit production and to prevent falling prices.

This situation changed dramatically when a new leader came to power in Libya in 1969. Colonel Muammar al-Qaddafi was unwilling to abide by the agreements between OPEC and the major oil companies. He soon nationalized most of the oil wells in Libya and took control of pricing. Occidental Petroleum, one of the largest independents, was primarily affected. Occidental sought help from Exxon, the biggest of the majors, believing that Qaddafi could be faced down by the withdrawal of oil experts from the country; however, in order to accomplish that, Occidental would need spare production to offset its Libyan losses. If it could obtain oil from Exxon at cost, it could afford to oppose the Libyan upstart. Exxon refused. Thus Qaddafi had asserted control over his nation's oil reserves while avoiding retaliation by the oil industry. As far as the majors were concerned, this set an unwelcome precedent. Moreover, Qaddafi drew the ire of the US government through his support for national liberation groups, such as the Palestine Liberation Organization (PLO), the Irish Republican Army (IRA), and the African National Congress (ANC).

By 1970, the United States was unable to produce as much oil as it was consuming. Its rate of oil production peaked in that year and has declined ever since. From this time onward, the US would become increasingly dependent on imported oil and would no longer be in a position unilaterally to stabilize world petroleum prices.

The major international oil companies periodically renegotiated the price of crude oil with the representatives of each country. Most OPEC members were Middle-Eastern countries that opposed Israel in the ongoing Arab-Israeli conflict, while the US had been a staunch economic and military supporter of Israel since its creation in 1948. When Israel decisively defeated the principal Arab states in the 1967 war, the interim peace settlement left the Sinai peninsula in Israeli control. Egyptian President Sadat proposed a permanent peace if the Israelis returned all the occupied territories, but Israel refused. Since no progress was being made in negotiations, Sadat decided to initiate a war with limited objectives.

In October 1973, after demanding the evacuation of United Nations observers from the Egyptian-Israeli border, Egypt attacked Israeli forces in Sinai. Equipped with Soviet-provided surface-to-air missiles and armored vehicles, the Egyptian army overcame the ensuing Israeli air attack. However, the

Israelis immediately requested and received replacement aircraft from the US. As the Israeli army prepared to cross the Suez Canal, a Soviet fleet moved into position in the eastern Mediterranean, raising the possibility that the war might escalate into a confrontation between the two superpowers. To avoid such a catastrophe, Israel and Egypt were pressured to accept a negotiated cease fire. To the Israelis, this conflict became known as the Yom Kippur War, to the Arabs as the Ramadan War.

The Arab oil countries had been negotiating with the major oil companies when the war occurred. Because the war's outcome hinged on massive US military aid to Israel, the Arab states broke off negotiations and imposed an oil embargo against the US. An artificial oil shortage ensued. During the next four months, consumers in the United States were forced to wait in long lines at gas stations. The Arab members of OPEC effectively drove up crude oil prices fourfold. The OPEC cartel succeeded in wresting from the major oil companies the ability to set prices globally; from now on, it would be the producing countries, rather than the majors, that would play the key role in influencing the price of petroleum.

While a special relationship had existed between the US and Saudi Arabia since 1945, when FDR and Ibn Saud had concluded a pact ensuring secure oil exports in exchange for ongoing support for the Saudi regime, that relationship would became even more significant from 1973 on. As the world's largest oil exporter, Saudi Arabia would be in a position to dominate OPEC and to set prices. Both Washington and Riyadh would further cultivate their mutual interests, which over time would center on US arms sales to Saudi Arabia, Saudi oil exports to the US, and Saudi control of world oil prices to American advantage.

Given the world's dependence on oil for transportation, industrial production, agriculture, and petroleum by-products, the international economy was shattered by the 1973 price shock and driven into an inflation that would continue until 1982. As the oil shortage reverberated through the global economy, the costs of industrial production and delivery of goods shot up. In 1974, the world experienced its greatest economic crisis since the 1930s. The period of substantial prosperity that had followed World War II came to an end.

