# A Post-Fukushima World:

## America’s NEW Energy Landscape

by

F. Gautschi

edited by Benna Michaels

five hat books

Five Hat Books LLC
499 Broadway # 115
Bangor, ME, 04401

Printed/Manufactured in the United States of America

Cataloging data:

Energy Supply
Energy Crisis
United States Energy Policy
Natural Gas
Oil and Gas
Coal
Geothermal Energy
Wind Power
Nuclear Energy
Hydroelectric Power
Hydrogen
Transportation Studies
Electric Car

Five Hat Books is a small publisher that specializes in bridging the gap between new authors, the public, and the broader publishing industry. For queries regarding the acquisition of this title for broader publication, please contact info@fivehatbooks.com.

ISBN: 978-0-9847-332-0-0

# TABLE OF CONTENTS

## Part One: Understanding Our Energy Sources

## Part Two: Building Solutions

# AUTHOR'S NOTE

Although all calculations in this book are based on reputable information, some involve estimates or forecasts. As a result, it is certainly possible to argue that the "true" value of some parameter may be a few percentage points different than the figure calculated here.

To judge the contents of this book in terms of such minor divergences would be a mistake. It does not materially affect our country's overall energy future that, for example, the "true" demand for jet fuel in 2025 may turn out to be 2.0 QADs, rather than the 1.81 QADs forecasted in 2009 by the US Energy Information Administration. What does affect our energy future and energy supply security is the overall trends—the big picture.

It is these trends, not fractions of percentages, that we must focus on and address.

# PREFACE: HOW DO WE MEASURE ENERGY?

To understand the problems that surround our country's projected energy supply/consumption situation, we need to understand how energy is measured. The standard unit of energy is called a *British thermal unit (Btu)*. A Btu is the energy required to increase the temperature of one pound of water by 1° Fahrenheit.

To measure the large amounts of energy consumed at a national level, we use a different unit, called a *QAD*. One QAD equals $10^{15}$ (1,000,000,000,000,000) Btu.

To put the QAD into perspective, imagine raising the temperature of all the water in Lake Michigan from 40° to 41° Fahrenheit. The amount of energy required to do this would be about 11 QADs—almost the amount of energy supplied by our annual domestic crude production in 2007.

# KEY ASSUMPTIONS IN THIS BOOK

No economic analysis or recommendation for future action could ever be made without relying on certain basic assumptions. Below is a brief summary of the key assumptions that underlie the scenarios and proposed solutions in this book. Other, more minor assumptions are referred to in the text as they occur.

## Fuel Costs

The only way to make fuel cost comparisons is to make assumptions about fuel prices. Appendix A lists the fuel costs used as the basis for cost comparisons in this book, and their sources. Fuel costs representative of the year 2007 have been used, rather than fuel costs representative of 2009/10, which are artificially low as a result of the strong worldwide economic downturn and the resulting drop in fuel consumption.

Where future fuel costs have been assumed, they are noted in the text.

## Electrical Power Generation Costs

As with fuel costs, cost comparisons among the different technologies for producing electrical energy can only be made by making assumptions about power generation costs. Appendix B lists the author's best estimates of electrical power generation costs for 2007/2008 for the different types of new power plants referred to in this book. The estimates are based on 2007 construction costs. Where applicable, the costs of equipping plants with $CO_2$ separation technology and/or sequestering $CO_2$ have been included in the estimates.

## Energy Choices: The Role of Internal Rate of Return (IRR)

To understand what causes a market to invest—or not invest—in energy-efficient technologies, it is necessary to understand a concept called the *internal rate of return* (IRR).

The goal of investment is to make money. If a company can make more money by investing its capital in certain business activities or in stocks, bonds, CDs (Certificates of Deposit), etc. than by investing in energy-efficient technology, then there is no economic incentive for the company to invest in energy efficiency. In fact, there is an incentive *not* to invest in energy efficiency, because the company can make a higher rate of return (or yield, as it is often called) by investing its money elsewhere.

Appendix C shows an example of how the rate of return on an investment in improved automobile fuel efficiency will vary depending on the price of gasoline. A similar kind of calculation can be made for every type of energy-saving technology.

## The New Energy Infrastructure and Its IRR

This book proposes one of several possible alternatives for a new US energy supply infrastructure. This alternative will, by the year 2025, greatly reduce this country's exposure to the risks of a projected tight worldwide fuel production/demand situation. For this alternative to be attractive to investors in a market economy, the IRR for moving to the new infrastructure must also be attractive.

In Chapter 11, the IRR for the investments required to build Phase One of the new energy infrastructure is estimated, and found to be competitive. The estimate of the IRR does not include the projected value of shielding our economy from future supply disruptions and surges in energy costs. Including an estimate of these protective benefits of the new energy infrastructure could easily improve the IRR by several points.

# INTRODUCTION

In the summer of 1987, I learned a lesson that I'll not soon forget. At the time, I was working in Brazil as a senior executive for a European company that manufactured electrical power generation and transmission equipment. Without warning, I was invited to Buenos Aires to meet with the Argentinean Minister of Energy. Since relations between Brazil and Argentina were somewhat cool at that time, the sudden request seemed rather surprising.

The reason for the invitation became obvious the minute I entered the airport terminal in Buenos Aires. It was the middle of summer, but the heat in the terminal was unbearable—far higher than the air temperature outside. As I soon found out, the city was receiving electricity for only two hours a day, and air conditioning was just one of many power-consuming amenities that were unavailable. The electricity shortage had been caused by low water levels in several hydroelectric power plant reservoirs, coupled with the unscheduled maintenance shutdowns of a nuclear power station and some fossil-fired power plants.

Without electricity for refrigeration and air conditioning, Buenos Aires, a city of 12 million residents, was an inferno. I had been invited by the Minister of Energy to discuss whether my company could supply and erect large gas turbine generators, at any necessary cost, to alleviate the electrical power shortage. Unfortunately, because of our existing contractual commitments and production scheduling, we could not meet the Minister's needs.

My stay in Buenos Aires was a nightmare, but not only for me. On top of the heavy human suffering, which included the breakdown of law and order, it has been reliably estimated that this one-month power crunch caused a loss of over one billion US dollars (1986 dollars) from the country's GDP. The power interruption was a costly lesson for the Argentinean Minister of Energy, who found out *that the most expensive energy is the energy that, when badly needed, is not available.*

###

Now, more than 24 years after the power crisis in Buenos Aires, many Americans have become deeply concerned with our own country's current energy situation. A few years ago in a interview with Thomas Friedman of the *New York Times*,(1) James Carville, the architect of Bill Clinton's 1992 election to the White House, stated that in the 2006 election year, the key issue was "energy independence, stupid". Carville based his opinion on a poll taken about three months prior to the election by Democracy Corps, his non-profit public opinion research group. Americans polled about their most important national security priorities had responded this way:

| | |
|---|---|
| Reducing our dependency on foreign oil | 42% |
| Fighting terrorism | 26% |
| The war in Iraq | 25% |

The results showed a significant shift from a similar poll taken in 2002, when the public ranked energy supply security as only its third priority. Clearly, increasing numbers of Americans were becoming aware of the economic risk inherent in our growing dependence on imported fuels. Although public concern regarding reliable energy supply may have diminished recently as a result of the energy price drops that followed the economic recession of 2007-2009, the risk to our economy has in no way changed.

