POWERING THE FUTURE

A Scientist's Guide to Energy Independence

daniel BOTKIN

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with Diana Perez

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Pearson Education, Inc.
Publishing as FT Press
Upper Saddle River, New Jersey 07458

Printed in the United States of America

First Printing March 2010

ISBN-10: 0-13-704976-5
ISBN-13: 978-0-13-704976-9

Pearson Education LTD.
Pearson Education Australia PTY, Limited.
Pearson Education Singapore, Pte. Ltd.
Pearson Education North Asia, Ltd.
Pearson Education Canada, Ltd.
Pearson Educatión de Mexico, S.A. de C.V.
Pearson Education—Japan
Pearson Education Malaysia, Pte. Ltd.

Library of Congress Cataloging-in-Publication Data

Botkin, Daniel B.
Powering the future : a scientist's guide to energy independence / Daniel Botkin.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-13-704976-9 (hardback : alk. paper) 1. Power resources—United States. 2. Power resources—United States—Forecasting. 3. Renewable energy sources—United States. 4. Energy policy—United States. I. Title.
TJ163.25.U6B68 2010
333.790973—dc22

2009052805

We have only two modes—complacency and panic.

—James R. Schlesinger, the first U.S. Energy Secretary, commenting on the country's approach to energy (1977)

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Contents

Acknowledgments

I wish to acknowledge the important contributions of the following and express my thanks and appreciation for their contributions. First, my wife, Diana Perez Botkin, worked closely with me on the manuscript. She is a professional editor with extensive experience, and we both saw this book as having a potentially useful role and were devoted to it. The extent to which the book is readily readable and accessible is due to her, and also to my sister, Dorothy B. Rosenthal, retired professor of science education, Long Beach State University, who read much of the material more than once. Pat Holl provided invaluable help in obtaining permissions for the book's illustrations.

Matthew Sobel, William E. Umstattd Professor, Chair of Department of Operations, Case Western Reserve University, provided insightful and important comments and suggestions about the economic analyses and cost forecasting, and carried out some essential economic calculations used in this book.

Kenneth P. Green, resident scholar, American Enterprise Institute, checked my calculations to make sure they were accurate.

My son, Jonathan D. Botkin, checked many calculations regarding alternative energy and helped with the interpretation of technical information. Robert Elliott, former Deputy Secretary of State, State of New York, and past mayor of Croton-on-Hudson, N.Y., helped me understand how best to communicate the ideas in this book to those involved in government and politics.

Professor Brian Skinner, Yale University, Department of Geology, guided me to experts on mineral resources. Dr. Franz J. Dahlkamp, author of *Uranium Deposits of the World* (originally published in 1993, new edition published February 2009) and member of the Advisory Board of Strathmore Minerals Corporation, corresponded with me about uranium resources, as did James K. Otton, Ph.D., Uranium Resource Specialist, U.S. Geological Survey. Tom Payne, director of the Ferroequus Railway Company Limited and president of the Great Northern Pacific Railway, Inc., provided essential information about costs of railroad construction. Professor Kingsley Haynes, Dean, School of Public Policy, George Mason University, helped with data about automobile transportation. Historian Dr. Alfred Runte, an authority on the history of railroads, helped me contact railroad experts. Ted Scudder, an anthropologist from Caltech and author of *The Future of Large Dams,* helped with my analysis of major new hydropower installations and the potential or lack of potential for more.

The following read all or parts of the manuscript and provided invaluable suggestions: Kenneth L. Purdy, Charles Sansone, Dr. Bruce Hector, and John Gibson; and Nancy E. Botkin. Dr. John H. DeYoung Jr., chief scientist, Minerals Information Team, U.S. Geological Survey,[1] helped to find reliable information about uranium and thorium ores and the economics and future of nuclear energy. Tom Veblen, Cargill Corp. executive (retired) and head of Superior Business Firm Roundtable, author of *The Way of Business,* helped me understand the perspective of a major corporate business executive on energy and society.

Of course, all statements, calculations, and conclusions are my own and I am responsible for any errors, but I have done my best to avoid any errors in calculations. No one and no organization, foundation, or any other entity has supported this book except the publisher. It is therefore a totally independent assessment by the author.

About the Author

Daniel B. Botkin is Professor (Emeritus), Department of Ecology, Evolution and Marine Biology, University of California, Santa Barbara, and President, The Center for The Study of The Environment, a non-profit corporation that provides independent, science-based analyses of complex environmental issues. The *New York Times* has called him "one of the world's leading environmental researchers," who has "done much to popularize the concept of using yet maintaining the world's natural resources."

His research includes creating the first successful computer simulation in ecology; studies of wilderness and natural parks ecosystems—from the Serengeti Plains of Africa to the Boundary Waters Canoe Area of Minnesota and Isle Royale National Park; threatened and endangered species—whooping cranes, salmon, bowhead and sperm whales, and African elephants. He was among the first to investigate possible ecological effects of global warming and to help NASA use satellite imaging to study the Earth's global environment.

His dozen books include *Discordant Harmonies: A New Ecology for the 21st Century,* which "is considered by many ecologists to be the classic text of the [environmental] movement," according to *The New York Times*. *Beyond the Stony Mountains* describes nature in the American West before European settlement, based on the journals of Lewis and Clark. *No Man's Garden* analyzes the value of nature and the relationship between people and nature. He has published op-ed pieces in many major newspapers concerning global warming, biological diversity, and energy, and more than 150 scientific papers.

His recent awards include the Astor Annual Lectureship for 2007 (Oxford University); annual distinguished visiting scholar for 2008 (Green Mountain College, Vermont); and the Long Beach Aquarium, Long Beach, California, has appointed him its first-ever distinguished visiting scientist for November 2008. He is also the recipient of the Fernow Award for Outstanding Contributions in International Forestry and the winner of the Mitchell International Prize for Sustainable Development.

His other academic appointments include Professor of Biology and Director of The Program in Global Change at George Mason University, Fairfax, VA; Professor of Systems Ecology at the Yale School of Forestry and Environmental Studies; and Research Scientist, The Ecosystems Center, Woods Hole, MA. His degrees are B.A. (Physics; University of Rochester), M.A. (Literature, University of Wisconsin), and Ph.D. (Biology, Rutgers University).

Preface

What this book is

This book is about how to solve our energy problem. It presents the facts concerning our energy needs, desires, and supplies, and the environmental and human effects of obtaining and using energy. It also includes calculations and analyses based on these facts. The purpose of the book is to provide U.S. citizens and our elected representatives with information that will enable us to make rational, economically and environmentally sound decisions.

What is our energy problem, and why do we have it? Some people believe that energy is a problem only because continued burning of fossil fuels will lead to undesirable global warming. But even without that possibility, the people of the world, and especially the people of the United States who use more energy than any other nation, have an energy problem: The need and desire for energy will increase faster than it can be provided from standard sources. As the world's population grows, and as living standards and expectations rise, people around the world will want more energy. Meanwhile, petroleum is limited and, according to estimates by petroleum geologists and economists, is likely to become so rare by 2050 that it may be too expensive for most energy applications. Pollution from fossil fuels will also continue to be a problem and is likely to worsen with increased mining and use. As the human population continues to grow and as quality-of-life expectations rise, competition for land and water will also increase. For the United States, military and economic security are also strong reasons for seeking energy independence, or as close to that as possible.

Some believe that we should become energy minimalists, each person using as little energy as possible. This book takes a different tack. It assumes that we should use energy as efficiently as possible, but that abundant energy is necessary for the quality of life that people today expect. Minimal energy would be that required to provide food, water, shelter, and access to medical care. Civilizations require more. People need to be educated; funds are needed for arts, humanities, sciences, and for recreation and entertainment. Life should be joyful, and music, dance, and the graphic arts don't come energy-free. If people have such limited energy available that they can only focus on the bare necessities of life, they don't have time to think about who to vote for, how to organize and run a political campaign, go to town meetings, and so on—the things that we take for granted but are necessary for a democracy. Thus it also may be that democracies benefit from, or even require, more than the minimal energy required for the barest human survival.

Of course, there is a wide range between just enough energy to get food, water, and shelter, and to have everything anyone could ever want—and the decision about what is a quality of life and what is extravagance is a question that goes far beyond this book. My point only is that we cannot have peace, culture, joy, and civilization, let alone freedom and democracy, without energy that allows us to do more than just survive. In the last chapter, I consider various scenarios, some of which contrast very great differences in per capita energy use.

And abundant and superabundant energy can be used for evil as well as good, fueling wars, vast armies, oppressive dictatorships, and terrorism, the worst of man's actions. But without enough energy, no one can work for what is good about and for people. Energy is the key. Physicists define energy as the capacity or the ability to move matter, which means it is necessary for a human being to do anything, including those things that are worthwhile and good.

The good news is that our energy problem can be solved: Today's technology can solve it. America can be energy-independent—our nation can provide a sufficient and sustainable supply of energy with relatively little change in the quality of our lives or in our overall standard of living. Indeed, done with great care, it will result in a better environment and an improved quality of life for most of us.

