Praise for
The Natural Gas Revolution

“Robert Kolb has written an excellent and comprehensive volume on the changing energy landscape. Both specialists and non-experts will benefit from the deep analysis he provides.”
—Gawdat Bahgat, Professor of National Security, National Defense University’s Near East South Asia Center for Strategic Studies

“...a very comprehensive scan of the gas landscape with associated shifts from unconventional developments.”
—Matthew Hulbert, Chief Political Advisor, Saudi Aramco

“I have gone over [this] fine effort and can find no reason to be critical or even add anything! Very well done and easy to understand. I enjoyed [the] sections on shale plays and China very much.”
—Randy Brown, Managing Partner, Tremont House Enterprises (Energy Group)

“I was very impressed with the in-depth information and historical data the book provides. It should be required reading for anyone in the industry now and in particular new employees coming into the energy business to help them understand the ‘big picture’ when it comes to energy in the world.”
—Paul Belflower, Vice President, Marketing & Supply, Mustang Fuel Corporation/Mustang Fuel Marketing

“In this crisp and compact book, Robert Kolb pulls together the fast, world-changing transformation in energy across the globe. As dessert, we get a delicious treat of maps and charts that make the new picture visually clear. If you want to understand how your world may change, read this book.”
—Steve LeVine, author of The Oil and the Glory

“This book is a ‘must read’ for anyone working in or interested in the natural gas industry. Kolb’s discourse is eloquent and very insightful as he takes the reader through history up to present day of the natural gas revolution. The book is a pleasure to read!”
—Betty J. Simkins, Professor of Finance and Williams Companies Professor of Business, Spears School of Business, Oklahoma State University
“In *The Natural Gas Revolution*, Robert Kolb presents a thorough yet readable insight into the natural gas industry and its prospects for the future. While he does not shy away from explanation of the technical aspects of natural gas production, he does so in a manner that makes the concepts understandable to a reader with no background in the industry. Neither does he avoid the controversy surrounding fracking and other environmental concerns. The book is well researched and documented and a compelling read even for those of us who are familiar with the energy sector. Anyone concerned with the future of energy on a domestic or global scale should find a few hours with this book as time well spent.”

—James L. Williams, WTRG Economics
The Natural Gas Revolution
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The Natural Gas Revolution
At the Pivot of the World’s Energy Future

Robert W. Kolb
To Lori.
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Preface

We live in the midst of a revolution in energy that has already changed the energy future of the United States and now is beginning to transform the rest of the world as well. Because energy is so vital to all modern economies, these developments are rearranging the relative strengths of many of the most important nations in the world. This book tells the story of how this revolution began, where it stands now, and how it is likely to transform the world.

Less than 10 years ago, the United States faced what appeared to be a permanent fate of massive imports of oil and natural gas. In the ensuing years, the country has suffered a massive financial crisis, has endured a deep and persistent recession, and currently struggles through a period of less-than-satisfying anemic economic growth. This malaise has been accompanied by the dynamic rise of China and the perception of many that the United States is on an irretrievable path toward losing its customary preeminence and, perhaps, even to becoming a second-tier nation. In addition, environmental problems in the form of climate change have been gaining increased world attention. Compared to many other leading nations, the United States has done little to address its carbon footprint. There has been almost unanimous agreement that reducing carbon emissions is going to be extremely difficult in an economy used to relying on hydrocarbon energy sources.

Much—perhaps all—of that anticipated dismal future is no longer part of the forecast for the United States. Because of remarkable technological advances in accessing energy and a continuing wave of new discoveries of gas and oil, it now appears almost certain that the United States will soon become a reliable net exporter of energy. Largely benefiting from improved methods in petroleum geology, major new discoveries are occurring almost monthly around the
world, even in areas long thought to be bereft of oil or gas, such as the eastern Mediterranean and the shores of Tanzania and Mozambique.

In the United States, geologists have long known of enormous quantities of gas and oil trapped in deep strata of shale and other sedimentary rocks that have held them inaccessible and beyond the reach of existing technology. But the twin technological innovations of hydraulic fracturing (“fracking”) and horizontal drilling have unlocked these resources and led to an energy renaissance in the United States. Over the same time, the world has extended its ability to ship gas in liquid form around the world, opening economic possibilities that have long been closed and freeing some nations from the grasp of limited supply options.