The good news is that there is public approval for government policies promoting higher energy efficiency—policies such as higher mileage standards for cars, more stringent insulation codes for buildings and energy conservation features for appliances. Under pre-recession market conditions, and under the market conditions projected for the post-recession period, such policies make economic sense. At pre-recession fuel prices, the hardware and software investments required to achieve higher fuel economies did generate financial returns that were equal to, or higher than, yields from bonds and other savings instruments—a situation that had not occurred since the oil price shock of the 1970s. Based on projections for post-recession fuel prices, investments in energy efficiency will once again generate financial returns higher than the returns obtained by investing in savings instruments. From an economic, as well as an environmental, point of view, the timing is right for re-examining our approaches to energy consumption.

There are three urgent reasons for undertaking this re-examination. The first is our projected future energy supply/consumption situation. In 2007, America imported 32% of the energy it consumed. Although estimates by the Energy Information Administration (EIA) of the Department of Energy(2) predict that by 2025, the percentage of imports will drop to 21% of the annual energy consumed, this goal is only achievable if domestic crude oil and natural gas production can be increased by a total of 46% and 20% respectively over the next 18 years. This is a very ambitious goal.

In 1956, a theory (examined in detail in Chapter 4) was published that predicted that America's domestic crude oil production would peak in the early 1970s. This peak did occur, as later confirmed by domestic crude oil production statistics. Over the last forty years, the growing gap between the decline in domestic crude oil production and increasing domestic demand has been filled by ever-increasing levels of crude oil imports. If domestic production of crude oil is to rise by 46% between now and 2025, it will require a very sharp reversal of our domestic production trends.

In a world with abundant energy supplies, the current and projected levels of US imports would be of minor concern; the system would be capable of self-stabilizing to correct for even major supply disruptions. However, as ever-growing worldwide crude oil consumption comes dangerously close to installed world crude production capacity, the picture changes. A tight crude production/demand situation leads to price volatility in the form of "volatility clusters", a succession of sharp and rapid changes in price in response to supply/demand variations. Even a small unexpected drop in production capacity can have unpredictable consequences on price. As a result, unforeseeable failures in production capacity (whether due to human action or natural disaster) have the potential to wreak havoc on our economy. Given the current and projected political conditions in some of the countries we import oil from, we have reason for concern.

In cases where the production level of a commodity is outstripped by demand, there are two viable strategies for reducing the resulting price volatility: demand side management (influencing demand levels) and supply side management (the management of supply levels and development of alternatives). These two concepts, and the role they can play in our energy future, are discussed in Chapter 2.

The second reason for re-examining our energy situation involves the increasing concern over the environmental impact of burning fossil fuels. In a document recently issued by the United Nations, scientists have reported with a 90% level of confidence that there is a strong correlation between global warming and the carbon dioxide ($CO_2$) generated by burning fossil fuels. Because the US produces about 20% of the carbon dioxide generated worldwide, the confirmed correlation between increased levels of $CO_2$ in the troposphere and increased global mean temperature (GMT), with its resulting global climate changes, must necessarily have major consequences for our energy situation. This book explores the ways that our new-found perspectives on global warming may affect our energy future.

Both the above-mentioned phenomena—price volatility and the environmental effects of burning fossil fuels—have already reached the public eye, with price issues arguably the more prominent of the two. On March 11, 2011, a third factor was added to the mix. An accident at the Fukushima Daiichi nuclear power plant in Japan brought sharp scrutiny upon the nuclear power industry and the affordable electrical energy that it produces.

Higher costs for transportation fuel, heating oil and natural gas are consuming an ever-increasing portion of the disposable income of America's middle class. Now, in the wake of the Fukushima nuclear disaster, the price of electricity may rise as well. Although the economic downturn of 2007-2009 saw a significant drop in fuel consumption, driving fuel prices down, the relief to the consumer will only be temporary. Once world economic growth reaches the pre-recession level, the large reductions in investment for new fossil fuel production capacity(3) that were made during this economic downturn will begin to have their inevitable effect, and fuel prices will quickly rise above their pre-recession levels. As price pressures build, and concerns about the safety of nuclear power threaten to cut off that source of relatively cheap electricity, the public will become increasingly vocal in its demands for alternatives.

Although the media continues to respond to public pressure by publicizing the more "conventional" renewable energy solutions, such as windmills and solar panels, more eye-catching concepts have also been showcased. For example, a recent newscast featured a restaurant owner who had his diesel-burning automobile modified to burn used cooking oil. Another "solution" presented a car equipped with solar panels. Many other concepts have been presented. Those who are not experts in the energy field can find it difficult to judge which, if any, of these new ideas can help consumers to stop the erosion of their disposable incomes that is being caused by our country's growing energy supply problem. It is also difficult for non-experts to judge the safety of new, state-of-the art nuclear power plant designs, or the long-term sustainability of nuclear energy.

Although some of the proposed solutions imply otherwise, there is no one-size-fits-all solution to meeting our future energy needs. To illustrate how a one-solution approach to a commodity supply problem can go seriously wrong, consider the famous "leap forward" taken by China in 1958. Faced with a shortage of iron, China launched a program to build tens of thousands of small iron smelters all over the country. For the most part, these smelters produced iron of such low quality that it had to be scrapped. The Chinese model resulted in a colossal failure; firstly, because there were no economies of scale, and secondly, because an acceptable, uniform quality of iron production across all those smelters was unachievable. It's a lesson that we'll do well to remember when planning our energy solutions.

As far as solutions go, our time to implement them is limited. Excluding war and serious political turmoil within our major fossil fuel suppliers, there are two factors that determine how quickly we must reach a solution. The first factor is the length of time it will take to reach maximum crude oil production worldwide (discussed in Chapter 4). If, by that time, America has not developed an alternative domestic fuel infrastructure to relieve its ever-growing demand for oil, the growing imbalance between world production and demand will create enormous oil price pressures, making crude oil unaffordable to whole regions and creating dire energy shortages. (Although the analogous peak in world natural gas production has a similar potential to create severe shortages, experts(4) predict that the peak in crude oil production will occur first, making it the critical factor.)