The tough news is that achieving this energy independence will be expensive and will require a national commitment that is unusual for a democracy, although not unprecedented. Examples of such commitment in our past include the expansion of European-based civilization westward with the Louisiana Purchase, the response of the nation to the Great Depression of the 1930s and to World War II, and our success in putting a man on the moon ten years after we decided to do so. However, such concerted national efforts are rare. Mostly, we tend to muddle through, often waiting to rebuild a bridge until the old one finally collapses.

The solution requires informed citizens and informed politicians. It requires political will and individual personal commitments in ways that we have not chosen to seek in past decades. A necessary and important part of energy independence is clear thinking, rational, science-based analysis. It requires innovation, creativity, invention, and entrepreneurship. This book is meant to be a foundation for the path to energy independence.

What this book is not

Two energy-related topics that are mentioned but not discussed in depth are carbon offsets and subsidies. The subject of subsidies is so big and complicated that a separate book would be needed to analyze the subsidies for each source of energy from cradle to grave—from discovery, invention, and exploration, to use and the problems of dealing with the wastes and land conversions. The same holds true for carbon offsets. By seeking a way to replace all fossil fuels, this book does point the way to reducing the production of carbon dioxide from burning fossil fuels. It just does not deal with the particulars and differences in carbon dioxide releases among different energy sources. There is no intention to minimize the importance of either of these topics.

The focus here is on how energy supply can be obtained technologically in a way that is as environmentally beneficial and benign as possible. Although I do discuss costs to some extent, this is not a book primarily about economics. My hope is that this book will provide a basis from which economists and others can consider in much greater detail the economic consequences of difference choices and the ways that a society and individuals can be motivated to choose and work toward a specific solution.

The energy solution has become a major political and ideological debate, and obviously a great deal of money, influence, and direction of our society is at stake. During the past few years, I have been asked to discuss the solution to energy supply in a number of forums, sometimes as part of a panel discussion or debate. It should not be surprising that many approach this important topic from a specific political and ideological goal, which leads them to pick the facts that support these goals and ignore those that don't. I believe that this approach is a road to failure. Of course, no one can be completely free of prejudgments and emotional assumptions, but to solve a large-scale technological problem like energy supply requires a rational approach. We have to be careful to see this as more of an engineering problem, solidly based in science, than an expression of a political philosophy or ideological conviction.

Why I wrote this book

As an ecologist with a background in physics, and as chairman of the Environmental Studies program at the University of California, Santa Barbara, I have long been interested in how energy is obtained and used in natural ecosystems, how energy from our environment affects us, and how we affect our environment in our pursuit of energy. For my work, I had to keep up with energy issues, and in doing so noticed some odd contradictions that began to occur around 2002. Solar and wind were already providing energy in many parts of the world, but environmental economists I worked with kept telling me a different story. "The conventional wisdom," they said, was that solar and wind power can never amount to anything.

At that time, my son, Jonathan, worked for a company called PowerLight, which manufactured and installed some of the largest solar energy facilities in the world. (He had previously worked for U.S. Windpower.) Deciding it might be interesting for all involved, I set up a series of telephone conferences between the environmental economists and the PowerLight engineers. Each time one of the economists asked a question about solar power and was answered by an engineer, the economist would reply, "But according to conventional wisdom, solar and wind energy can never amount to anything." This went on for three weeks of conference calls, until finally the engineers and I gave up, discouraged because nobody seemed interested in the facts.

Soon afterward, the *New York Times* published an interview with James Lovelock, the famous British chemist and environmentalist who came up with what he called "the Gaia Hypothesis," an expression of the idea that we are all connected to all of life by a planetary system. Commenting on the energy problem, Lovelock said, "If it makes people feel good to shove up a windmill or put a solar panel on their roof, great, do it. It'll help a little bit, but it's no answer at all to the problem."

Meanwhile, hundreds of thousands of people in developing nations were buying or building cheap solar and wind devices to provide them with enough electricity to cook their food, run computers and some small home appliances, and thereby join the modern age. It wasn't just making them feel good; it was improving the fundamentals of their lives.

With all the debate about our energy supply, the end of the era of cheap and abundant oil and gas, and concerns about global warming, I decided to look at each form of energy: how much is available, how much we now use, how much we will use in the future, and what our options are to move away from fossil fuels. The approach would be the same one I have used for all scientific problems: looking at the most reliable data available and making the obvious calculations and analyses. In the past, I'd always been surprised by what the facts revealed, because so often what they told me contradicted the conventional wisdom. In many cases, the facts—especially quantitative information—necessary to reach a conclusion are completely lacking because nobody ever bothered to get them, and without these, of course, even the simplest calculations and analyses haven't been done.

Many people have come to think of energy independence as a good for a number of obvious reasons. Politicians know this sounds good and promote it. But no matter what your reasons for seeking independence, it's almost certainly not practical or necessary to become 100% independent, because importing significantly less oil and from a broad range of countries would answer the strategic and reliability and other problems. But what percentage is to be the goal? And what is the maximum per cent we should import from one nation that we may not be on good terms with, versus what percentage from nations that we are? You the reader can fill in these blanks as you see fit, but for the sake of clarity in my thinking, and simplicity in my calculations, I have used the concept of 100%. And this is not because I am promoting the idea that this is absolutely necessary, only that it makes a very clear context for thinking and calculating our own domestic use of all the various current and possible energy sources.

With so many people talking and writing about the energy issue, why should you pay attention to this book? Because to the best of my ability I have hunted down the most solid facts and information and analyzed them as carefully and as free of my personal biases as possible, searching out the facts, doing the calculations, and checking those measurements and calculations with experts in their fields. Some colleagues have suggested to me that the mineral and fossil fuel data are crude and unreliable. But these are our only starting point for any analysis at this time; we're stuck with them unless major new data collection programs begin. You will surely find some of the results surprising, and I hope you will also find them helpful.

Introduction

Blackout!

FIGURE I-1 The big blackout of 2003. A bright full moon over a darkened New York City skyline during the blackout that started Thursday, Aug. 14, 2003, and affected 80,000 square miles in the eastern United States and Canada. *(Source: Bob Gomel/Time & Life Pictures/Getty Images)*

Thursday, August 14, 2003

It was one of those muggy New York City summer days that began like all the others. But it ended in a way that was an eerie precursor of the electric-power problems that would have major impacts on New Orleans after Hurricane Katrina in August 2005, and remain an ominous threat to all of us who live in a modern industrialized society.

Our apartment in Manhattan's Chelsea neighborhood, west of Fifth Avenue between 34th Street and 14th Street, had an unobstructed view of the city from the 20th floor but did not have air conditioning. It had "air cooling"—cool air pumped from a central energy plant through underground steam pipes and up into our apartment—and on this hot day it was doing its usual mediocre job, making it only about 5 degrees cooler inside than out. Indeed, as the morning wore on, our eastward-facing terrace fell into shade and actually became more comfortable than the apartment. We leaned against the railing and looked up at the Empire State Building just to the northeast.

As always, Manhattan was an impressive sight, a seemingly invincible metropolis, a triumph of modern civilization over raw nature. Our use of abundant and cheap energy was everywhere evident: in the streets teeming with taxis, buses, and trucks; in the sounds of big air-conditioning units on rooftops, jackhammers, and street cleaners—sounds of internal combustion engines of every size. Even indoors we could hear our heating/cooling convectors blowing, the elevators running, the water pumps thumping through the walls, an amplified guitar played by an upstairs neighbor, someone's vacuum cleaner, and power tools being used to renovate an apartment somewhere in the building.

But unknown to us, hundreds of miles away in the Midwest something was going wrong that would soon affect this great city and thousands of square miles around it.[1]

Noon: New York City's temperature climbed to 91°F, the hottest so far that month. It hadn't rained to amount to anything for ten days, and it hadn't been this hot since July 5, when the temperature climbed to 92° F. Today, the sun shone through a gray-blue haze.[2]

It wasn't hot just in New York City; it was hot throughout the northeastern United States and adjacent Canada, and air conditioners across these thousands of square miles drew huge amounts of electricity. That electricity flowed over a gigantic grid system, thousands and thousands of miles of high-tension wires across the Midwest and eastern United States and Canada, from the Great Lakes of Michigan to the Atlantic Ocean shores of Canada. The Midwest Independent Transmission System managed the huge electrical grid of the eastern United States and Canada for about 30 big power companies.

In elementary school, we were given a pamphlet from the local power company that showed a picture-book idealization of how electricity gets to your house. There was a generating station, usually shown as a hydroelectric-power dam, with wires coming out of it that ran along tall high-tension poles across the countryside to your town and then through a series of transfer points to a telephone pole outside your house and then to your home. It seemed simple: a place that made power, a way to transmit it, and us to use it.