In 1979, the Iranian people overthrew America's long-time brutal client, the Shah, who had been installed in office by the CIA in 1953. Soon war broke out between Iraq and Iran, two major oil-producing countries in the Middle East, with the US covertly supporting Saddam Hussein of Iraq in an effort to punish the new Iranian Islamist regime. Since Europe imported large amounts of oil from both Iran and Iraq, a further artificial shortage ensued, and the international price of crude oil doubled again. In 1973, before the war between

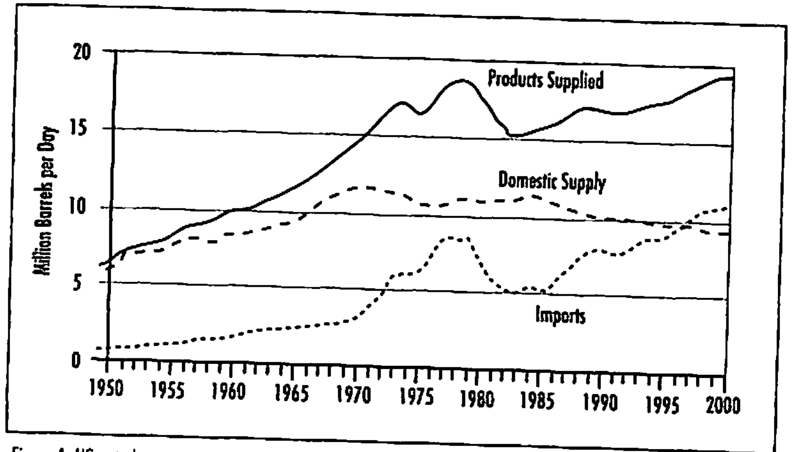

Figure 4. US petroleum overview, 1949–2000 (Source: US Energy Information Administration)

Egypt and Israel, oil prices had hovered at around $3 per barrel. After the embargo, the price rose to $12 per barrel, and after the commencement of the 1979 Iran-Iraq war it soared to more than $30 per barrel. As the resulting inflation worked its way through the international economy, the cost of all goods increased substantially. In the US, the price index of consumer goods rose approximately 10 percent per year for several years in the late 1970s and early 1980s.

This economic upheaval motivated intense efforts toward energy conservation, the development of alternative energy sources (solar hot-water panels, wind turbines, methane digesters, etc.), and a search for new oil reserves. Industries made significant progress in improving building construction practices to conserve energy, in producing lighter and more fuel-efficient automobiles, and in developing more efficient lighting systems.

Investment in nuclear power plants increased as forecasters projected great increases in energy consumption in years to come. However, these projections went unrealized, due largely to the effectiveness of conservation measures. Conservation proved itself the least expensive response to the energy shortage. Nuclear power, by contrast, was extremely costly due to the expense of providing safety measures against the hazards of radiation release.

Higher oil prices also stimulated new exploration, which resulted in the discovery of new reserves in the North Sea, off the coasts of Nigeria and Angola, in Mexico, and on the north slope of Alaska.

Since the oil crises had not been due to a real shortage of oil, but to political events, conservation and increased reserves combined to generate a large oil surplus. OPEC was unable to sustain high prices, and in 1982 oil prices began to fall substantially. Inflation subsided and both the international economy and the US stock market enjoyed a recovery.

During the 1980s, many OPEC countries cheated on export quotas. Kuwait was the worst culprit, arbitrarily adding 50 percent to its reported reserves in 1985 to increase its quota, which was based on reserves. At the same time, Iran was motivated to cheat in order to finance its war with Iraq. Saudi Arabia found itself acting as the swing producer, reducing or increasing its production to keep prices stable; by 1985, the Saudis were selling less than half their quota. Up to this time, Britain had agreed to sell its North Sea oil at the official OPEC price, but Margaret Thatcher decided to let the price fluctuate. Reagan and Thatcher wanted to bring down the Soviets and persuaded King Fahd to increase his country's production substantially, thus dropping the price. The Soviets relied on oil for foreign exchange, which it needed to match America's new arms buildup (principally, Star Wars).[10] In 1986, Saudi Arabia flooded the market and drove crude prices down sharply — from over $30 to less than $10; some producers were selling oil for as little as $6 a barrel. For the industry, this constituted a third oil shock: such low prices devastated US independent producers. Despite evident damage to the Soviet economy and despite their free-market rhetoric, Reagan and Bush intervened, threatening to impose tariffs. Eventually both OPEC and non-OPEC producing countries agreed to coordinate production in order to maintain stable higher prices — though this never actually worked. The outcome was a victory for the Saudis, once again underscoring their power in the global market, but it led to a new commitment on America's part both to increase its presence in the Middle East (a decision that played a role in the lead-up to the Gulf War of 1990-91) and to diversify its import sources, relying more on Venezuela, Colombia, Ecuador, Canada, and Mexico — and less on the Arab states.