The second factor that determines how long we have to solve our energy supply problems is the recently confirmed correlation between increased greenhouse gas (mainly $CO_2$) concentrations and increased global mean temperature. With this correlation now confirmed, pressures will mount for legislative action aimed at strongly increasing combustion efficiency and/or sequestering (containing) $CO_2$ generated by the use of fossil fuels, and/or the implementation of a "carbon tax" on $CO_2$ emissions. This tax actually represents the estimated cost to prevent future damage to the environment caused by increased GMT (or, as the concept is called, internalization of an external cost). The costs for sequestration of $CO_2$ emissions and other mechanisms of cost internalization will drive the prices of fossil fuels significantly higher.

Either of the two key events cited above—reaching maximum crude oil production worldwide, or complete internalization of the costs of $CO_2$ emissions in order to significantly reduce the use of fossil fuels and their impact on the environment—is capable of seriously impacting our economy. The time left before either event occurs is the time we have left to put an alternative domestic fuel infrastructure into place. Based on today's knowledge, it appears that this window of opportunity will be short, probably less than a quarter of a century.

To continue our current way of life, we need a new energy infrastructure capable of guaranteeing a reliable, environmentally sustainable and cost-competitive energy supply. Moreover, the foundations of this new infrastructure must be built using the best technologies that are commercially viable *now*. The development period for promising, but currently non-viable, technologies could easily take up half of our available time window. We simply cannot wait. Once a new infrastructure based on currently viable technologies is in place, we can, of course, improve it as new technologies are brought to fruition, but the basic infrastructure must be built now, using the technologies that are currently viable.

The good news is that there is much we can do with technologies that are already proven and available. However, if we're to successfully meet our energy needs, we'll need to find a way to address the NIMBY (Not In MY Backyard) syndrome that afflicts so many attempts at industrial development. As a recent example of NIMBYism, consider the efforts by a group of property owners at Cape Cod, Massachusetts, to stop the construction of a sea-based windmill farm because of the alleged degradation of the scenic view, even though the project met all applicable environmental laws.

It is a fact that harnessing any form of energy for the benefit of our society will impact the environment in some way. Effective environmental protection must strike a workable balance between protecting the environment and the realities of the energy harnessing process. The purpose of this book is to help Americans understand our country's energy situation so they can participate in the development of realistic solutions.

The book is divided into two parts. Part One explores the energy sources we have available to work with. Each energy source is discussed in terms of its past and present contributions, its "costs" (both financial and environmental), and its possible and probable role in meeting our future energy needs. To truly understand our options, we must first understand our energy sources. Part One includes a detailed analysis of nuclear energy, including a review of the Fukushima Daiichi nuclear power plant accident and the lessons learned. Once the individual components in our energy mix have been described, Part Two of the book explains how we can use the available technologies to create realistic energy supply solutions which are environmentally sustainable and which will reduce America's dangerous exposure to the risks inherent in today's ever-tightening worldwide energy production/demand situation.

This book presents technologies and concepts that, in the author's view, meet the criterion of being commercially viable now. Some experts may disagree with the author's approach, arguing for the inclusion of feasible, but as-yet commercially unproven concepts that require more time to mature. These experts may argue that the US could pay a high price for deciding to implement its new energy supply infrastructure on a timeline that does not allowing the promising, but as-yet unproven concepts, the opportunity to prove out over time. Unquestionably, this is a valid concern—but time is tight. Only in the future, when performance and cost data are available for these as-yet commercially unproven concepts, will we know what the most perfect solution should have been.

A related question arises: who will be the judges chosen to separate the commercially viable concepts from the "feasible, but commercially unproven" ones? Who will pick the winners and losers?

No new technology can be commercialized without the emergence of design and operating standards. Historically, these standards have been developed within a forum consisting of pertinent government authorities, potential suppliers and customers. The commercial viability of a new concept depends strongly on the work done within this forum. For example, the commercial viability of the US nuclear power plant fleet, which currently supplies 21% of our electrical energy needs, arose through just such a collaborative process. Therefore, it is crucial that as we work toward a new energy infrastructure, the industry/government/consumer collaborative process be streamlined to minimize turnaround times for concept approval and issuing of licenses.

In some ways, developing a balanced energy strategy is like playing a game of chess. Each energy source can be compared to a different chess piece, each with its own specific abilities and limitations. The difference, of course, is that in chess, the rules of the game are arbitrarily imposed, whereas the "rules" for each of our available energy sources are inherent in the source itself—where it's found, how easy it is to harness, the costs associated with developing it, and the environmental consequences of using it. For example, wind power is a non-$CO_2$-emitting energy source that can reliably generate electricity only in areas where there is a sufficiently steady wind source and enough space to build the wind-collection units. These facts define the role that wind power can reasonably be expected to play in our energy solutions.

To ensure our future, we must act now. By reading this book, Americans can obtain the clear, basic information that they need to play an active role in our country's development of realistic, sustainable energy supply solutions.

Whether or not the reader agrees with the roles proposed for the various energy sources in this book, one thing is certain: every energy supply alternative that is currently commercially feasible is presented and discussed, giving the reader a complete overview of the choices.

## NOTES

1. *The Energy Mandate*, Thomas L. Friedman, New York Times, reprinted in the International Herald Tribune, October 14, 2007
2. *Annual Energy Outlook 2009*, EIA (Energy Information Administration)
3. *Gas Under Pressure*, Barron's Magazine, January 20, 2009
4. *Comments on Future Natural Gas Supply*, Kjell Aleklett, Workshop on Oil & Gas Depletion, Berlin, May 24, 2004

# PART ONE: UNDERSTANDING OUR ENERGY SOURCES[1]

---

[1] Strictly speaking, hydrogen, electricity and gasoline are energy carriers, not energy sources. However, for ease of expression, this book will refer collectively to all energy carriers, fuels, and energy-generating agents such as wind power, as “energy sources”.

## Chapter 1
# AN OVERVIEW OF OUR ENERGY SITUATION

Hundreds of excellent books and articles have been written about the energy supply situation in the United States. The goal of this chapter is to provide a short, concise summary of our most recent energy situation. Although the full picture is rather complex and summarizing it is a challenge, this chapter attempts to include all the essential elements. Data from the year 2007 has been used, rather than more recent data, because the deep recession of 2007-2009 has caused a significant but temporary drop in worldwide energy consumption and a corresponding temporary distortion in energy pricing. Data from 2007 therefore provides a more realistic starting point for describing our current energy situation as it exists within a longer-term context.

Table 1.1(1) shows an overview of America's available energy sources in 2007, as reported by the US Energy Information Administration (EIA). It's immediately apparent that in 2007, 85% of our available energy came from fossil fuels. Crude oil and petroleum products accounted for about 40% of the total, natural gas for about 23% and coal for about 22%. Of the remaining 15%, 8% came from nuclear power, while about 6.5% came from renewable energy sources such as hydro-power plants, geothermal, wind, biomass and ethanol. (Although ethanol is a biomass product, it currently holds a special place in the public spotlight, so it is listed and discussed separately in this book.)

> See the Preface for definitions of *Btu* and *QAD*, the units of measurement used for energy.