For 40 years, many of the world’s large economies, including those of the United States, Western Europe, and Japan, have been held as virtual energy hostages, a precarious circumstance of deep concern to policymakers and much of the public. This dependency of the West has been made worse by the nature of the countries that have been the world’s energy jail keepers: Russia and the exporting nations of the Mideast. Following the United States, other nations are starting to extract their own shale gas and oil resources that appear to be abundant and widely distributed around the globe. Even nations that truly possess no gas or oil, such as Japan, can now at least look forward to a variety of suppliers, including many allies.

Chapter 1, “To the Brink of Innovation,” examines the U.S. energy situation just after the turn of the twenty-first century. It was not a pretty picture. U.S. oil production peaked in 1970 and fell steadily for almost 40 years, until 2008. The United States also faced a serious deficit of natural gas and a future of gas imports. The longstanding failure to develop alternative energy sources, an inability to confront the problems of global climate change, and a general environmentally inspired hostility toward hydrocarbon sources of energy all conspired to create quite a serious energy situation. Yet unknown to almost everyone, the United States was about to enjoy a sudden large
increase in energy production. In 2008, as if from another planet, came the first significant increase in oil production.

In contemporary public discourse in the United States, few topics generate more passion than the technology behind the new wave of energy production. Chapter 2, “They Call It a Revolution,” explains this technology in nontechnical terms. Opponents of hydraulic fracturing fear that the process will taint aquifers on which populations depend for their very lives. The technique requires the pumping of water, sand, and chemicals into a well under high pressure to fracture the shale beds in which the gas or oil has been locked. Doing so frees the gas or oil to flow into the well and to the earth’s surface for capture and use. While hydraulic fracturing has been in use for decades, what makes the technique so newly powerful is its combination with horizontal drilling. The sedimentary rocks containing the gas or oil lie in horizontal beds. To reach into them, the driller sinks a vertical well for some distance and then turns the drill to operate at a 90-degree angle and to traverse the shale bed. From any point of view, the ability to drill horizontally at a depth of a mile or more below the earth’s surface is a marvelous technological tour de force.

Merely acquiring energy without a means of transporting it to the point of use remains only a half-achievement. Chapter 3, “Liquid Natural Gas and the World Gas Revolution,” explains the long, slow, and now-maturing development of a worldwide transportation network that allows natural gas to be liquefied by chilling, pumped onto ships, transported to its destination, re-gasified, and then taken to the ultimate consumer. This aspect of the gas revolution is important because it allows producing nations to cash in on their newly discovered bounty, and it also makes it possible for receiving countries to secure needed energy resources at a more favorable price and to diversify their suppliers.

Chapter 4, “Environmental Costs and Benefits,” considers the very real environmental challenges of the natural gas revolution. As mentioned, these include the danger of polluting critical water
sources. But there are a number of other issues as well, including water consumption, the disposal of water laced with chemical and other pollutants generated in the production process, the disturbance of the land around the well site, and the changes that are brought to communities rich in these newly accessible resources. If all these challenges can be addressed successfully, we still face the issue of relying on hydrocarbons as opposed to once and for all, somehow, making a rapid transition to truly renewable and carbon-neutral sources of energy. There is another side to the environmental balance sheet, however. While waiting for the perfect world of completely renewable energy to arrive, substituting natural gas for coal and oil promises significant environmental benefits. Generating electricity by burning natural gas rather than coal is much cleaner. China derives 70% of all its energy from coal, and the environmental costs of that policy are well known. Also, as the United States moves ever more away from coal and toward natural gas for electricity generation, the large economies of the Eurozone are becoming more coal dependent as they close gas-fired plants and accelerate the building of coal-fired power plants.