1980 – 2001: Lost Opportunities and the Prelude to Catastrophe

The oil crises of the 1970s had produced a significant shift in public attitudes about energy. Many groundbreaking books about the links between energy consumption and social and environmental problems were published during the late 1970s and early 1980s, including *Entropy*, by Jeremy Rifkin; *Soft Energy Paths*, by Amory Lovins; and *End of Affluence*, by Paul and Anne Ehrlich. President Jimmy Carter appeared on television to tell the American people that "[o]urs is the most wasteful nation on Earth; we waste more energy

than we import" and to exhort the American people to engage in a massive national effort to conserve.[11] Spurred by tax subsidies and grants, businesses specializing in energy conservation, and in solar and wind power, sprang up by the hundreds.

With the advent of the Reagan-Bush administration in 1980, the official discourse on energy suddenly changed again. In campaign commercials, Reagan's publicists proclaimed that it was "morning in America": the people of the US should forget their worries about energy-resource limits and return to their proper pastimes: spending, driving, and wasting. In a highly symbolic act, Reagan ordered the solar hot-water panels installed by Carter on the White House roof removed and junked. Subsidies for conservation measures and for the development and purchase of alternative-energy systems evaporated.

During the 1980s, junk-bond king Ivan Boesky proclaimed that "greed is good," and the US undertook massive investments in military hardware. The Reagan-Bush administration also covertly supported the Contras and other mercenary militias in Central America that opposed peasant efforts at land reform; significantly for future energy-related events, it also supported the Mujaheddin and other militant Islamicist movements in Afghanistan, which opposed Soviet influence in south-central Asia. Representatives of the US administration convinced King Fahd to pay for arms to be shipped from Egypt to the Mujaheddin, many of whom would later give rise to the Taliban.

The collapse of the Soviet Union in 1991 — shortly following its oil-production peak in 1987 — came as a puzzling surprise to US strategists, despite the fact that they had wished and plotted for this very eventuality for decades. Though the USSR had a long border with the Middle East, the US had managed to prevent the Soviets from forming strong trade or military alliances with any of the major Persian Gulf oil producers. The only major exception consisted of loans and trade agreements between the Soviets and Iraq. Had such alliances expanded, the USSR and the Middle East together would have had the resources necessary to successfully challenge the West, both economically and militarily. Moreover, the Soviets could have cushioned the effect of their oil-production peak in 1987 with imports, as the US did in the 1970s, and perhaps avoided collapse. But this was not to be: as it happened, the USSR's production peak, coming shortly after the oil price drop of the mid-'80s, proved devastating to its oil export dependent economy.

The US, with its former foe now in a state of economic chaos, found its ideological justifications for international military hegemony being undermined. Against whom or what was the US protecting the world now? Hence the American search, beginning in the early 1990s, for new enemies to replace the old Soviet Union.

The Gulf War of 1991 began with a dispute between Iraq and Kuwait over ports in the Gulf and over oil export quotas. Iraq's plan to invade Kuwait appeared initially to have been condoned by the US, and so the real motives for the entrance of the United States into the conflict were unclear. President Bush (Sr.) had sent his emissary Henry Shuyler to persuade his then-ally Saddam Hussein to intervene in OPEC to hike oil prices for the benefit of his Texas constituents. Bush and his advisers knew that OPEC cheated and fell on the idea of a border incident whereby Iraq would take the southern end of the Rumaila field, from which the Kuwaitis were pumping. On the eve of the invasion, the US Ambassador in Baghdad, April Glaspie, said, "We have no opinion on the Arab-Arab conflicts like your border disagreement with Kuwait" — a statement countersigned by Secretary of State James Baker in Washington. Saddam assumed he had a wink and nod to invade his neighbor.[12]

Speculations about the reasons underlying the devastating US military intervention that followed had to do with control of Iraq's oil reserves, which were second only to those of Saudi Arabia — where the US installed permanent military bases during the war. In his book *Iraq and the International Oil System: Why America Went to War in the Gulf*, national security affairs analyst Stephen C. Pelletière examined US motives in the war in depth, concluding that the Gulf War represented a forcible expression of America's resolve to consolidate its control of the Middle East.[13] Iraq's decisive victory over Iran in 1988 had come as a shock to Washington, and neither the US nor Israel was about to tolerate a strong, independent, militarily competent Arab nation in the region.