But that isn't how it works anymore for most of North America. Instead, energy from many generating stations flows into a central grid, and this grid then spreads like a complex spider web throughout the countryside so that everybody's home is ultimately connected to everybody's source of energy, more or less. And the sources of energy were becoming more varied every year, with wind turbines and solar energy parks beginning to add electricity to the grid. The giant tangle of wires consists of more than 150,000 miles of interlocked power lines connecting plants that generate more than 850,000 megawatts. This amount of energy is hard to imagine, but look at it this way: One megawatt of electricity is about enough to power 300 homes, so the grid carries enough electricity for 255 million homes.

New York State alone was using 28,000 megawatts. That's more than 37 million horsepower, enough to run 370,000 automobiles starting a race at full acceleration at the same time; enough to power 280 million 100-watt light bulbs, about one bulb for every person in the United States at that time.[3] But unlike those 370,000 cars, all these electrical devices were connected, like the colored lights on a Christmas tree.[4] The surges were huge, too, 3 billion watts surging up and down New York State's high-tension power lines.

The grid has 130 control centers operating 24/7.[5] Most of the time everything works, but on this day at around noon, hundreds of miles away from New York City in Carmel, Indiana, Don Hunter, one of the coordinators of the Midwest Independent Transmission System, saw that there was too much electricity flowing on the wires. If the power load got too high, the grid could break down, even catch fire, just like an overloaded electric circuit in your home.

Concerned, Hunter put in a call to the Allegheny Company, one of the 30 cooperating power producers and distributors his firm coordinated, and asked them to reduce their electrical load on the grid.

Allegheny's representative at first agreed, but then said, "Don, question for you. I got a call from the people at our marketing end. They want to bring on another unit at Wheatland." [6]

"We would have to say no to that, at this point," Hunter responded.

But Allegheny Power went ahead and upped its power production anyway.

1:00 pm: The grid started to unravel. In Cincinnati, Ohio, an employee at Cinergy Corporation, another of the on-the-grid electric power producers, called the Carmel, Indiana, coordinating offices.

"Hey, we've got big problems," the Cinergy employee, Spencer, said.[7]

"We don't want no big problems," a center employee responded.

"No, we've got a huge problem," Spencer said, explaining that a major transmission line across Cinergy's system in Indiana had gone down, and the power moving east through the state was endangering other lines. To protect the still functioning lines, Cinergy wanted generators in the western part of the state to cut their electrical output and asked that generators to the east simultaneously increase production, assuring that enough power would continue to be available but taking some of the load off the remaining power lines. "We need to get something under control here.…We're setting for bigger problems if we don't get this under control quick," Spencer said.

4:10 pm: The entire northeastern power grid started to become unstable. Electric power flow suddenly reversed direction between Michigan and Ontario, and then power started to oscillate all over the grid, the flow increasing and decreasing rapidly, tripping safety circuit breakers. New England and the Canadian Maritime circuit switched off the main grid immediately, and this saved them, so they kept working independently. But the oscillations set off a cascading blackout throughout the rest of the grid, starting somewhere in the Midwest and shutting down electricity in Ohio and Michigan and then on to other states. Suddenly, power went out in eight states and the Canadian province of Ontario, creating North America's largest blackout.

Back on our terrace in New York City, we saw traffic lights on Eighth Avenue wink out. Big floodlights on skyscrapers went dark. Although we didn't know it, more than 100 power plants had just shut down—80 fossil-fuel plants and 22 nuclear. In New York City, 6.7 million customers lost electricity in a few minutes. In the Northeast, 50 million people lost electric power.

4:17 pm: The loss of air conditioning on a hot summer day would have been bad enough, but much more than that was gone. Take Detroit, for example, right in the center of the blackout, and where events were well recorded. The blackout hit Detroit at 4:17 p.m. One thing about electricity, it moves fast, and when it goes, it goes quickly.[8] The city's airport shut down because all its lights and electronics were powered by electricity from the grid. Northwest Airlines alone would soon have to cancel 216 flights in and out of Detroit Metropolitan.

Rush-hour commuters were stalled everywhere. Perhaps the worst spot to be driving was in or into the Detroit-Windsor Tunnel between Michigan and Ontario. About 27,000 commuters used it daily. Some were stuck in the dark. People waited seven hours in the line to go through.

Amtrak trains stopped running; the railroad was without electric signals, and, even more surprising, no one had any idea where any train was. Even the main train from Detroit to Chicago was lost temporarily. You might ask why people stuck on trains didn't use their cell phones to give their trains' locations. The answer is that all cell phones stopped working too—the towers that sent and received their signals were powered by the grid. Even Detroit's homeland security director couldn't use his cell phone. The city was suddenly much more vulnerable to terrorism.

Water became a problem. Half of the Detroit region's residents, 4 million people, were suddenly without water because water in Detroit is moved by electric pumps also running off the grid. An arsonist set fire to a two-story duplex, but without water pressure the city's firemen could do little. Worse, an explosion occurred because of the blackout at the Marathon Ashland Refinery *in* the city. At the moment, the firemen couldn't do anything about it.

Although hospitals have backup generators, in some cases they weren't enough. A backup generator at the North Oakland Medical Center broke down and sent smoke through a hospital in Pontiac, Michigan, and 100 patients had to be evacuated.[9] Fortunately, the hospital's emergency vehicles had fuel even though all the gas stations had stopped pumping.

You couldn't buy gasoline, because at that time gas stations had only electric pumps connected to the grid. (Early in the 20th century, gas stations used pumps worked by hand.)

Dusk, August 14: The view from our lofty perch showed an island of light—Penn South, our ten-building cooperative complex—in a sea of darkness that was the rest of the city. Even the colored lights atop the Empire State Building had gone dark. Our island of light existed because Penn South has its own electrical generating station that operates both on and off the grid and thus was running despite the blackout. It hadn't yet occurred to me that such an off-the-grid electrical generator might be part of a future solution to our nation's growing energy needs.

Friday, August 15: The power outage continued the next day. In Detroit, the more imaginative did a little creative thinking and made some money. Tim and Deb McGee opened a breakfast bar in their driveway with a row of tables and chairs.[10] Others did the usual price gouging. According to the *Detroit Free Press,* a skinny kid stood on a street corner in Dearborn, Michigan, waving a water bottle and shouting, "*Wattaa wattaa, wattaaaaaaa! Only two bucks!*" Reading about this, I thought of the New Hampshire house I'd once lived in that had an old-fashioned water pump in the kitchen. Even back in 1963 friends thought we must be a little crazy to depend on that antique, but folks in Detroit certainly could have used a few of them on August 15, 2003. At the least, it raised the question of whether there weren't alternatives to a single grid, perhaps a mix of energy sources that would give our cities and our nation better energy reliability and security.

Most amazing is how quickly so much that we take for granted about modern civilization and its technology was suddenly revealed to be fragile.

This event, our nation's largest blackout, was short-lived, but it demonstrated two truths we have been reluctant to face: how dependent we are on cheap, easily available energy and how vulnerable our one huge, complex, interconnected energy-supply system is.

By Friday afternoon, a lot of the power had been restored in Michigan. By 9:00 p.m., power was restored to New York City and adjacent Westchester County to the north. It hadn't been a long blackout, but it had covered a large area and, despite its brevity, had many effects.

Why did the lights go out?

Spencer and others who kept the giant grid running knew the breakdown was not an "accident" in the ordinary sense. It was the disastrous result of a series of events and a set of conditions that were well understood by those in charge.

There are basic problems with the grid as it exists today. First, it's getting old—few of the transmission lines are younger than 15 years.

Second, in recent years it wasn't being cared for; spending to maintain and repair the grid declined. From 1988 to 1997, investment in new transmission lines decreased almost 1% every year, and maintenance spending for existing lines decreased more than 3% per year, while at the same time power demand increased 2.4% a year. With growing interest in improving the grid, some recent developments are encouraging. In 2009, the U. S. Recovery and Reinvestment Act provided $343 million to build a new grid transmission line in the Pacific Northwest to increase the amount of electricity from wind power. But so far these are small advances compared to the overall need.[11]

Third, the grid hasn't kept up with technology. For example, state-of-the-art digital switches, which could respond better and faster in power emergencies, haven't been installed.

Fourth, the grid was built for use in emergencies only—say, when one utility's power plant went down and it needed to temporarily borrow power from another system. But today the grid is used in ways that were not foreseen and for which it was not designed.

Fifth, the grid's control centers cannot force member companies to comply. In the few minutes before the blackout started, employees at the Midwest grid control center were in a bind: Their company was responsible for preventing a collapse, but it couldn't force the member companies to act; it could only try to persuade them. "It would be kind of a voluntary thing," Janice D. Lantz, a spokeswoman for the Hagerstown, Maryland-based Allegheny Company, explained later. Individual companies resisted attempts at centralized control. They wanted local control over their own actions.[12] And they had it.

At the start of the blackout, some key people were not aware of the problem until it was too late. Representatives of the International Transmission Commission said they were unaware of the problem until two minutes before the power went out in Michigan. Detroit Edison made the same claim.