Chapter 5, “The United States and China,” begins an extended treatment of the effects of the world energy revolution as it will play out around the world. The United States and China have the two largest economies in the world, and both stand to be major beneficiaries from the natural gas revolution. The United States has already begun to cash in, while China sits atop the world’s largest shale gas reserves, waiting to be tapped once China succeeds in assembling the necessary expertise and infrastructure. Chapter 6, “The World’s Other Large Economies,” turns attention to the other eight countries that make up the world’s 10 largest economies: Japan, Germany, France, Italy, the United Kingdom, Brazil, India, and Russia. As we will see, most of these countries are beneficiaries of the natural gas revolution, but Russia almost certainly will be a big loser.
Beyond the big 10 economies, many other nations have a stake in the natural gas revolution, and Chapter 7, “The Other Contending Nations,” explores the role that these countries will play. Iran, Qatar, and Turkmenistan, occupying second through fourth places in total world reserves of natural gas, following Russia in first place, have different problems and opportunities. But many other countries are also dramatically affected, ranging from Argentina to Australia, Turkey to Tanzania, and Malaysia to Mozambique. Developments in the world energy revolution have brought many small or even previously insignificant producing countries into the energy spotlight.

Chapter 8, “The Next Energy Revolutions,” the book’s concluding chapter, considers two further energy revolutions that are on the horizon. The first of these is the development of shale oil on parallel with what is already well under way with shale gas. The chapter also introduces a completely new and untapped resource that is the world’s largest hydrocarbon resource—the mysterious and previously inaccessible “fire ice”—or methane hydrates.

A Note on Energy Values and Conversions

Quantities of energy are expressed in a variety of measures and forms, due in part to our continuing reliance on both the metric and English systems. Also, hydrocarbon energy comes in a variety of forms—solid, liquid, and gaseous—and different measures are suitable to each. But in whatever form, these energy sources are all reducible to a common measure—their energy content. These brief notes are intended to help you understand and compare the basic measures.

We begin with a measure of energy, the British thermal unit (Btu). 1 Btu is the energy required to raise 1 pound of water by 1 degree Fahrenheit. To make the Btu more salient, we can note the following approximate equivalences of energy content:

1 food calorie ≈ 4 Btu
So a normal daily intake of 2,000 food calories is equivalent to about 8,000 Btu.

1 gallon of gasoline \( \approx 139,000 \) Btu

1 barrel of crude oil = 42 gallons \( \approx 5,800,000 \) Btu

1,000 cubic feet of natural gas \( \approx 1,023,000 \) Btu \( \approx 8.05 \) gallons of gasoline

Quantities of natural gas are expressed both in metric measures and English measures. The typical unit of measurement in the metric system is the cubic meter:

1 cubic meter \( \approx 35 \) cubic feet

In the United States, the average residence uses about 75,000 cubic feet, or about 2,100 cubic meters, of natural gas per year:

75,000 cubic feet \( \approx 76,725,000 \) Btu \( \approx 13 \) barrels of crude oil \( \approx 618 \) gallons of gasoline

Quantities of crude oil are often expressed in metric tonnes:

1 metric tonne = 1,000 kilograms \( \approx 2,205 \) U.S. pounds

1 metric tonne of crude oil \( \approx 7.33 \) barrels \( \approx 4,000,000 \) Btu

A standard term of measuring large quantities of energy is in millions of tonnes of energy equivalent (MTOE), meaning the energy equivalent to 1 million tonnes of crude oil.

Large quantities of natural gas are often measured in billions of cubic meters (bcm), a quantity of gas sufficient to serve 468,000 U.S. residences for one year.

When gas is liquefied, it is called LNG, for liquefied natural gas. Liquefying gas reduces the volume of gas by a factor of about 600, so that LNG is much more energy dense than gas:

1 tonne of LNG \( \approx 1.22 \) tonnes of crude oil

1 tonne of LNG \( \approx 1,360 \) cubic meters of natural gas \( \approx 48,000 \) cubic feet of natural gas
Plate 1  The Structure of Oil and Gas Reservoirs

Plate 2 The Natural Gas Resource Triangle

Source: Slightly adapted from Stephen A. Holditch, “Tight Gas Sands,” Journal of Petroleum Technology, June 2006, 84–90. Figure 1, p. 84.
Plate 3  Unconventional Natural Gas and Oil Plays in the United States

Source: Adapted from U.S. Energy Information Administration, “Review of Emerging Resources: U.S. Shale Gas and Shale Oil Plays,” July 2011, Figure 1, p. 6. Artwork prepared by Ira G. Liss.
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Artwork prepared by Ira G. Liss.
Plate 25  The Pressure and Temperature Interface for Methane Hydrates