**TABLE 1.1 US ANNUAL ENERGY SUPPLY FOR 2007, INCLUDING EXPORTS**

| | QADS OF ENERGY(1) PER YEAR | PERCENTAGE OF TOTAL |
|---|---|---|
| Natural Gas Plant Liquids | 2.41 | 2.3% |
| Crude Oil (domestic) | 10.73 | 10.1% |
| Crude Oil (imports) | 21.9 | 20.6% |
| Liquid Fuel Imports (2) | 6.97 | 6.6 % |
| Subtotal | 42.01 | 39.6% |
| | | |
| Dry Natural Gas (domestic) | 19.84 | 18.7% |
| Dry Natural Gas (imports) | 4.72 | 4.4% |
| Subtotal | 24.56 | 23.1% |
| | | |
| Coal | 23.5 | 22.1% |
| Nuclear Power | 8.41 | 7.9% |
| Hydro Power Plus Other Renewable Energy | 3.43 | 3.2% |
| Biomass | 3.23 | 3.0% |
| Other imports(3) | 0.99 | 0.9% |
| **TOTAL** | 106.13 | 100.00% |

1. one QAD equals one quadrillion BTU (1,000,000,000,000,000 BTU)
2. includes petroleum products etc
3. includes coal coke and electricity

Source: US Energy Information Administration, Annual Energy Outlook 2009

Table 1.2(2) lists our current annual consumption of energy sources, along with estimates made by the EIA to project how the US will meet its energy needs in 2025. These estimates are based on many assumptions, including a projected average economic growth rate of 2.5% over the next 20 years. (The 2.5% rate was chosen by EIA as the most probable rate, based on all other assumptions used.) How closely our future conforms to these estimates will depend on a variety of factors, including fuel production costs, governmental rules and regulations, reserve estimates, environmental policies, investment strategies, technology developments and so on. The availability and cost-competitiveness of the various fuels in 2025 will depend largely on how competent—and how lucky—we are in discovering and developing new

**TABLE 1.2 COMPARISON OF CURRENT AND PROJECTED US ANNUAL ENERGY SUPPLY FOR 2025**

| | **YEAR 2007** (QADs of Energy[1]) | **YEAR 2025** (QADs of Energy[1]) |
|---|---|---|
| Natural Gas Plant Liquids | 2.41 | 2.56 |
| Crude Oil (domestic) | 10.73 | 15.64 |
| Crude Oil (imports) | 21.9 | 14.76 |
| Liquid Fuel Imports [2] | 6.97 | 5.67 |
| Subtotal | 42.01 | 38.63 |
| | | |
| Dry Natural Gas (domestic) | 19.84 | 23.81 |
| Dry Natural Gas (imports) | 4.72 | 3.13 |
| Subtotal | 24.56 | 26.94 |
| | | |
| Coal | 23.5 | 25.05 |
| Nuclear Power | 8.41 | 9.05 |
| Hydro Power plus other Renewable Energy | 3.43 | 4.91 |
| Biomass | 3.23 | 7.86 |
| Other imports[3] | 0.99 | 1.14 |
| **TOTAL** | **106.13** | **113.58** |

1. one QAD equals one quadrillion BTU (1,000,000,000,000,000 BTU)
2. includes petroleum products
3. includes coal coke and electricity

Source: US Energy Information Administration, Annual Energy Outlook 2009

production technologies and processes, and how accurately we can locate new recoverable reserves and predict future production costs.

Given that many unpredictable factors are involved, how can we build a consensus as to the best approach for meeting our energy needs in 2025 and beyond? Defenders of the “efficient market” concept argue that the market will decide, and will provide us with the best solution.

Although the market is, in many cases, pointed in the right direction, it generally focuses on a rather short time frame. Most company bonus schemes for top executives focus on measuring results over a time frame of 12-24 months. The market reacts as if it worked under a similar scheme, focusing on shareholder gratification over a 12-month period. However, as we shall soon see, most of the technology alternatives that have a high long-term potential for providing reliable, environmentally sustainable and cost-competitive energy also take a long time to develop and implement. As a result, the market might not fully appreciate, or correspondingly reward, actions taken now which will protect our economy in 10-15 years, but which tie up resources now while generating returns much later.

As we develop solutions, it's also vital to remember that even though cost-competitiveness (including the costs of environmental compatibility) is very important, the key factor in designing an effective energy supply concept is *supply reliability*. Compare the success of the Philippines and Indonesia in attracting foreign investment in the early 1990s. Although the Philippines had an ample supply of trained manpower and investor-friendly laws, US companies preferred to invest in Indonesia, because the Indonesian electricity supply was reliable, while the Manila area was suffering from daily blackouts.

To ensure supply reliability, it's crucial to anticipate and plan for potential "common mode failures"—failures which lead not only to a breakdown of the main energy supply systems but to the breakdown of the corresponding backup systems as well. Recall the case of Buenos Aires discussed in the Introduction. The Buenos Aires power supply concept was correctly based on a diverse portfolio of energy sources, which should have prevented a complete breakdown of the electrical energy supply. However, a human error in the planning of maintenance work, together with low reservoir water levels and some other factors, led to a failure mode in which the entire electrical energy supply system collapsed. A more recent example of a common mode failure was the disruption in the US gasoline supply that occurred after hurricane Katrina destroyed gasoline refineries that had been built near a hurricane-prone area, but were not constructed to withstand Category 3 wind forces. Last, but not least, the oil embargo imposed by the Arab members of OPEC in 1973 is another example of a common mode failure in our crude oil supply system. Whenever alternative fuel production concepts are being developed, potential common mode failure mechanisms must be identified and planned for.

## HOW ARE WE USING OUR ENERGY?

Table 1.3(3) shows the 2007 energy consumption of each major US economic sector, broken down by the type of energy used. As the table shows, all sectors depend strongly on fossil fuels.

Table 1.4(4) compares the 2007 energy consumption per sector with the projected consumption figures for 2025. As the table shows, our relative reliance on fossil fuels will drop by about six percentage points by 2025; however, in absolute terms, we will consume the same amount of fossil fuels—totaling 86 QADs of energy—that we consumed in 2007. For reasons we'll explore further on, this situation is deeply disturbing.