And because there is just one grid in any area, few had any alternative sources of electricity after the grid went down. Here and there families had purchased portable generators powered by small gasoline engines, but most people found these too complicated to use, and many were reluctant to store gasoline in their houses. Throughout most of the nation, there didn't seem to be any alternative. There was the big power system, and if it failed, you suffered. In summer, you turned to your stockpile of candles and bottled water, hoped not to lose everything in your freezer, and simply waited and sweltered. In winter you piled on more clothes, since most home heating systems required electricity to make them run, whether they were fueled by natural gas or oil, the two major fuels to heat America's buildings.

Can we prevent more, and bigger, blackouts?

Plenty of people will tell you that a nation that turns more and more to solar and wind energy is asking for more trouble of this kind. They argue that wind and solar are too variable, that there aren't any good ways to store the electricity they produce, and that massive electrical generation from them will only further destabilize the grid.

People still heating their homes with firewood ask why we don't go back to biological fuels. And there was just the beginning of interest in large-scale farming of crops like corn that would be turned into alcohol to run cars, trucks, and electrical generators. This, they would soon be arguing, was a better way to go because America already had large facilities to store liquid and gas fuels.

Watching the city go dark from our Manhattan apartment, we could see once again how much our modern way of life depends on energy—and not just a minimal amount of energy to help us get food, water, and shelter. We need an abundance of energy for all the aspects of life that people enjoy and depend on, from recreation to health care. I believe we can achieve this.

There are four parts to our energy crisis: (1) lack of adequate sources of energy; (2) the need to move away from dependence on fossil fuels; (3) lack of adequate means to distribute energy safety, reliably, and consistently; and (4) inefficient use of energy, with major environmental effects. We have to solve all four problems and solve them quickly. What do we do first? Can we do it all in time? What is the best energy source? Is there just one that is best, or does the solution lie with some combination of energy sources?

Improved ways of distributing energy are crucial. In the big blackout, gasoline couldn't be pumped at gas stations because few stations had installed small electric generators to run the pumps. The lack of these small generators at gas stations symbolized how our electrical generating system had become centralized. That old technology could have been a backup today, but wasn't. Or a gas station could keep a small gasoline-powered generator, the kind many homeowners have on hand for emergences. Few thought about off-the-grid local energy generation. Most who did were solar- and wind-energy enthusiasts.

A friend who built her house in the hills above Santa Barbara, California, was one of these enthusiasts. Unconnected to the grid, the house stored energy generated from the wind and the sun in a huge array of lead-acid batteries, the same kind that are in your car. But these were housed in large glass cylinders, so you could watch the acidic water bubble as electrical energy flowed into it from the wind turbine and solar cells. These, by the way, generated direct current (DC) electricity. Because most modern appliances run on alternating current (AC), to use anything with an electric motor, such as a vacuum cleaner, she had to have electronics that converted the DC to AC. But that process used a lot of the energy. So her house was wired with two systems, one AC and one DC. The lights ran on the DC.

Because so few houses had taken this off-the-grid route, providing electricity for a house like my friend's was pretty much a do-it-yourself hobby that took a lot of time. I admired it, but at the time it didn't seem likely that much of America could go that way. But during the blackout, a lot of people watching the food spoil in their refrigerators would have been grateful for such a system if they had known about it. Ironically, the great electrical public works projects of the 1930s, meant to bring electricity to the farm as well as the city, pretty much brought an end to local electrical power generation, or any local energy generation other than wood in fireplaces and woodstoves. That's why traveling across America's farmland you see so many of those quaint windmills that used to pump drinking water for cattle now sitting idle, with perhaps a blade or two missing.

At present, about 85% of the total energy used throughout the world, and also in the United States, comes from fossil fuels. Everyone is familiar with the controversies about fossil fuels: Coal, oil, and gas are highly polluting fuels that we use to our detriment as well as our benefit; oil and gas are going to run out, with first oil and then natural gas becoming economically unavailable in the not too distant future; and those concerned about global warming believe we must move away from these fuels. For the United States, which is no longer producing as much oil and gas as it uses, moving away from these fuels is necessary for energy independence, for national security, and for a stable and productive economy.

There are many proponents of each source of energy, each claiming that their favorite source is *the* solution. Petroleum and natural gas enthusiasts say that there is bound to be a lot more of those fuels out there somewhere under the ground and under the ocean. We've always found more in the past. Some say, "Trust us; we will find more."

Biofuels have their enthusiasts as well, ranging from small-farm cooperatives to giant agricorporations. They say, "Trust us; pretty soon the technology will be invented to make our biofuel crops energy-efficient, and we will grow our own energy solution." Solar, wind, and ocean enthusiasts meanwhile ask us to follow them.

Which then is a possible, practical, and reliable solution? In writing this book, I have had to dig out a lot of obscure facts, do a lot of calculations from those, including costs and land area required, and think about what mix of all the sources of energy will be the solution.

First, some terms you need to know

The definition of *energy* seems straightforward enough: Energy is the ability to move matter. So what's so complicated about it? For one thing, it's still a difficult concept. Yes, it's the ability to move matter, but even though we need it and use it all the time, we can't see it—it isn't a "thing" like a table or chair or automobile or computer or cell phone.

For another thing, talking about energy is confusing because of all the terms used to discuss and measure it. It comes in so many different units. At the supermarket, we buy potatoes in pounds or, outside the United States, in kilos; we don't have different measurements for baking potatoes, boiling potatoes, red potatoes, Yukon Golds, and sweet potatoes. Each kind of energy, however, has its own measure. The two teams most familiar to us are calories, when we're trying to lose weight, and watts, when we check what size light bulb we need to buy. But that's just the beginning. Oil is discussed in terms of barrels; natural gas in cubic feet or, worse, in terms of its energy content, expressed in British thermal units (BTUs), an old measure dating back to the beginnings of the Industrial Revolution. Electricity, as well as any energy source used to make electricity, comes in several measures: *watts,* or, more commonly, *kilowatts* (KW), which are thousands of watts; sometimes *megawatts* (MW), millions of watts, to describe the capacity of a generator; and kilowatt-hours or megawatt-hours, the actual energy yield or output. Some people discuss energy in terms of *joules,* a measure of energy originating in Newtonian physics.

And that's not all. People write about huge and unfamiliar numbers, like a quadrillion BTUs (a *quad*) and *exajoules* (don't ask). Even the simple calorie that we're all familiar with, the one listed on food packages, is actually an abbreviation of *kilocalorie.* The real (and little) calorie is the amount of heat energy that raises a gram of water from 15.5°C to 16.5°C. That's so small an amount that dietitians talk in terms of a thousand of these—enough to raise a liter of water (about as much as a medium-size bottle of gin) that same 1°C.

At least we come across calories (that is, *kilo*calories) and watts in our everyday modern life. But we rarely get to compare them. At the fitness center where we go to exercise, the Elliptical Trainer machine does it, showing us the watts and the calories that we generate per minute and that we therefore are using as we exercise. The other day I was using about 130 watts on the machine, enough to run one 100-watt light bulb with a little left over.[13]

A historical perspective

Our current energy crisis may seem unique, but it has happened to people and civilizations before.[14] All life requires energy, and all human societies require energy. Although we can't see and hold energy, it is the ultimate source of wealth, because with enough energy you can do just about anything you want, and without it you can't do anything at all.

Human societies and civilizations have confronted energy problems for thousands of years. Ancient Greek and Roman societies are a good case in point. The climate of ancient Greece, warmed and tempered by the Mediterranean Sea, was comparatively benign, especially in its energy demands on people. Summers were warm but not too hot, winters cool but not very cold. With the rise of the Greek civilization, people heated their homes in the mild winters with charcoal in heaters that were not especially efficient. The charcoal was made from wood, just as it is today. As Greek civilization rose to its heights, energy use increased greatly, both at a per-capita level and for the entire civilization. By the 5th century B.C., deforestation to provide the wood for charcoal was becoming a problem, and fuel shortages began to occur and become common. Early on in ancient Greece, the old and no longer productive trees in olive groves provided much of the firewood, but as standards of living increased and the population grew, demand outstripped this supply. By the 4th century B.C., the city of Athens had banned the use of olive wood for fuel. Previously obtained locally, firewood became an important and valuable import.

Not surprisingly, around that same time, the Greeks began to build houses that faced south and were designed to capture as much solar energy as possible in the winter but to avoid that much sunlight in the summer. Because the winter sun was lower in the sky, houses could be designed to absorb and store the energy from the sun when it was at a lower angle but less so from the sun at a higher angle. Trees and shrubs helped.

The same thing happened later in ancient Rome, but technology had advanced to the point that homes of the wealthy were centrally heated, and each burned about 275 pounds of wood every hour that the heating system ran. At first they used wood from local forests and groves, but soon the Romans, like the Greeks before them, were importing firewood.[15] And again like the Greeks before them, they eventually turned to the sun. By then, once again, the technology was better; they even had glass windows, which, as we all know, makes it warmer inside by stopping the wind and by trapping heat energy through the greenhouse effect. Access to solar energy became a right protected by law; it became illegal to build something that blocked someone else's sunlight.