Artwork prepared by Ira G. Liss.
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To the Brink of Innovation

World Energy—A Rapid Tour of the Past 200 Years

From the beginning of human history until about 1750, a common date for the start of the Industrial Revolution, the world was poor, and societies were equal—or at least very roughly so, and dramatically so compared to the state of the world today. Over the past 250 years, some nations have succeeded in building economic institutions and deploying technological innovations to facilitate economic growth. These movements have been the primary drivers of a rapid increase in wealth that was initially concentrated in the United Kingdom and soon spread to other early-moving nations. More recently, other societies have adopted institutions and technologies that permit economic progress, and wealth has spread to many other nations. The original Industrial Revolution has been superseded by further industrial and societal revolutions.

Some historians emphasize the role of the rapid technological changes that occurred starting about 1750, while others emphasize what they see as the greater importance of improving institutions that guarantee property rights and propel economic growth. Whatever the ultimate cause of the prosperity that began some 250 years ago, the world’s new wealth arrived on a drip, then a trickle, and finally a flood of energy derived from hydrocarbons. Pre-industrial societies
consumed relatively little energy, deriving virtually all energy from organic sources. These sources were either human or animal muscle power, or substances that were burned for energy, like wood and peat. Before about 1700, power derived from wind, water, and hydrocarbons played only a negligible or nonexistent role.\textsuperscript{3} No matter the sophistication of intellect or the brilliant organization of society, a total reliance on these organic energy sources placed an upper bound on human consumption and wealth, so the almost universal condition of poverty “did not arise from lack of personal freedom, from discrimination, or from the nature of the political or legal system, though it might be aggravated by such factors. It sprang from the nature of organic economies.”\textsuperscript{4}

Only the past few centuries have seen a significant increase in energy use. The increased exploitation of new energy sources has paralleled the development of technologies that have been able to actually make productive use of that newfound energy. Without industrial technologies, new energy sources could only be used for heating, and the difficulty of accessing new energy supplies has helped to limit human energy consumption.

The new sources of power that accompanied and made possible the rise of industrial technologies were first coal and then oil. Table 1.1 and Figure 1.1 show the transition of the world’s energy sources since 1800, when the Industrial Revolution was already in full swing.

<table>
<thead>
<tr>
<th>Fuel Transition</th>
<th>Decade</th>
</tr>
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<tbody>
<tr>
<td>Coal overtakes biofuels</td>
<td>First decade of the nineteenth century</td>
</tr>
<tr>
<td>Oil overtakes biofuels</td>
<td>1950s</td>
</tr>
<tr>
<td>Oil overtakes coal</td>
<td>1960s</td>
</tr>
<tr>
<td>Gas overtakes biofuels</td>
<td>1960s</td>
</tr>
</tbody>
</table>

In Figure 1.1, the different sources of energy are expressed in a common unit of energy, the energy contained in 1 million barrels of
oil. Perhaps most surprisingly, the entire nineteenth century, with all its rapid technological change and innovation, was still dominantly fueled by organic energy sources—non-petroleum resources including wood, peat, and the muscle power of animals and humans. Coal, however, gained an ever-more-prominent role starting in the middle of the nineteenth century. Nonetheless, coal surpassed organic energy as a world energy source only at the beginning of the twentieth century. Oil surpassed organic energy sources in world usage only in the 1950s, and it did not surpass coal until the 1960s.

![The Succession of Energy Sources: Biofuels, Coal, and Crude Oil](source)

### Figure 1.1 The Succession of Energy Sources: Biofuels, Coal, and Crude Oil


Coal’s slow move to ascendancy over organic energy sources stemmed from the relatively slow spread of the Industrial Revolution to other parts of the world. Only northern Europe and the United States saw rapid industrialization following the breakthroughs in the United Kingdom. In these advanced economies, coal was king, supplying more than 90% of all of England’s energy as early as the 1850s. Meanwhile, though it was relatively close to the source of innovation,
Italy had a distribution of energy sources in the 1850s much like England’s in the 1550s.\(^6\)

Figure 1.2 shows that the past 200 years of energy history has featured a falling share for organic energy sources, and that trend continues to the present, with biofuels now constituting less than 10% of world energy usage. Nuclear and hydropower are together even less important than biofuels, constituting slightly more than 8% of total world energy usage. Solar power and wind power are both too slight to be factors. Thus, the world currently relies on hydrocarbons—coal, oil, and natural gas—for more than 80% of energy. Focusing on energy derived just from the three main hydrocarbons, oil provides 37%, slightly leading coal at 35%, with natural gas following at 28%. However, the importance of gas is rising and even accelerating. Natural gas supplied 7% of the world’s energy in 1950, and it supplies 23% today; its proportion is almost certain to increase.