## WHERE IS OUR ENERGY COMING FROM?

### Crude Oil and Natural Gas

America currently produces about 27% of its crude oil consumption. Our domestic crude production peaked in the early 1970s, and as a consequence, crude oil imports have

**TABLE 1.3 US ENERGY USE BY ECONOMIC SECTOR IN 2007**

| | **TOTAL ENERGY CONSUMPTION** (QADs of Energy(1)) | **RENEWABLE ENERGY** (QADs of Energy(1)) | **NUCLEAR ENERGY** (QADs of Energy(1)) | **FOSSIL FUELS IN** (% of the Total) |
|---|---|---|---|---|
| Residential | 21.48 | 1.61 | 3.04 | 16.7 |
| Industrial | 32.6 | 3.34 | 2.93 | 26 |
| Commercial | 18.5 | 1.29 | 2.19 | 14.8 |
| Transportation | 28.62 | 0.61 | 0 | 27.7 |
| **TOTAL** | 101(2) | 6.85 | 8.16 | 85.2 |

1. all numbers except last column shown in QADs (1 QAD = 1,000,000,000,000,000 Btu)
2. differs from Total in Table 1.1 because Total does not include annual exports

Source: US Energy Information Administration, Annual Energy Outlook 2009

**TABLE 1.4 US ENERGY USE BY ECONOMIC SECTOR – CURRENT AND PROJECTED USE FOR 2025**

| | | **TOTAL ENERGY USE** (QADs of Energy[(1)]) | **RENEWABLE ENERGY** (QADs of Energy[(1)]) | **NUCLEAR ENERGY** (QADs of Energy[(1)]) | **FOSSIL FUELS** in (%) of Total |
|---|---|---|---|---|---|
| Residential | 2007 | 21.48 | 1.61 | 3.04 | 16.7 |
| | 2025 | 23.21 | 2.58 | 3.02 | 16.1 |
| Industrial | 2007 | 32.6 | 3.34 | 2.93 | 26 |
| | 2025 | 32.92 | 4.78 | 2.05 | 24 |
| Commercial | 2007 | 18.5 | 1.29 | 2.19 | 14.8 |
| | 2025 | 22.47 | 2.96 | 4.14 | 14.1 |
| Transportation | 2007 | 28.62 | 0.61 | 0 | 27.7 |
| | 2025 | 30.21 | 2.95 | 0 | 25 |
| **TOTAL** | 2007 | 101[(2)] | 6.85 | 8.16 | 85.2 |
| | 2025 | 108.8[(2)] | 13.27 | 9.21 | 79.3 |

1. all numbers except last column shown in QADs (1 QAD = 1,000,000,000,000,000 Btu)
2. differs from the Total in Table 1.2 because Total does not include annual exports

Source: US Energy Information Administration, Annual Energy Outlook 2009

increased steadily since then. Figure 1.1[(5)] lists the countries that America imported crude oil from in 2007. Looking at the list of countries that we're relying on to meet our energy needs, and remembering the previous discussion of common mode failures, it is difficult not to feel a high level of concern.

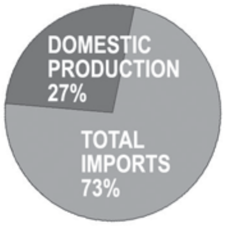
As previously discussed, reliability of supply is a vital factor in keeping energy prices stable. However, the level of reliability of our current oil supply is a matter for concern. As the 2007 production figures show, worldwide crude oil production is only slightly below the total installed production capacity. If additional production capacity is needed at a relatively short notice, the only significant reserve capacity available, totaling about 2 million barrels per day, belongs to Saudi Arabia. Should some of the less-than-politically-stable countries listed in Figure 1.1 (for

**FIGURE 1.1 OIL DEMAND AND SUPPLY 2007**

**TOTAL CRUDE OIL IMPORTS BY COUNTRY**
**(thousands of barrels per day)**

| | |
|---|---|
| CANADA | 2,527 |
| MEXICO | 1,317 |
| VENEZUELA | 1,214 |
| SAUDI ARABIA | 1,563 |
| ANGOLA | 468 |
| IRAQ | 658 |
| NIGERIA | 1,110 |
| RUSSIA | 421 |
| BRAZIL | 200 |
| ALGERIA | 514 |
| VIRGIN ISLANDS | 366 |
| UNITED KINGDOM | 185 |
| KUWAIT | 252 |
| ECUADOR | 224 |
| COLOMBIA | 218 |

Source: US EIA, Crude Oil and Total Petroleum Imports, Top 15 Countries



**US CRUDE OIL DEMAND AND SUPPLY 2007**

| | |
|---|---|
| Total Consumption | 20.7 Mbd |
| Imports | 15.1 Mbd |
| Domestic Production | 5.6 Mbd |

Source: US Energy Information Administration, Annual Energy Outlook 2009

example, Venezuela and Nigeria) suddenly lack the ability or the will to continue supplying the United States with oil, the world does not have enough spare production capacity to immediately make up the deficit.

Because there is so little additional production capacity, a major disruption in the crude oil supply infrastructure anywhere in the world, whether through natural disaster, terrorism or political action, will cause extreme price volatility. As shown in Table 1.5(6), the US is the world's largest consumer of oil. The current supply situation, with its constant prospect of shortage and rising oil prices, represents a serious potential threat to our national security.

Although our strategic reserve of crude oil (currently at a level of about 700 million barrels, which corresponds to about 50 days of "normal" oil imports) could be used to alleviate some of the price volatility created by a shortage, the main purpose of the reserve is to protect our economy in the event of extraordinary circumstances such as wars or natural disasters. There is no doubt that today's oil supply situation has created a high degree of vulnerability, not only for the US economy, but for the world economy as a whole.

**TABLE 1.5 TOP WORLD OIL CONSUMERS 2007 (THOUSANDS OF BARRELS PER DAY)**

| RANK | COUNTRY | CONSUMPTION |
|---|---|---|
| 1 | United States | 20,680 |
| 2 | China | 7,565 |
| 3 | Japan | 5,007 |
| 4 | Russia | 2,820 |
| 5 | India | 2,800 |
| 6 | Germany | 2,456 |
| 7 | Brazil | 2,400 |
| 8 | Canada | 2,365 |
| 9 | South Korea | 2,214 |
| 10 | Saudi Arabia | 2,210 |
| 11 | Mexico | 2,119 |
| 12 | France | 1,850 |
| 13 | United Kingdom | 1,740 |
| 14 | Iran | 1,708 |
| 15 | Italy | 1,702 |

Source: US Energy Information Administration (EIA), Country Energy Profile

The US does have major crude oil reserves which were, until recently, off limits for development. According to EIA(7), America has about 18 billion barrels of recoverable crude oil under the Outer Continental Shelf off the coasts of Florida, New Jersey, California, Alaska and the Gulf of Mexico. (The figure of 18 billion barrels of recoverable crude oil, equivalent to our projected crude oil imports for approximately the next 4 years, is considered by some to be too low an estimate.)

About 30 years ago, these deposits were designated "off limits" to exploration for environmental reasons. Although Congress lifted this ban on drilling in September 2008, the process for obtaining drilling permits is very time consuming.

America's situation with regard to natural gas is more favorable. The country currently supplies 81% of its own natural gas, with the remaining 19% coming from our NAFTA neighbors, primarily Canada.