Some argue today that we should become energy minimalists and energy misers, that it is sinful and an act against nature to use any more than the absolute minimum amount of energy necessary for bare survival. But looking back, it is relatively straightforward to make the case that civilizations rise when energy is abundant and fall when it becomes scarce. It is possible (although on thinner evidence) to argue that in the few times that democracy has flourished in human civilizations, it has done so only when energy was so abundant as to be easily available to most or all citizens.

As a result, in this book I argue for changes in where and how we get and use energy, but I do not argue that we should become energy minimalists or energy misers. On the contrary, I think we need to learn how to use as much energy as we can find in ways that do not destroy our environment, do not deplete our energy sources, and do not make it unlikely that our civilization will continue and flourish in the future.

The path to such a world is possible but not simple, not answered with a slogan, not solved by a cliché. If you value your standard of living and the way of life that our modern civilization provides, with its abundant and cheap energy, follow me through this book as we examine each energy source and the ways in which some can be combined into viable energy systems for the future.

A traveler's guide to this book

Each of the first nine chapters discusses a major source of energy: how much energy it provides today, how much it could provide in the future, how much it would cost, and its advantages and disadvantages.

We begin with conventional fuels—fossil fuels, water power, and nuclear fuels—energy sources that dominated the 20th century. We then go on to the new energy sources, those that may have played small roles in the past but are now viewed as having major energy potential. In addition, we devote a chapter to energy conservation. The last part of the book talks about larger and broader issues that involve, or could involve, some or all energy sources: how to transport energy; how to transport ourselves and our belongings; how to improve energy efficiency in our buildings.

And finally, in the last chapter, I attempt to put the whole thing together in formulating a first approximation of an achievable and lasting solution to our energy problem.

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Oil

FIGURE 1.1 A modern oil-drilling ocean platform. Platform Holly, a few miles off the coast from Santa Barbara California, was installed in 1966 and has produced oil since. *(Source: Linda Krop, Environmental Defense Center, Santa Barbara, CA)*

Key facts

- Worldwide, people use about 30 billion barrels of oil a year, which works out to 210 gallons per person. The worldwide total is expected to increase to 50 billion barrels a year—350 gallons per man, woman, and child—in the next few decades.
- In 2005, the United States used 28% of all the oil consumed in the world.
- In recent years, the United States consumed about 7.5 billion barrels of petroleum a year, dropping to 7.1 billion barrels 2008 (23% of the world's total consumption). More than 60% is imported; 17% of that is from the Persian Gulf.
- Two-thirds of all transportation energy in the United States comes from petroleum—2.2 billion gallons a day: 55% of this for ground transport of people, almost 36% for ground transport of freight, and just under 10% for air transport of both people and freight.[1]
- According to conventional estimates, at the current rate of use Americans will run out of oil in less than 50 years.

It's a stretch, but imagine you're an Eskimo living 1,500 years ago

It's around A.D. 500, and you're part of a small group of Eskimos struggling northeast in Siberia near the Bering Strait and crossing by boat into what is now Alaska. There you find other Eskimo groups whose lives are a struggle—living at the margin, barely enough food, hard to do anything but try to keep warm and figure out where the next meal will come from. This was the life of most Canadian Eskimos at that time, a struggle for existence.

But according to anthropologist John R. Bockstoce, an expert on Eskimo culture and Eskimo and Yankee whaling, you and your Eskimo relatives coming from Siberia, called the Birnirk culture, brought with you inventions for hunting. One of these was a harpoon made of bone and antlers that, like a modern whaling harpoon, would slide closed into the flesh of the whale and then lock in an open position when the whale tried to swim away. Your group also had kayaks, umiaks, and drag-float equipment and began using these devices to hunt whales. This led to a fundamental change in your lives. Whale meat and oil gave you so much more energy than your neighbors that your group did much more than simply hunt and think about the next meal. With the basic necessities of life—food and shelter—assured, people could use their surplus energy and time in more enjoyable ways: telling stories, painting pictures, singing—in other words, being "civilized" in the modern sense. Or if they were concerned that their food supply might dwindle, they could use that excess energy and time to acquire more territory, more food, more power—in other words, to wage war.[2] The ability of early Eskimos to obtain meat and oil from whales is analogous to our ability to get petroleum cheaply and easily from the ground. As long as it was available that way, we could while away our leisure time with video games, golf, travel, and whatever else we wished. But by now almost everyone understands that petroleum is a finite resource that will be used up pretty soon if we continue to rely on it as one of our major sources of energy. Moreover, it's equally clear that the use of petroleum, rather than declining, is going to increase, especially since the huge populations in China and India are rapidly increasing their ownership and use of automobiles.

Where does petroleum come from?

The fossil fuels—petroleum, natural gas, and coal—are just that, fossils. Coal was formed from the remains of trees and other woody plants, covered by soil and then buried deeper and deeper and subjected to heat and pressure, which converted their remains to mostly carbon, but with a fair amount of other elements that were part of the plants and the surrounding soil (for more on this, see Chapter 3, "Coal"). Petroleum and natural gas are believed to be the fossil remains of marine organisms.

All fossil fuels that we take out of the ground today were produced eons ago from the growth of photosynthetic organisms—algae, certain bacteria, and green land plants, organisms that can convert the energy in sunlight into energy stored in organic compounds, and do so by removing carbon dioxide from the atmosphere and releasing pure oxygen. The energy that fossil fuels contain is thus a form of solar energy, in most cases provided over many millions of years and stored since then.

Over time, much of the carbon from the carbon dioxide that algae, green plants, and some bacteria removed from the atmosphere was then sequestered—stored in the soils, rocks, and marine deposits, and prevented by various physical and chemical processes from returning to the atmosphere. When fossil fuels are burned, the sequestered carbon is released into the atmosphere as carbon dioxide (CO_2), which acts as one of the primary greenhouse gases.

Since petroleum and natural gas are not solids and thus are lighter than the rocks that surround them deep in the Earth (Figure 1.2), they tend to rise under pressure from the rocks and get trapped in geological pockets, like the one shown in Figure 1.3—although in some rarer situations the oil makes it to the surface, as it does in Southern California. Thus, the search for oil and gas is not random; petroleum geologists know which kinds of rock formations they are likely to occur in.

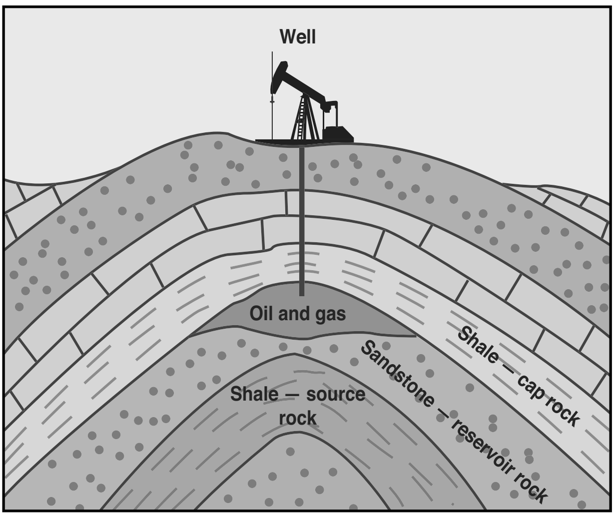

FIGURE 1.2 A typical location of oil and gas. Oil or gas rarely gets pushed right up to the surface, as it does at the La Brea pits in Los Angeles, famous for having trapped many ancient and extinct mammals whose fossils have become familiar. *(Source: D. B. Botkin, and E. A. Keller,* Environmental Science: Earth as a Living Planet. *New York, John Wiley, 2009)*

FIGURE 1.3 A natural oil seep along the California shore at Santa Barbara. Pressure from surrounding rocks has pushed petroleum up to the surface, where it flows into the Pacific Ocean, revealing itself by its bright reflection of sunlight. *(Courtesy of the University of California, Santa Barbara, UCSB Map & Image Laboratory, from the research collection of Prof. Jack E. Estes)*[3]

How much energy does petroleum provide?

In recent years, the United States consumed about 7.5 billion barrels of petroleum a year, dropping to 7.1 billion barrels 2008. More than 60% of petroleum is imported; 17% of this from the Persian Gulf.[4] Petroleum provides about 37% of the world's energy and 41% of the energy used in the United States,[5] most of which is used for transportation. The United States alone uses 8.4 billion barrels of oil a year. According to the U.S. Department of Energy, essentially all the energy used in transportation in the United States comes from fossil fuels,[6] and two-thirds of all transportation energy in the United States comes from petroleum: 2.2 billion gallons a day—55% (1.2 billion gallons a day) for ground transport of people, almost 36% (789 million gallons a day) for ground transport of freight, and just under 10% (210 million gallons a day) for air transport of both people and freight.[7] In contrast, petroleum provides only 1% of the electricity produced in the United States.[8] Most electricity in the United States is produced from coal, hydropower, and nuclear power. To keep things simple, think about petroleum as *the transportation fossil fuel.*

How much petroleum is there, and how long will it last?