![Shares of World Energy Sources, 1800–2008](image)

**Figure 1.2** Shares of World Energy Sources, 1800–2008

That natural gas has gone from a 7% to a 23% share of total world energy in 60 years is all the more impressive when measured against the vast acceleration of world energy usage, as Figure 1.3 shows. In 2008, world energy usage was 10 times as large as in 1900 and 22 times as large as in 1800. Only a relatively small part of this increased energy usage can be attributed to population growth. Rather, there has been a marked increase in energy usage per capita, which has fueled a dramatic increase in per capita gross domestic product (GDP) as well. From 1820 to today, world per capita GDP has risen by a factor of 10, while in the industrialized West, per capita income has surged by a factor of 20 over the same period.7

Figure 1.3 The World’s Energy Sources, 1800–2008

Hydrocarbons: From the Beginnings to Maturity

Today our lives depend so fully on energy derived from hydrocarbons that it is almost impossible to realize how recently these energy sources began to play a significant role in human history. Coal’s dominance gave way to oil due in large measure to oil’s role in transportation. Today, oil rules the energy day and captures our geopolitical attention. A Russian engineer drilled the world’s first oil well in 1848, in Baku on the Caspian Sea. Baku was producing almost the entirety of the world’s oil supply around 1860. Today, as the capital of Azerbaijan, Baku continues to be an important hub of hydrocarbon production and transportation. In the United States, oil collected from surface seeps was first used as an ingredient in patent medicine around 1850, but some innovators recognized oil’s potential as a source of energy for lighting.

The first oil well in the United States was drilled in Titusville, Pennsylvania, in 1859 by “Colonel” Edwin Drake; it set off the first American oil boom. The following decades saw a competition among several players. John D. Rockefeller’s Standard Oil was big in the United States, and the Swedish Nobel family came to be the most important players around Baku. The Nobels were soon joined by a succession of other non-U.S. firms, with the French Rothschilds also playing a prominent role.

It is not too much to say that crude oil made the automobile and that the automobile made oil one of the world’s most important commodities. Although it was not the first country to drill, the United States quickly came to lead world production. Over the 1900 to 1950 period, the United States produced more than half of the world’s oil. The bounty of U.S. oil played a critical role in both world wars. Within days of the 1918 armistice, the French Senator Victor-Henri Bérenger stated, “Oil, the blood of the earth, has become the blood of victory.” Not to be outdone by French metaphors, Earl Curzon of England remarked that the Allies had “floated to victory on a wave of
Although obtaining some oil from Mexico and Persia, the real source of the blood, or wave of victory, came from the United States, which supplied 80% of the Allies’ oil in the last year of World War I. By contrast, Germany had sufficient coal and natural gas but could draw only on Romania for a secure supply of oil.

Oil from the United States played a similar dramatic role in the winning of World War II, as Table 1.2 shows. Germany had adequate supplies of coal, outproducing every other combatant, even able to convert coal and natural gas to oil and then to gasoline. Nonetheless, the Allied powers outproduced the Axis collective by 63%. But with the war truly being a world war, navies and armies could only get to the front by using oil power, not coal. It was in crude oil production and availability that the Axis suffered the most serious disadvantage. Collectively, the Allies outproduced the Axis in oil by a factor of more than 15. Of that total Allied production, the United States contributed 80%, as it also did in World War I. So if the Allies in World War I rode to victory on a wave of oil, the Allies got to and won World War II on the strength of its massive superiority in crude oil, which was overwhelmingly provided by the United States.