However, the future for natural gas is not worry-free. Domestic gas production from existing fields is declining, and new fields coming on line cannot produce enough gas to offset this decline. The situation is not helped by the fact that until recently, significant amounts of domestic gas reserves were placed off-limits for environmental reasons. About 42% of the reserves are located in the Rocky Mountains, with 18% in the Gulf of Mexico and the remaining 40% located on the East and West Coasts. EIA(8) estimates that these reserves total about 80 QADs, equivalent to 4 years of domestic gas production at 2007 production levels. Some regard this estimate as far too low. As is the case with "off-limits" crude oil reserves, Congress lifted the ban on drilling in September 2008, but the process to obtain drilling permits is very time consuming. The role that unconventional gas such as shale gas will play in our future gas supply is discussed in Chapter 5.

## Coal

Coal is America's largest domestic fossil energy source. The US currently produces the equivalent of 23.5 QADs of coal annually, and reserves are large enough that even if production levels were increased by 100%, we could sustain the increased output easily for more than the next 50 years.(9)

As is the case with oil and gas, coal's future as an energy source will be affected by the growing public concern regarding $CO_2$ emissions from burning fossil fuels. These emissions, also called *greenhouse gases* and *anthropogenic gases* (literally, "gases generated by humans"), are considered to be a contributing factor in the current increase in global mean temperature (GMT), more commonly known as "global warming". Chapter 3 explores the strong scientific evidence of a correlation between the increased concentration of anthropogenic gases in the atmosphere and increases in GMT. Without doubt, this correlation and its consequences will have a major impact on our energy supply strategy.

## RENEWABLE ENERGY SOURCES

The important renewable energy sources are hydro (water), geothermal, wind, solar, biomass and ethanol. Table 1.6(10) shows 2007 figures for renewable energies used in the areas of electrical power generation, heat generation and transportation, and the projected levels for 2025.

**TABLE 1.6 RENEWABLE ENERGY CONSUMPTION IN 2007 AND PROJECTED CONSUMPTION FOR 2025**

| | 2007 (QADs of Energy[1] ) | 2025 ( QADs of Energy [1]) |
|---|---|---|
| **Electrical Energy** | | |
| Hydropower | 2.46 | 2.96 |
| Geothermal | 0.31 | 0.44 |
| Biogenic Municipal Waste | 0.17 | 0.24 |
| Biomass | 0.26 | 1.41 |
| Solar Thermal | 0.01 | 0.02 |
| Solar Photovoltaic | 0 | 0.01 |
| Wind | 0.32 | 1.12 |
| Subtotal | 3.53 | 6.2 |
| | | |
| **Heat Generation** | | |
| Municipal Waste | 0.16 | 0.12 |
| Biomass | 2.01 | 2.24 |
| Biofuels | 0.43 | 1.63 |
| Subtotal | 2.6 | 3.99 |
| | | |
| **Transportation** | | |
| Ethanol in E85 | 0 | 1.24 |
| Ethanol in Gasoline Blending | 0.65 | 1.04 |
| Bio Diesel | 0.06 | 0.23 |
| Liquids from Biomass | 0 | 0.53 |
| Subtotal | 0.71 | 3.04 |
| | | |
| **TOTAL** | **6.84** | **13.23** |

1. one QAD equals one quadrillion BTU ( 1,000,000,000,000,000 BTU )

Source: US Energy Information Administration, Annual Energy Outlook 2009

## Hydro Power

Of the 6.84 QADs of renewable energy currently being tapped, hydro power accounts for 2.46 QADs, or 35% of the total. By 2025, the amount of hydro energy being tapped is projected to reach only 2.96 QADs,(11) with most of the increase achieved by modernizing existing hydro power stations via advanced water turbine and electrical generator technology.

Why are no new hydro power plants planned? The answer is simple: most of the projects that are economically feasible (i.e. have an attractive internal rate of return) have already been built. Many of the remaining opportunities are economically and environmentally unattractive, with the most common obstacles including complex approval procedures and new regulations, particularly regulations pertaining to minimum river water flow requirements, which would often make it necessary to drain water over the dam, instead of storing the water to harness its energy at an optimal moment in the future.

Predictions for hydro output in 2025 (Table 1.6) assume that there will be no significant changes in weather patterns over the next 20 years. Falling water levels could adversely affect output.

## Geothermal Energy

Geothermal energy production is projected to grow from 0.3 to 0.44 QADs by 2025(12). As discussed in Chapter 7, this growth will be geographically limited to certain parts of the country.

### CONVERTING MEASURES OF ENERGY

It can be useful to think about energy expenditures in more than one way. Below are some example conversions between common forms of measurement.

**BTUs to Watts:** a Watt (W) is a unit that measures the *rate* of energy conversion. BTUs per unit time can be converted to Watts. For example, an average wind mill produces mechanical energy at a rate of about 1422 BTU per second. This is equal to 1,500,000 Watts, or 1500 Kilowatts (KW).

Note: one million Kilowatts (KW) = one Gigawatt (GW).

**MBD to QADs:** Mbd stands for "million barrels per day". Assuming an average energy content of 6 million BTU per barrel of crude oil, one Mbd equals about 0.00588 QADs per day.

## Wind Power

The amount of wind energy harnessed annually in the US is expected to reach 1.12 QADs in 2025.(13) In terms of installed electrical generation capacity, this corresponds to 39.31 GW, far less than today's installed wind power capacity in Europe. According to the European Wind Association, European capacity at the end of 2008 totaled around 65 Gigawatts (GW), capable of harnessing about 1.28 QADs of wind energy. (As a point of reference, the total installed electrical generating capacity in 2007 in the US was 968 Gigawatts.(14))

Chapter 7 explores the role that wind power could be given in our future energy infrastructure, in particular as a replacement for part of our imported natural gas. Chapter 7 will also explain why wind power appears less attractive in the US than in Europe.

## Solar Power

There are essentially two concepts for harnessing the sun's energy and transforming it into electrical energy: the photovoltaic process and the solar-thermal process. The photovoltaic process transforms sunlight directly into electricity. By 2025,(15) this process is expected to be used in the US to transform 0.01 QADs of sunlight into about 720 million KWhrs of electrical energy per year. This equals about 0.08% of the electrical energy generated each year in US commercial nuclear power plants.

The second concept for capturing the sun's energy is the solar-thermal concept. In this process, thousands of trough-shaped mirrors track the sun over the course of the day, focusing the sunlight to heat a fluid contained in black pipes. The fluid, in turn, heats water in a steam generator, which produces steam. The steam then drives a turbine generator to generate electricity. It is expected by the year 2025,(16) the solar-thermal process will be used to generate 1920 million KWhrs of electricity annually, equal to 0.2% of the electrical energy generated in US commercial nuclear power plants in 2007.

Chapter 7 discusses both the photovoltaic and solar-thermal energy processes in detail, and discusses some hurdles that must be overcome before solar power can play its proper role in our future energy portfolio.

### Biomass Energy, Ethanol and Biodiesel

Broadly speaking, biomass-based energy generation uses non-fossilized plant matter as an energy source. The energy is liberated either by burning or by microbial attack, using one of many available technologies. Unlike fossil fuels, biomass fuels are considered renewable resources.