These are straightforward questions, so one might expect them to have straightforward answers. Don't petroleum geologists and oil corporations know how much oil is in the ground, how much they can sell in a year, and therefore how long oil will last? Wouldn't this be a basic part of an oil company's business plan?

Unfortunately, it's not that simple. As economists and petroleum geologists will tell you, there is always more in the ground than you can get out, and the percentage you get out depends on how hard you want to work, or how much you are willing to pay, to get it. When oil was very, very cheap, around the first decades of the 20th century, it wasn't worth much to develop new technologies to get every last drop when the initial gusher and subsequent flow eased and the oil no longer flowed freely out of the ground. Today, we have many ways to push more of the underground oil to the surface or separate it from the rocks that hold it. So the answer to how much oil is in the ground is: It depends on what you are willing to pay.

As to the second question—how long will Earth's petroleum last?—economists will tell you that rather than being drained to the last drop, petroleum will eventually become so rare and so expensive to get out of the ground that it will no longer be useful as fuel. People may collect it, the way they collect other precious minerals, and display little jars of the black goo on their coffee tables as decorations and as evidence of their wealth. The real question therefore is not when every drop of oil will be gone but when it will no longer be economically worthwhile to extract it.

What will raise the price of oil and thereby make it worthwhile to try harder and harder to get it? One standard answer is that the price of oil will rise rapidly when peak production is reached—that is, when discovery of new oil declines. Another economic turning point is when the rate of supply drops significantly below the demand.

As petroleum reserves shrink, they get harder and harder to find

We're using more and more petroleum and finding less and less of it. Indeed, petroleum geologists suggest that we're going to run out of petroleum in the next few decades. History seems to be on the side of this viewpoint. In 1940, five times as much oil was discovered as consumed. Forty years later, in 1980, the amount of petroleum discovered just about equaled the amount consumed. And by the turn of the 21st century, world consumption of petroleum was three times the amount that was discovered.[9] Based on this history and our knowledge of the kinds of rocks where petroleum can be found, it seems likely that oil production in the United States will end in 50 years or at least by the end of this century, and world oil production soon after.

To understand how petroleum geologists think about these things and make calculations, you first need to understand the terms *resources* and *reserves*. A petroleum resource is the total amount of oil that is estimated to exist. A reserve is part of the resource, the part that, at the time it is evaluated, is judged to be eventually extractable both legally and economically. *Proven reserves* are those that have been determined to be legally and economically extractable right now. (The proven reserves idea leaves open the possibility that as prices for petroleum rise, it may become economically worthwhile to extract oil from reserves that are now considered too costly to use.)

Today, petroleum geologists estimate that the world's proven reserves are 1 trillion barrels (42 trillion gallons), and that total reserves—oil that eventually will be legally and economically accessible—are probably 2–3 trillion barrels. These estimates are based on a lot of geological knowledge as well as the location and size of existing oil wells. In fact, there is a wide range in the estimates of how many barrels of oil are now or soon will be considered proven reserves. For example, the U.S. Energy Information Administration reports values from 1–4 trillion barrels.[10]

In predicting when the oil supply will become a serious problem, petroleum geologists focus on the peak oil point—the time when one-half of Earth's oil has been exploited. This is usually projected to occur sometime between 2020 and 2050, although a variety of experts believe it has occurred already in the United States. The time of peak oil production is important because we can assume that when that point is reached, the price of oil will rise rapidly. The Energy Information Administration presents a range of estimates for the time of world peak oil production, from as early as 2020 to as far into the future as 2121.[11]

The implications are huge about how much time this gives the nations of the world to prepare for a planet without petroleum. Given the way most people and societies go about planning for events that they hope won't occur until far in the future, it seems likely that if peak oil production is expected to occur a century or more from now, little will be done to move away from fossil fuels in the next year or even the next decade, and when the time comes we'll all just muddle through. This will be unfortunate, because moving away from petroleum (and the other fossil fuels) is a good idea for reasons other than direct energy supply. For example, we could stop worrying about international conflicts over oil, avoid direct pollution from toxins given off by petroleum, and reduce the release of greenhouse gases. Those who place a high priority on a healthful, pleasant, and sustainable environment would therefore prefer to be told that peak oil is almost upon us, so that nations will be spurred to action.

For a more straightforward estimate of when the world will run out of petroleum, here are some numbers. Worldwide, people use about 30 billion barrels of oil a year (210 gallons a year per person). Conservatively—not taking into account the maximum potential increase in automobiles in China and India—worldwide consumption is expected to rise to about 50 billion barrels a year by 2020, which means that the whole world will use up today's proven petroleum reserves in about 20–40 years and use up the total estimated reserves in about 60 years. Since not all our many uses of petroleum may be readily adaptable to other fuels, this puts a lot of time pressure on all nations to get something going quickly to replace petroleum, especially for transportation.

However, there is another point of view, which is that conventional petroleum geologists greatly underestimate both the available amount of petroleum and how efficiently oil can be gotten out of wells. This viewpoint was well expressed in the *Wall Street Journal* op-ed piece titled "The World Has Plenty of Oil," by Nansen G. Saleri, president and CEO of Quantum Reservoir Impact, in Houston, and former head of reservoir management for Saudi Aramco.[12]

Mr. Saleri says that present oil mining technology gets only one-third of the oil out of a well; the rest clings to the rocks and is just held too tightly for current pumping methods to get it out. "Modern science and unfolding technologies will, in all likelihood, double recovery efficiencies," he writes. "Even a 10% gain in extraction efficiency on a global scale will unlock 1.2–1.6 trillion barrels of extra resources—an additional 50-year supply at current consumption rates."[13]

Mr. Saleri argues that rising prices for petroleum will fuel technological development that will increase extraction efficiency. Two major oil fields in Saudi Arabia are already yielding two-thirds, rather than one-third, of the oil out of the wells. Mr. Saleri writes that the total resources are 12–16 trillion barrels, not the 1 to 3 trillion barrels of conventional estimates, and that 6–8 trillion of these total resources are in conventional wells, the rest in "unconventional" sources, shale oil and tar sands, from which it is difficult and environmentally costly to get oil. Present attempts to recover oil from these unconventional sources are disrupting and polluting land (more about that later). Even with his optimistic assumptions, he estimates that peak oil production will be reached between 2045 and 2067—in 38–59 years.

Geography is against us

Unfortunately for most of us, petroleum reserves are not distributed evenly around the world. Quite the opposite; they are highly concentrated (Figure 1.4) and, worse yet, concentrated in parts of the world that, on the whole, are not the ones that use the most petroleum today but will likely require more in the future (Figure 1.5). The Middle East has 62% of the world's oil reserves (Figure 1.6); the rest of Africa 9.7%; South and Central America 8.6% (most of it in Venezuela and Brazil); the Russian Federation 6.6%. North America has just 5%, half of it in the United States.[14] So, as Figure 1.4 makes clear, oil reserves are extraordinarily concentrated geographically.

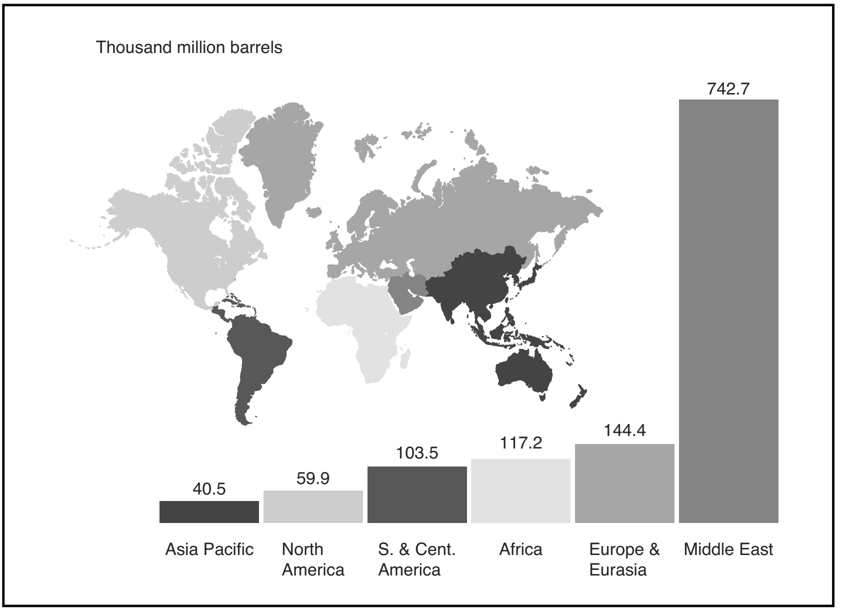

FIGURE 1.4 The world's known oil reserves (2006).[15] *(Source: BP Statistical Review of World Energy, June 2007; London, British Petroleum Company)*