Table 1.2  Coal and Crude Oil Suppliers in World War II
(Millions of Metric Tons)

<table>
<thead>
<tr>
<th></th>
<th>Allies</th>
<th>Axis Powers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>USA</td>
<td>USSR</td>
</tr>
<tr>
<td>Coal</td>
<td>2,149.7</td>
<td>590.8</td>
</tr>
<tr>
<td>Crude oil</td>
<td>833.2</td>
<td>110.6</td>
</tr>
</tbody>
</table>


Note: Approximately two-thirds of German oil production was in the form of synthetic oil derived from coal or natural gas.
A Rude Awakening

U.S. crude oil production continued to increase after World War II, peaking in 1970, at a production of 9.6 million barrels per day. From this high mark, the United States suffered a persistent slide in production for decades.

Coming almost immediately after the peak in U.S. oil production, the Organization of the Petroleum Exporting Countries (OPEC) oil embargo of 1973–1974 was a rude awakening. The United States had experienced other shortages in the many decades of previous oil history, including the West Coast Oil Famine of 1920, probably the first oil shock of the transportation era. But the 1973–1974 experience was several orders of magnitude larger than any previous supply interruption, and it galvanized the attention of the American public, which was forced for the first time in memory to wait in line to fuel its cars.

Within days after the initiation of the oil embargo, President Nixon put the United States on the road to energy independence, declaring on November 7, 1973, “Let us set as our national goal, in the spirit of Apollo, with the determination of the Manhattan Project, that by the end of this decade we will have developed the potential to meet our own energy needs without depending on any foreign energy source.” Ever since that time, the nation has been on the long road to that elusive and seemingly ever-receding goal, with every president since Richard Nixon renewing the pledge and commitment to energy independence.

Thus, the three decades that followed the oil embargo were largely unhappy ones for energy in the United States. For oil—the critical energy source—the story was one of ever-increasing usage, ever-falling production, and ever-larger imports, and the same was
largely true of natural gas. Even in those times, and continuing to the present day, coal has presented no supply problems. Presently, the United States has about 240 billion metric tons of coal, and even though it is producing almost 1 billion metric tons per year, that is less than one-half of 1% of proved reserves. “Proved reserves” are essentially in-ground resources confidently known to exist that can be extracted profitably under current economic conditions. Generally, “reserves” refers to “proved reserves.” Put another way, the United States has almost 250 years’ worth of coal at present levels of consumption, and it is actually producing more than it consumes. With oil and gas, the situation has been quite otherwise.

U.S. Oil and Natural Gas at the Turn of the Millennium

Figure 1.4 shows the recent history of oil production and consumption in the United States. Even at the height of production, the United States consumed more oil than it produced, and in the 30 years from 1970 to 2000, the gap generally widened, with increasing consumption and falling production. The situation for natural gas has been superficially different but similar in actual fact. As shown in Figure 1.5, in the United States, the production and consumption of natural gas were in a rough balance initially, but starting in about 1986, consumption increased rapidly, even while production increased. The ultimate result was that the gap between consumption and production grew ever wider toward the end of the twentieth century.
Figure 1.4 U.S. Crude Oil Consumption and Production, 1970–2000

Figure 1.5 U.S. Natural Gas Consumption and Production, 1970–2000
Source: U.S. Energy Information Administration.
Also, U.S. oil and gas reserves fell significantly from 1970 to 2000, as Figure 1.6 shows. From this dwindling resource base, the United States continued to extract more and more of both oil and gas, as shown in Figure 1.7. By 2000, the United States was extracting about 10% of its oil reserves and about 11% of its gas reserves each year. While there had been fluctuation in the production-to-reserves ratio for both oil and gas, the general trend was upward, and this was particularly true for natural gas. Further, part of the reason that these rates of production were not higher was resistance to oil and gas production on environmental grounds. Thus, the energy picture for the United States at the start of the new millennium was certainly perilous.

Figure 1.6 U.S. Oil and Natural Gas Proved Reserves, 1970–2000 (1970 = 100.0)

Source: U.S. Energy Information Administration.
Figure 1.7  U.S. Oil and Gas Produced, as a Percentage of Proved Reserves, 1970–2000

Source: U.S. Energy Information Administration.