Ethanol is an energy source produced in the US using corn as a feedstock. As already noted, although ethanol is a biomass product, it is discussed separately in this book to highlight its contribution as an automotive fuel in the transportation sector. Annual production of ethanol is projected to grow from 0.55 QADs in 2007 to 1.75 QADs in 2025.(17) Chapter 8 includes a detailed review of ethanol's potential and limitations.

Biodiesel is a non-petroleum-based, renewable form of diesel fuel derived from natural oils such as soybean oil and other vegetable oils. Biodiesel is blended with distillate fuel oil. US annual production of biodiesel is expected to grow from 0.03 QADs in 2007 to 0.23 QADs in 2025.

Other liquid hydrocarbons are produced from biomass via the Biomass-to-Liquid process (BTL). It is expected that by 2025 this process will yield 0.47 QADs of energy annually.(18)

## HOW DEPENDENT ARE WE ON IMPORTED ENERGY?

As summarized in Table 1.3, in 2007 America consumed 101 QADs of energy, of which 33% was imported. For 2025, EIA predicts that the proportion of US energy that is imported will drop to 22%, equivalent to a reduction of 10 QADs. More than two thirds of this drop will come from a reduction in annual oil imports, made possible by a projected reduction in overall US oil consumption of 2.23 QADs and a projected domestic crude oil production increase of 4.9 QADs. As mentioned earlier, this projected production increase is an extremely ambitious goal.

In 2007, US crude oil imports added up to 22 QADs, totaling 67% of our crude oil consumption for the year. By 2025, these imports are projected to drop to 48%, still a considerable percentage. Given that about 75%(19) of our total crude oil usage is required to keep our transportation sector—and in turn our economy—running, the importance of a reliable and cost-competitive energy supply becomes apparent.

As already mentioned, worldwide crude production capacity as of 2007 was only about 2% to 3% above worldwide demand. Even with our projected decreases in crude oil imports, a political crisis in Venezuela or Nigeria would send crude oil prices skyrocketing and cause significant damage to our economy. Not only that, we will need to address the potential effects of $CO_2$ emissions associated with the use of crude oil and other fossil fuels.

## WHAT CAN WE DO?

To reduce our excessive dependence on imported crude oil and reduce $CO_2$ emissions, there are two major initiatives we need to pursue:

1. *Wiser use of our energy.* Two ways that we can use our energy more wisely are:

   a. significantly increase conservation efforts, and

   b. improve the efficiency of the processes we use to transform the chemical energy from crude oil derivatives into mechanical energy.

   Wiser use of energy is one element of Demand Side Management, a concept discussed in the next chapter.

2. *Substitution* of crude oil with domestic alternative fuels.

It will be an enormous challenge to substitute a significant portion of our imported crude oil with cost-competitive, reliable domestic energy. To reach such a goal, we will likely have to draw on several kinds of substitute energy, including renewable sources (Chapters 7 and 8).

The first step in developing a portfolio of domestically-sourced energy alternatives is to identify and quantify the potential contributions and limitations of each energy source, then look for ways to reduce the limitations associated with that energy source. The future reliability of our energy infrastructure, and the cost of our energy supplies, will depend on just how well we are able to do this. In Chapters 4-10, we will explore each of our energy sources in turn—how they have been used in the past, what they can do for us, what their limitations are and what we can and cannot expect from them.

## KEY IDEAS IN THIS CHAPTER

1. In 2007, 85% of America's energy came from fossil fuels.
2. Most energy alternatives that have a high potential for providing reliable, environmentally sustainable and cost-competitive fuel production over the long term also have long lead times for implementation. Therefore, to have a new energy infrastructure in place before crude oil prices reach permanently prohibitive levels as a result of supply constraints and/or costs for handling greenhouse gas emissions, it is important to recognize the hurdles and the long lead times inherent in developing a new energy infrastructure.
3. Although cost-competitiveness is important, supply reliability is the key factor in designing an effective energy supply plan.
4. America's domestic crude oil production has peaked, and tapping into newly available reserves will not provide the increase in domestic crude production that the US would need to cover its projected future energy requirements. Except for shale gas, whose future production levels are not accurately known, US domestic natural gas production is also declining.
5. There is very little spare crude oil production capacity in the world today. Although the 2007-2009 recession temporarily increased the gap between world maximum

supply and world demand, economic recovery will cause this gap to shrink again, such that a major disruption in crude oil production anywhere in the world will cause extreme price swings.

6. America has large coal reserves, but concerns over emissions, in particular the growing concern over carbon dioxide ($CO_2$) emissions, will affect how we use this resource.
7. In the US, most of the economically feasible hydroelectric plants have already been built, so we cannot expect to harness significant new amounts of hydroelectric energy.
8. Renewable energy sources (geothermal, wind, solar, biomass, ethanol and biodiesel) can and will play a role in substituting for some of our imported crude oil and natural gas.
9. To reduce our excessive dependence on imported crude oil, we must:
    a. increase our conservation efforts, and
    b. improve the efficiency of the processes we use to liberate energy from crude oil and its derivatives, and
    c. replace crude oil and natural gas with alternative fuels that can be produced in America
10. Each energy source has its own potential contributions and limitations. We need to understand these before we can design reliable, sustainable and cost competitive energy supply solutions that work.

## NOTES

1. *Annual Energy Outlook 2009*, EIA (Energy Information Administration)
2. Ibid
3. Ibid
4. Ibid
5. *Overview of US Oil Production and Imports*, Knight-Ridder Tribune
6. *Countries with Largest Oil Consumption in 2005*, Exxon Mobil
7. *Impact of Increased Access to Oil and Natural Gas Resources in the Lower 48 Federal Outer Continental Shelf*, Phyllis Martin, EIA
8. Ibid
9. *US Coal Reserves*, Update 1997, EIA
10. *Annual Energy Outlook 2009*, EIA
11. Ibid
12. Ibid
13. Ibid
14. Ibid
15. Ibid
16. Ibid
17. Ibid
18. Ibid
19. Texas Chapter 26, Exhibit 26-1, EIA

## Chapter 2

# THE BASICS OF ENERGY MANAGEMENT

To meet its energy needs, the US uses many different forms of energy, delivered by a variety of suppliers. To date, unless unusual circumstances are in effect, the various forms of energy have generally been available when needed. For example, when a light switch is turned on, electric power is generally available. When a motorist pulls into a gas station, there is fuel available for purchase. In other words, when the system is functioning smoothly, supply is adequate to meet demand.

How does this happen? By what underlying mechanism are a vast number of individual energy needs translated into the presence of "enough" energy, available at the points where it is needed? More importantly, how might this mechanism break down, and what are the ramifications for our future energy-supply planning? This chapter explores some of these questions.