Whatever the motive, the result was a quick military victory for the US and ongoing devastation for Iraq, which continued to suffer under UN-imposed trade sanctions for the following decade. During the hostilities, American strategists had apparently done some quick thinking and realized that they could make Saddam the swing producer of last recourse. By embargoing Iraq, they kept two to three million barrels of crude per day off the world market at no cost to anyone but Saddam. This is perhaps why they stopped at the gates of Baghdad and left him in power. Later, when oil prices rose uncomfortably, the US relaxed the embargo for "humanitarian" reasons, and most of Iraq's subsequent exports made their way to American gas tanks.

Beginning in 1993, the US attempted to control global oil prices through a policy of Dual Containment, in which the export quotas of Iraq and Iran were assigned to the nations of the lower Gulf as a reward for their economic and logistical support during the Gulf War. Thus one side effect of the war was that, because the US forcibly took most of Iraq's production off the world market for the ensuing decade, another world oil glut was averted — but only partly so. Despite a significant price surge during the war itself, the remainder of the decade saw stable though generally falling prices. Consequently, revenues to producing countries dwindled. Saudi Arabia, which had one of the fastest-growing populations in the world, faced diminishing per-capita incomes and simmering political unrest, the latter exacerbated by the presence of US military bases on land sacred to all Muslims.

Simultaneously with the development of the Dual Containment policy, the US began using the World Bank, the International Monetary Fund, and related institutions to secure non-OPEC oil sources through its funding of pipelines and exploration in less-consuming countries in Asia, Africa, and South America. From 1992 on, at least 21 agencies representing the American government, multilateral development banks, and other national governments approved billions of dollars in public financing in roughly thirty countries for energy projects that not only gave US oil companies new sources, but also aided a relatively new company called Enron — a complex entity involved in energy trading and distribution — to gain global reach. In India, Guatemala, Panama, Colombia, and other countries, Enron struck deals with local politicians giving the energy firm control over electrical and gas utilities. Enron executives began lavishing generous campaign donations on Democrats and Republicans alike, and soon, US officials started twisting arms: for example, Mozambique was threatened with a cutoff of US foreign aid if it did not accept Enron's bid for a natural gas field.[14] Enron also implemented a domestic strategy, bribing state politicians to deregulate their utilities industries; in California, deregulation would result in the artificial energy crisis of 2001, in which utilities customers suffered through blackouts while the state itself racked up billions of dollars of debt in attempts to pay off electrical power generators and distributors (including Enron) that had been enabled by deregulation to systematically create both severe shortages and windfall profits.

The Clinton-Gore administration had taken office in 1993 amid high hopes, on the part of environmentalists, that some of the support for energy conservation and renewable energy programs that had flourished under Carter's administration would be revived. These hopes were based largely on Gore's timely book *Earth in the Balance* (1992). However, few substantial energy-policy changes were actually enacted during the following eight years.

Throughout the 1990s the most notable international political-economic development was the accelerating globalization of manufacturing, distribution, and corporate influence. Globalization was a complex phenomenon that outwardly had to do with high-speed communications, long-distance transportation, and the lowering of trade barriers through international agreements administered by trade adjudication bodies like the World Trade

Organization; however, it had its roots in the inherent dynamics of industrialization itself.

In the previous two centuries, the machine-based production system had expanded by producing low-cost goods using fossil-fueled equipment to replace the skilled, and thus more expensive, labor of artisans. One result of industrialization was that the proportion of each enterprise's income going to wages typically fell, while the proportion going to investors and moneylenders gradually increased. This meant that, as more production processes became mechanized, the buying power of industrial workers would inevitably wane, resulting in a massive overproduction of goods and the bankrupting of the entire system, unless foreign markets could be found for manufactured products.

During the 20th century, more and more countries adopted mechanized production in the hope of escaping poverty. Those that had industrialized earlier were always in a favored position because they held both more economic power and also machine tools, dies, and patents to production processes; selling production rights and equipment to developing nations enriched the already industrialized countries. Slowly an industrial pyramid emerged. Though its apologists always dangled the promise that eventually the entire world would live at the same standard as people in Europe and America, in fact the pyramid was always growing steeper, with countries at the top growing richer and those at the bottom growing poorer. The same trend of increasing economic inequality was occurring within many countries as well, most notably the US.

By the 1990s, the point had been reached where there were virtually no more pre-industrial markets to be taken over. This left corporations in the industrial pyramid with no one to displace but each other; inevitably, international competition grew much more intense.