The geopolitical situation around the turn of the millennium could only exacerbate reasonable fears about the energy future for the United States and its principal allies. The war between Iraq and Iran had dragged on for almost the entire decade of the 1980s, reducing production for both countries. Iraq’s invasion of Kuwait in 1991 only emphasized the turbulence of the Persian Gulf region, with its critical energy supplies. Then came the attack on the World Trade Center in New York in September 2001, ushering in a new era of conflict and supply disruption in the region. In assessing the near- and short-term futures for natural gas in May 2001, the U.S. Energy Information Administration (USEIA) noted that gas prices had more than doubled in the decade 1990 to 2000, and it forecast that prices would rise by 34% in just the next two years.\textsuperscript{13} Further, so much gas had been withdrawn from storage that the USEIA saw its replenishment as a challenge that would add to price pressure. The same report noted that some policy analysts were questioning the ability of natural gas to play its expected role in supporting economic growth.
Looking out to 2020, the USEIA predicted that total U.S. energy consumption would increase by about one-third over the period, as would the use of oil. The report also predicted that the use of natural gas would increase by almost two-thirds. As a result of these increases, the USEIA predicted that the United States would have to increase gas imports by about three-quarters and oil imports by two-thirds.\textsuperscript{14}

The natural gas supply and demand problems for the United States stemmed from several sources. In the aftermath of the embargo-induced energy crisis of the early 1970s, Congress passed the Powerplant and Industrial Fuel Use Act of 1978 as a centerpiece of President Carter’s energy policy. One of the key purposes cited in the act was “to encourage and foster the greater use of coal and other alternate fuels, in lieu of natural gas and petroleum, as a primary energy source.” In essence, the law required that new electricity-generating plants that were designed to run on natural gas had to also be capable of using coal or some other non-gas fuel. The act also restricted the use of natural gas in large boilers. In the years following the enactment of the act, demand for natural gas waned, prices fell, gas came into excess supply, and exploration for and development of new gas resources slowed. Given the long lead times for energy development, the disincentives to exploration and development inherent in the act soon caused significant problems.

In recognition of the excess supply that developed right after and partially in response to the 1978 act, Congress voted for repeal of the act in 1987. As the USEIA noted, this repeal “set the stage for a dramatic increase in the use of natural gas for electric generation and industrial processing.”\textsuperscript{15} Soon after this repeal came “third-generation” combined-cycle gas-fired power plants, which were much more efficient and economically attractive than prior technologies. The repeal of the 1978 act, improved technology, and low gas prices stimulated a switchover to the construction of gas-fired power plants, which contributed to a demand surge for gas. In the next 20 years, the use of gas jumped more than 100%, due largely to the expanded use of gas in generating electricity.\textsuperscript{16}
Natural gas sources can be either conventional or unconventional. In short, a conventional natural gas deposit is essentially gas trapped in a single underground reservoir, much like a subterranean pool of water. By contrast, unconventional natural gas deposits consist of gas dispersed over a wider area and held in a variety of rock formations, such as shale, coal, or sandstone. (These types of deposits are explored more fully in Chapter 2, “They Call It a Revolution,” as they play an important role in the natural gas revolution.) In 2000, the USEIA published an assessment of technically recoverable natural gas in the lower 48 states, both conventional and unconventional, as shown in Table 1.3. (Technically recoverable oil and gas are resources that it is possible to access with current technology, without reference to the economic viability of doing so.) The total estimate was more than 22 trillion cubic meters, divided almost exactly evenly between conventional and unconventional deposits. This is enough gas to fill the volume of the New Orleans Superdome more than 5 million times.

Table 1.3 U.S. Unproved Technically Recoverable Natural Gas Resources Onshore in the Lower 48 States, as of January 1, 2000 (Billion Cubic Meters)

<table>
<thead>
<tr>
<th>Region</th>
<th>Conventional</th>
<th>Unconventional</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tight Sands</td>
<td>Coal Bed</td>
</tr>
<tr>
<td>West Coast</td>
<td>623</td>
<td>170</td>
</tr>
<tr>
<td>Rocky Mountains</td>
<td>1,557</td>
<td>5,380</td>
</tr>
<tr>
<td>Midcontinent</td>
<td>2,633</td>
<td>425</td>
</tr>
<tr>
<td>Southwest</td>
<td>1,586</td>
<td>425</td>
</tr>
<tr>
<td>Gulf Coast</td>
<td>4,502</td>
<td>736</td>
</tr>
<tr>
<td>Northeast</td>
<td>368</td>
<td>680</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>11,270</strong></td>
<td><strong>7,815</strong></td>
</tr>
</tbody>
</table>