## BALANCING ENERGY SUPPLIES AND NEEDS

From a macroeconomic point of view, a country's energy sector can be represented by the following equation:

$$\begin{array}{c} \text{Annual local energy} \\ \text{production} \\ + \\ \text{imports of the different} \\ \text{kinds of energy sources} \end{array} = \begin{array}{c} \text{Annual local energy} \\ \text{consumption} \\ + \\ \text{exports of the different} \\ \text{kinds of energy sources} \end{array}$$

Both sides of the equation are subject to variations, and these variations can be either within or outside of human control. Variations outside human control include events like an earthquake that destroys the important infrastructure of an oilfield, or a hurricane that severely damages oil platforms, just as hurricane Katrina did in the New Orleans area in 2005.

In a stable energy sector, annual energy production plus imports matches annual energy consumption plus exports closely enough that any small variations are absorbed by local energy storage capacity, such as large storage tanks located near shipping facilities. During World War II, for the first time in US history, energy distribution was managed by the US Government in order to balance energy production and demand. Then, in 1973, when the Arab members of OPEC (Organization of Petroleum Exporting Countries) decided to stop the supply of crude oil to our country, Government again intervened, allocating the limited crude oil supplies so as to avoid the collapse of the US transportation system—the bloodstream of our economy. The objective of these governmental actions was to reduce domestic consumption of crude oil derivatives to a level that matched the reduced supply of crude oil. Around the time of the Government intervention in 1973 , the terms "Demand Side Management" and "Supply Side Management" appeared in our economic vocabulary..

*Supply Side Management* (SSM) involves the use of market projections and cost- and reliability-objectives to manage energy resource development, including identifying options, planning, construction, extraction and preparation of the resource for the end user. On the other side of the equation, *Demand Side Management* (DSM) includes a host of actions aimed at managing energy use in order to equalize demand whenever energy supply becomes constrained. Some core components of DSM are energy conservation, the use of alternate energy sources (such as substituting natural gas for gasoline), management of energy demand at various times of day, government-mandated performance standards such as minimum car mileage and maximum appliance energy consumption standards, and so on. Although this book focuses mainly on supply side management, this is an appropriate point for some comments on demand side management.

Ideally, in an efficient market, any imbalance between energy supply and consumption would be corrected by the market itself, mostly through price adjustments. However, there are factors—for example, the existing regulatory environment that requires annual average electricity pricing instead of real time pricing—that require specific DSM actions in order to correct the imbalance between energy supply and demand. Consider the pricing of electricity. If electricity prices were updated every fifteen minutes to reflect real production costs, and this information was made available to the consumer, then individual consumers could choose, at their discretion, when to operate major appliances such as air conditioners, water heaters, etc. Implementing this concept would allow consumers to reduce their monthly electric bills by more than 20%.(1) It would also, as we shall see later in this chapter, allow electrical power suppliers to reduce their total investment in expensive power generation equipment.

The market is trending toward such solutions. A major Florida utility(2) has signed up more than a million customers for its "On Call" program, under which, when the demand for electricity approaches maximum production capacity, the electrical power supplier can remotely turn off water heaters, air conditioners, and pool pumps for short periods of time, via signals sent over the power lines and received in small control boxes attached to the appliances. The incentive for consumers to join such a program is a lower price for the electricity used.

Another element of DSM, one often not given the attention it deserves, is the reduction in discretionary energy consumption. Specific actions can include reducing the use of one's personal car, selecting responsible thermostat settings in houses and apartments, replacing incandescent light bulbs with modern compact fluorescent bulbs, turning off computers overnight, and so on.

The potential energy savings can be considerable. For example, a recent study(3) found that roughly half of the over one hundred million PCs located in US offices are not properly shut down at night. The 43 billion KWhrs of electricity consumed annually by these computers is equivalent to the electrical energy generated annually by about 6 nuclear power plants of 1000 MW electrical output each. As a point of interest, if the electricity were generated in pulverized-coal fired plants instead of nuclear power facilities, the process would emit 48.3 million tons of $CO_2$ annually.

As another example, replacing all incandescent lamps in the residential sector with compact fluorescent lamps would save about 28%(4) of the 213 billion KWhrs of electricity currently used for lighting.(5) If this electricity was being generated in pulverized-coal fired plants, the annual reduction in $CO_2$ emissions would total 67.2 million tons.

Although this book deals primarily with the supply side management of energy, any serious nationwide energy policy would be grossly incomplete without a strong reliance on DSM as well. The list of DSM components mentioned above is by no means complete. Throughout this book, many other examples of DSM are mentioned and, where applicable, their contribution in the new energy supply infrastructure is quantified.

## UNDERSTANDING THE POWER GRID

No discussion on demand side management would be complete without an explanation of the mechanics involved in electrical power transmission and distribution. The *electrical transmission grid* (sometimes called simply "the power grid", or just "the grid") transports large amounts of high-voltage electrical energy from the point(s) where the electricity is generated to point(s) close to where the electricity is consumed. At these destination points, the voltage of the electricity flow is reduced and the *electrical distribution grid* takes over to transport the electricity to the consumer.

As electrical energy flows through transmission and distribution lines, it must overcome the resistance of the wires, a process which causes some of the energy to be lost in the form of heat. Two factors that influence the amount of energy loss are the distance traveled and the load (amount of electricity) carried by the wires. Ideally, the transport of electrical energy will occur with minimal losses. However, over time, the major centers of electricity generation and consumption have both shifted, such that the power grid no longer transports electricity to the distribution centers with minimal losses. If we could start "from scratch" and lay out a set of electricity transmission lines that would minimize the energy losses involved in getting power from its current generation points to consumers, the transmission grid would look significantly different than it currently does. Our current power grid is a patchwork of compromises—and the result is high transmission losses. It is estimated that up to 8% of the electrical energy entering the US power grid is currently lost as heat before reaching the consumer.(6)

For better or worse, the shape of the power grid influences our development of new energy sources. Before electricity can be made available to a wide market, as opposed to a limited number of merely local consumers, the electricity must be introduced into the power grid. Therein lies the problem. Renewable energy sources such as geothermal steam, sunlight, wind and falling water do not necessarily lie in locations close to the power grid. Unlike coal, gas, oil and nuclear, these energy sources cannot be transported; they must be converted to electricity on the spot. If a renewable energy resource happens to lie in a remote location, the costs associated with delivering the electricity to the power grid may be high enough to make the resource uneconomic to develop. Often promoters of renewable energy underestimate how ill-prepared our transmission grid is to move large amounts of power over long distances—for example, to move electricity generated by wind from the windy plains of central America to the large centers of consumption along the coasts. A Natural Renewable Energy Laboratory study released in January 2011 concluded that supplying 20% of the country's electrical power with wind would require 23,000 miles of new electrical transmission line. In a recent interview(7) a member of the Federal Energy Regulatory Commission underlined the precarious state of our transmission grid by stating that the country badly needed a "transmission interstate superhighway system".