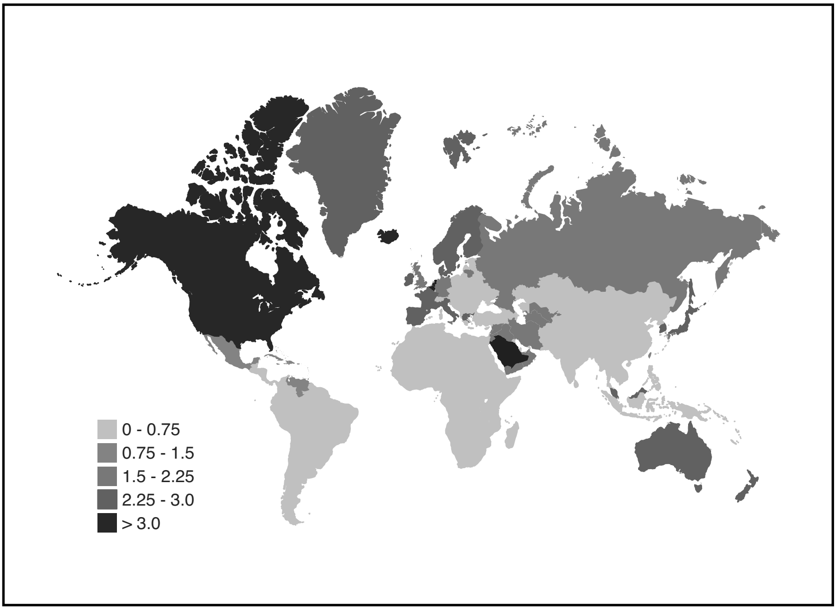

FIGURE 1.5 Oil consumption per capita (metric tonnes, 2006). Compare the consumption with known reserves. *(Source: BP Statistical Review of World Energy June 2007; London, British Petroleum Company)*

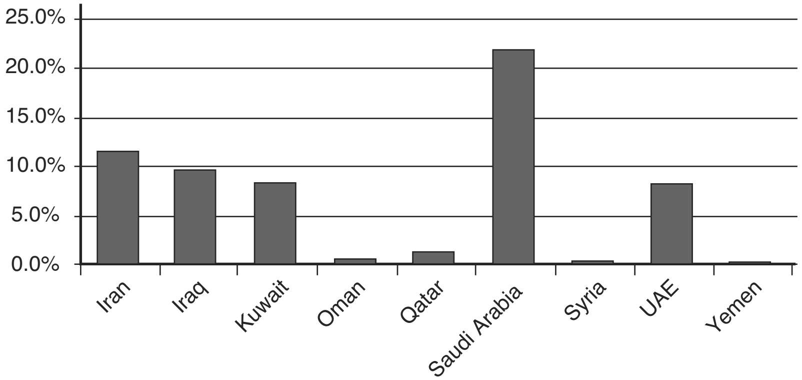

FIGURE 1.6 Middle Eastern nations have 62% of the world's available oil. Most of this is in five nations: Saudi Arabia (with more than 20%), Iran, Iraq, Kuwait, and the United Arab Emirates.[16]

It would be naive to think that the lopsided geographic distribution of petroleum will not continue to create international conflicts. As long as the United States and other countries without vast oil reserves continue to depend so heavily on petroleum, these conflicts are likely to increase, which is all the more reason to turn to other sources of energy as soon as possible.

Although the Middle East dominates world oil reserves, most of that oil goes to Europe, Japan, and Southeast Asia, whereas the United States imports a lot of oil from Canada, Mexico, and Venezuela (Figure 1.7). Obviously, the more oil the United States imports, the more vulnerable its economy is to the reserves in other nations and to political and environmental events that limit or prevent this importation. Given the importance of abundant energy for a vibrant economy and society, greater energy independence is an important goal, but for petroleum this is not and will not be possible for the United States.

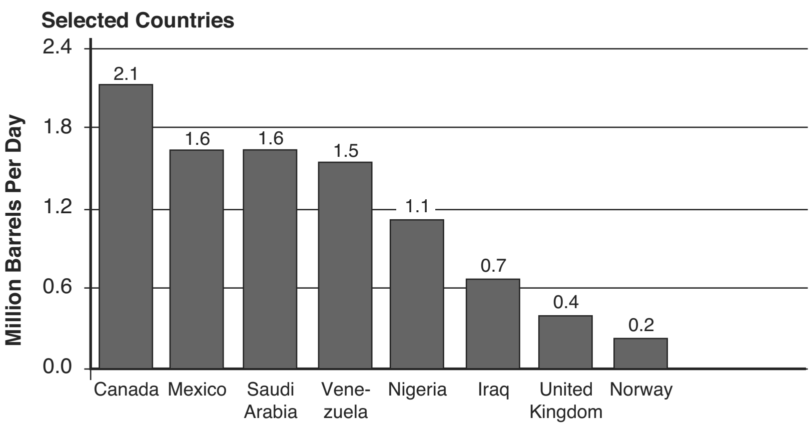

FIGURE 1.7 Where the United States gets its oil. *(Source: Energy Information Administration, 2008)*[17]

Where might new oil reserves be found?

Recent discoveries of oil have been primarily in the Middle East, Venezuela, and Kazakhstan.[18] Ironically, global warming may change this, since less ice in the Arctic may mean more opportunities for oil exploration where it was difficult before. Also, while at present drilling for oil in Arctic waters is mostly limited to a depth of 300 feet and in some cases 2,000 feet, new ships will make it possible to drill for oil in water 12,000 feet deep.[19] One estimate suggests that 400 billion barrels of oil may be found in the Arctic oceans.[20]

Although this is a lot of petroleum, at current rates of use it would add only eight years to the time we have before the world runs out of oil.[21] And there's a potential downside: More global warming provides more sources of oil—for example in the Arctic, which produces more greenhouse gases, which lead to more global warming.[22] Then, too, there is already plenty of concern about oil spills and their effects on ocean ecosystems, sea and shore birds, and fisheries, and the ability to drill much deeper in a much larger area increases the risk of drilling-caused spills.

Two unconventional sources of oil: oil shales and tar sands

As explained earlier, petroleum under pressure from underground rocks fills pockets in the rocks. But in addition, some muds trap petroleum as they form into shales, resulting in a dense rock filled with oil. The oil is tightly bound within the rock and can be released only if the shale is heated to 900°F. At this temperature, a ton of shale may yield as much as 14 gallons, and three tons of shale would be needed for each barrel of oil. Heating three tons of rock to 900° takes a lot of energy and leaves behind a lot of crushed rock. Much of this rock is obtained from surface mines, and even more energy is needed afterward to restore the damaged land—restore it as much as possible, that is. Not only are oil shales a highly polluting energy source, destructive to the land, but also their net energy yield is low compared to conventional sources of oil.

Tar sands (sometimes also called oil sands) are geologically similar to oil shales, but the petroleum impregnates sand or clay rather than mud. Again, the petroleum is so completely mixed with the inorganic material that one can't pump the oil out. The sand has to be mined, primarily by strip mining, and then washed with hot water. As with oil shales, a mess remains—in this case dirty water as well as tons of sandy rock. Tar sands are said to yield as much as one barrel for about every two tons processed.

Those who believe there is a lot more oil out there than 1–3 trillion barrels are basing their estimates partly on what could be gotten from oil shale and tar sands. An estimated 3 trillion barrels of oil exist in oil shales and about the same in tar sands. Together, these massive but difficult-to-use sources could triple the amount of oil available, if all of it could be recovered.

Much of the world's known tar sands and oil shales are in North America. The United States has two-thirds of the known world oil shale, and it is estimated to contain 2 trillion barrels of oil. Some 90% of U.S. oil shale is in the Green River formation underlying parts of Colorado, Utah, and Wyoming and extends over 17,000 square miles, an area larger than Maryland.[23] Canada has an estimated 3 trillion barrels of oil in tar sands, most of it in a single huge area near Alberta now called the Athabasca Oil Sands. Since so much energy is required to get the oil out of these rocks, the net yield would not be nearly as great as from conventional oil wells. Still, the government of Alberta states that tar sands yield six times the amount of energy required to process them.[24]

Oil shales and tar sands are already causing major environmental controversies, since so much oil exists in them, and since mining and refining it are so polluting. Mining the 2 trillion barrels of petroleum from U.S. oil shales would leave behind 9 trillion tons of waste rock—an amount equal to the weight of 24 *million* Empire State Buildings. To put this into perspective, in 2007, all the freight transported in the United States weighed 21 billion tons. So it would take all the freight transportation available in the United States about 424 years to move that much waste rock.[25]

Three tar sands mines are operating today: Suncor (opened in 1967), Syncrude (since 1978), and Muskeg River of Shell Canada (opened in 2003). They are producing 1 million barrels a day[26] and have affected 120 square miles.[27] Mining Athabasca Oil Sands takes 2.2 to 5 barrels of water for every barrel of oil.[28] Water used for this processing comes from the Athabasca River, which starts in the beautiful Canadian Rockies as the outflow from the Athabasca Glacier. The government of Alberta states that only 3% of the average annual outflow of the glacier is required to process the sands,[29] but environmental groups estimate that it will require a quarter of Alberta's freshwater.[30] This water would end up in holding ponds, contaminated by toxic chemicals from the mining and processing: mercury, arsenic, and a variety of organic compounds that are carcinogenic.[31]

Effluents from present tar sand operations are being blamed for human and wildlife ailments,[32] and the holding ponds present an even greater hazard. According to Professor David Schindler of the University of Alberta, a leading aquatic ecologist, "If any of those tailings ponds were ever to breach and discharge into the river, the world would forever forget about the *Exxon Valdez*."[33]

Currently, oil production from Athabasca Oil Sands costs between $15 and $26 a barrel, compared with about $1 per barrel from Saudi Arabia's wells. But when oil prices exceeded $130 a barrel in 2008, mining those tar sands began to sound like economic sense—except for the pollution (at the time of this writing, oil is $72 a barrel).