Thus, there was lots of gas onshore, but it needed to be extracted. However, legal restrictions prohibited the development of much of
this gas, particularly in the Rocky Mountain region. Further, while the industry had the technology to develop much of this gas, it was not feasible economically. Often the difference between a proved reserve and a technically recoverable reserve depends simply on the price of the resource and the cost of exploiting the resource. Offshore the United States, there are also vast amounts of technically recoverable gas. The USEIA’s analysis divided them into the Pacific, Gulf of Mexico, and Atlantic regions, holding a total of 6.7 trillion cubic meters. However, the entire Pacific and Atlantic regions were legally out of bounds for development, as was one of the three subregions of the Gulf of Mexico. These legal restrictions excluded 1.7 trillion cubic meters of offshore gas from production. Thus, with the new millennium, the prospects for natural gas in the United States appeared highly forbidding on both the supply and demand sides of the equation. Far from being a single voice of doom, the bleak future portrayed by the USEIA represented the consensus of wisdom on the subject of hydrocarbons in general and natural gas in particular.

Contrasted with these dire predictions, and not fully understood or anticipated by anyone, the energy future of the United States and the world stood on the cusp of a dramatic change. As we will see, there was soon to be a remarkable jump in estimates of gas resources, and new technologies would make it economically feasible to develop much gas that previously had been only technically recoverable.

Notes

1. See, for instance, Robert E. Lucas, Jr., “The Industrial Revolution: Past and Future,” Minneapolis Federal Reserve Bank Annual Report, May 1, 2004, p. 1: “Living standards in all economies in the world 300 years ago were more or less equal to one another and more or less constant over time.”

2. As Douglass North and Robert Thomas put it, “The industrial revolution was not the source of modern economic growth. It was the outcome of raising the private rate of return on developing new techniques and applying them to the production process.” It was, in short, the development of secure property rights protected by a system of laws enforced by a capable government that made

3. This is not to minimize or neglect the intellectual achievements of an earlier time. For example, Lynn White chronicles the amazing inventions and technological innovation of the medieval period. Rather, these inventions and technologies were not deployed in a large-scale, sustained, and society-changing way until the advent of the Industrial Revolution. See Lynn White, Jr., *Medieval Technology and Social Change*, Oxford, UK: Oxford University Press, 1966.


8. In his Pulitzer-winning book, on which this section largely relies, Daniel Yergin includes a compelling narrative of these early days of oil. See *The Prize: The Epic Quest for Oil, Money, and Power*, New York: Free Press, 1991.


12. “I am recommending a plan to make us invulnerable to cutoffs of foreign oil…. new stand-by emergency programs to achieve the independence we want.” (President Gerald Ford, January 15, 1975). “This intolerable dependence on foreign oil threatens our economic independence and the very security of our nation” (President Jimmy Carter, July 15, 1979). “We will continue supportive research leading to development of new technologies and more independence from foreign oil” (President Ronald Reagan, February 18, 1981). “There is no security for the United States in further dependence on foreign oil” (President George H. Bush, August 18, 1988). “We need a long-term energy strategy to maximize conservation and maximize the development of alternative sources of energy” (President Bill Clinton, June 28, 2000). “This country can dramatically improve our environment, move beyond a petroleum-based economy, and make our dependence on Middle Eastern oil a thing of the past” (President George
W. Bush, January 31, 2006). “These are extraordinary times, and it calls for swift and extraordinary action. At a time of such great challenge for America, no single issue is as fundamental to our future as energy. America’s dependence on oil is one of the most serious threats that our nation has faced....It falls on us to choose whether to risk the peril that comes with our current course or to seize the promise of energy independence” (President Barack Obama, January 26, 2009). “For decades, we have known the days of cheap and accessible oil were numbered....Now is the moment for this generation to embark on a national mission to unleash America’s innovation and seize control of our own destiny” (President Barack Obama, June 15, 2010).


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