Corporations adopted two strategies to survive: further automating, thus displacing human labor almost entirely; or moving production to countries where labor was cheaper. The combined result was that the share of industrial revenues being paid in wages and salaries fell even further, so that ever more people were left without the financial means to buy priced goods. For the hundreds of millions of people who had previously lived as self-sufficient rural peasants and who had been uprooted by the process of agricultural industrialization, the results were catastrophic. Corporations also began to merge at record rates since, lacking other new sources of revenue, they were now forced to consume each other.[15]

By this time the bulk of new investment capital was flowing not to manufacturing, but to speculation in fluctuating currencies, derivatives, options, and

futures. The cumulative effect of such speculative investments was to enrich the financial elites and to undermine the long-term stability of the system as a whole. With surplus production capacity in almost every sector and investment capital leveraged to absurd lengths, the world teetered on the brink of economic collapse.

In the US, George W. Bush and Dick Cheney took office in 2000 following a deeply flawed election. With strong ties to the oil industry and to Enron, the new administration quickly proposed a national energy policy that focused on opening federally protected lands for oil exploration as well as on further subsidizing the oil industry; Cheney pointedly proclaimed that energy conservation "... may be a sign of personal virtue, but it is not a sufficient basis for a sound, comprehensive energy policy."[16]

Enron, George Bush's largest campaign contributor, had grown to become the seventh largest corporation in the US and the sixteenth largest in the world. Despite its reported massive profits, it had paid no taxes in four out of the five years from 1996 to 2001. The company had thousands of offshore partnerships, through which it had hidden over a billion dollars in debt. When this hidden debt was disclosed in October 2001, the company imploded. Its share price collapsed and its credit rating was slashed. Its executives resigned in disgrace, taking with them multimillion dollar bonuses, while employees and stockholders shouldered the immense financial loss. Enron's bankruptcy was the largest in corporate history up to that time, but its creative accounting practices appeared to be far from unique, with other corporations poised for a similar collapse.

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In light of what was about to happen, the period from 1973 to 2001 can be seen as having represented a pivotal but lost opportunity. The oil embargo of 1973 and the global economic turmoil accompanying the Iranian revolution made it clear how dependent the world economy had become upon petroleum, and how dependent the US had become upon oil imports. Moreover, everyone knew that oil was a resource that was inherently nonrenewable and therefore limited in supply. The rational response would have been to undertake massive, ongoing conservation efforts and investments in a transition to renewable energy sources. Such efforts were tentatively begun, but quickly abandoned. Greed and political influence on the part of the oil companies were no doubt factors in preventing that course from being pursued. But the companies do not deserve all of the blame: free-market economists and their acolytes in political office genuinely believed that the all-knowing market would provide for every contingency and that resource shortages would never amount to a serious problem.

In hindsight, the reasons for abandoning the path of conservation seem tragically wrongheaded. There was at the time a sizeable minority who decried the return to heedless consumerism, but their voice was destined not to prevail. The path actually taken was one not only of consumptive excess and increased global competition but also of a growing attempt on the part of US geopolitical strategists to control global petroleum resources. Its consequences would materialize dramatically on the morning of September 11, 2001.

Chapter 3

Lights Out: Approaching the Historic Interval's End

Pangloss is admired, and Cassandra is despised and ignored. But as the Trojans were to learn to their sorrow, Cassandra was right, and had she been heeded, the toil of appropriate preparation for the coming adversity would have been insignificant measured against the devastation that followed a brief season of blissful and ignorant optimism ...

Today, Cassandra holds advanced degrees in biology, ecology, climatology, and other theoretical and applied environmental sciences. In a vast library of published book and papers, these scientists warn us that if civilization continues on its present course, unspeakable devastation awaits us or our near descendants ...

As a discomforted public, and their chosen political leaders, cry out "Say it isn't so!", there is no shortage of reassuring optimists to tell us, "Don't worry, be happy."

We sincerely wish that we could believe them. But brute scientific facts, and the weakness of the Panglossian arguments, forbid.

— Ernest Partridge (2000)

... by early in the twenty-first century, the era of pumping "black gold" out of the ground to fuel industrial societies will be coming to an end.

— Paul Ehrlich (1974)

We've embarked on the beginning of the last days of the age of oil.

—Mike Bowlin, Chairman and CEO, ARCO (1999)

My father rode a camel. I drive a car. My son flies a jet airplane. His son will ride a camel.

— Saudi saying