Oil shales are not yet in commercial development, but Shell Oil Corporation has invested many millions of dollars in attempts to develop this petroleum source.[34] The near future will bring a major battle over North American tar sands and oil shales since they offer huge profits at great environmental costs.

Growing worldwide competition for a dwindling resource

International competition for petroleum is growing, in large part because rapidly rising standards of living in India and China are leading to a greater number of automobiles. India now has 5.4 million vehicles, up 500% in just 20 years.[35] China has 34 million registered motor vehicles.[36] In 2006, sales of personal autos rose 30% in China, to 5.8 million,[37] and China's total vehicle sales reached 7.22 million. To put this into perspective, this is close to half the number of cars sold in the United States in 2007 (about 16 million).[38] In 2003, China became the world's fourth-largest automobile-producing nation, behind only the U.S., Japan, and Germany.[39] This increased competition alone is enough to push petroleum prices up. And they're going to go even higher. The cost of generating electricity with oil (and with natural gas) in the United States has been rising sharply. Domestic electricity cost 20% more in 2006 (the most recent date for which data are available) than in 1995.[40]

If supplies are dwindling, why watch petroleum go up in smoke?

On May 15, 2007, the *Wall Street Journal* reported that Aramco, a highly profitable state-run Saudi oil giant, had signed a huge deal with Dow Chemical. Why would the world's largest producer of fuel oil be interested in making a deal with a chemical company? Since petroleum is an excellent base for many artificial chemicals, a large number of very popular and very profitable products—including most plastics—that most of us would be unwilling to do without are made with them. According to the *Wall Street Journal,* the Aramco-Dow agreement is supposed to lead in 2013 to a joint venture that will build plants to produce 7 million tons a year of these chemicals.[41] And by the end of May 2008, Dow Chemical announced that it would have to raise the price of its petrochemicals 20% because of the rising price of crude oil.[42] Why waste whatever petroleum we have left by burning it all up fast as fuel? Why not use alternative energy sources and save petroleum for other important purposes that use much less of it?

Environmental effects of petroleum

Petroleum causes pollution at every stage, from mining and recovery to refining, transporting, and using it as fuel. Drilling wells can cause direct pollution via oil spills. Drilling also often involves injecting watery liquids into the wells; later released as drilling muds, these cause their own toxic pollution.

The notorious *Exxon Valdez* oil spill taught us that transporting oil by tanker ships can lead to disaster. Transporting oil by pipeline or truck can also lead to spills, because pipes break and trucks sometimes have accidents.

Crude oil—oil as it comes out of the ground—is many chemicals mixed together, and these must be separated into gasoline, kerosene, diesel fuel, heating oil, and heavier materials. This is what a refinery does: Like a giant chemistry set, it heats crude oil and separates its chemicals according to their density. The strong odors that make passersby wrinkle their noses are petroleum chemicals that the refinery has released into the environment—chemical pollutants. Travelers nearing the end of the New Jersey Turnpike on their way to the tunnels into New York City know exactly what I'm talking about.

These are just an indication of the potential for refineries to leak chemicals into the air, soil, and groundwater; to suffer accidental fires and breakages that produce more pollution; and to create sites that are heavily toxic for future generations.

Effects of the Exxon Valdez Alaskan oil spill are still with us

On March 24,1989, the tanker *Exxon Valdez* spilled 10.8 million gallons of crude oil into Prince Edward Sound, Alaska. Although it was not the largest spill ever, the oil slick extended over 3,000 square miles and inflicted heavy damage. The wildlife affected have been estimated to include 250,000 to 500,000 seabirds, at least 1,000 sea otters, about 12 river otters, 300 harbor seals, 250 bald eagles, and 22 killer whales.[43] Nearly 19 years later, the spill still affects Alaska's fisheries, and lawsuits over its effects include the Alaskan Eskimos' $2.5 billion suit for damages.[44] Costs of this kind are not usually counted in tallying the total costs of petroleum.

Petroleum exploration versus conservation of endangered species

The Arctic National Wildlife Refuge is a classic example of the conflict between the search for more petroleum and the conservation of wildlife and endangered species. The refuge is in beautiful country. It was established in 1960 and expanded in 1980 to cover 19 million acres, larger than the combined area of Massachusetts, New Hampshire, and Vermont (Figure 1.8, top). It is the primary breeding ground for 123,000 caribou of the Porcupine herd (named for the Porcupine River [Figure 1.8, bottom]) and is also a major wintering ground for this population.

The refuge also contains an estimated 10 billion barrels of oil. How much of this could be recovered is uncertain—conservative estimates are about 3 billion barrels. The possibility of drilling for oil in the refuge was remote until the 21st century; the George W. Bush administration pushed for it, arguing that it would help make the United States more energy-independent. But the United States has been using about 7.5 billion barrels of oil a year, so at best all the oil in the Arctic National

Wildlife Refuge would buy the U.S. less than a year's worth of oil. At the time of this writing, neither the Obama administration nor Congress has made any decisions about drilling there.

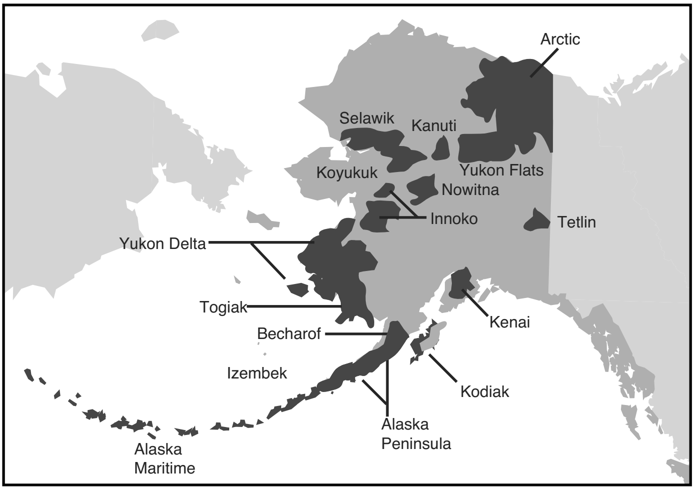

FIGURE 1.8 Map of Alaskan National Wildlife Refuges (top). Each dark area is a refuge. The Arctic National Wildlife Refuge, the one discussed in this book, is listed as "Arctic" at the top right. Caribou within the refuge (bottom). *(Courtesy of the U.S. Fish & Wildlife Service: http://arctic.fws.gov/caribou.htm. See also http://arctic.fws.gov/pdf/ispch.pdf)*

Here are some of the other ways that petroleum pollutes. Burning petroleum pollutes the air, creating health problems and damaging plants and wildlife. Among the primary petroleum-generated air pollutants are ozone, nitrogen oxides, and particulates. Also, pipelines and storage tanks leak. In 2001 a rifle bullet punctured the Trans-Alaska Pipeline, resulting in a small but nonetheless damaging spill. Among the good news is that although the 2002 Alaska earthquake ruptured the earth under the pipeline, the line stayed intact.

The bottom line

- Known petroleum sources will run out in less than 50 years (according to conventional analysis) or perhaps in 100 years or so (unconventional analysis).
- Whatever the exact time when petroleum runs out, we have a choice: We can devote a large portion of our time, resources, and energy to seeking new oil and improving extraction efficiency, or we can seek sustainable and cleaner energy sources.
- Petroleum is one of the three most polluting energy sources (the other two are nuclear power and coal). The potential for pollution will increase as conventional oil sources run out and the world turns to the unconventional sources: tar sands, oil shales, and deep ocean drilling.
- In an ideal world, the search for new energy sources would move away from petroleum, but so much money can be made from obtaining and selling crude oil that oil development will likely continue in the short term despite increasing pollution and increasing knowledge of its health and environmental effects.

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