Oklahoma Oil and Natural Gas: Our Place in the Big Picture

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INTRODUCTION

The Oklahoma energy landscape cannot be fully appreciated without an understanding of the larger, global issues that ultimately control it; hence the need to review the big picture. The conclusions in this article are predicated on a reversal of a geological axiom, "the present is the key to the past." Here, knowledge of our energy past and how we arrived at our present situation is crucial to understanding what promises to be an unsettled energy future.

This is the last of three articles examining the oil and gas industry in Oklahoma, written for non-technical readers interested in the petroleum industry. The first two, "Oklahoma Oil: Past, Present and Future" and "Oklahoma Natural Gas: Past, Present and Future," were published in the Fall and Winter 2002 issues of *Oklahoma Geology Notes*. Although each paper was written to stand alone, readers are encouraged to review the first two articles, as the principles that have shaped Oklahoma's energy history apply equally to the world at large. The articles can be purchased in hard copy from the Oklahoma Geological Survey Publications Office (405-360-2886), or accessed on the Oil and Gas page in the Fossil Fuels section of the Survey's Web site: **http://www.ogs.ou.edu/**.

The issue of energy is more critical today than ever before. Because the United States (like most of the developed world) is no longer energy-independent, issues involving domestic production, consumption, regulation, and prices must be examined against a backdrop of worldwide economic cycles and regional political stability. Security in our energy future is now inextricably linked to foreign policy and the ability to constructively interact with the governments of the producing nations on which we depend. For a nation that historically has prided itself on independence, the situation is sometimes uncomfortable. However, until consumption of fossil fuels diminishes, our long-term economic security will depend on the stability, good will, and economic interests of other nations.

Inexpensive energy in abundance is one of the greatest factors responsible for the unprecedented prosperity now enjoyed by the U.S. and the rest of the developed world. Though as history shows, dependence on oil and natural gas makes us sensitive to interruptions of supply. Whether these interruptions are short term or long, they inevitably result in higher prices that reduce economic growth; and any government that finds its economy at risk may be forced to neglect other national interests in an effort to maintain its energy supply. The precarious nature of this linchpin of the world economy, and the unforeseen consequences that securing its supply entail, will continue to rivet the attention of the world.

Much has been published about the world energy situation by the many organizations dedicated to its research. Critical variables, including size of the resource base, increases in future energy demand, and world productive capacity always will be in dispute. As a result, forecasts are often as much a function of the bias of authors as the data on which their predictions are based. Reasonable people can always disagree about the world's energy future. Even if the resource base were known precisely, and the infrastructure for moving oil and gas to the market always in place, we still would face economic, environmental, and political imponderables whose effect no one can predict. The only indisputable facts are that the world runs largely on oil and natural gas and the resource base for those commodities is finite.

As no viable alternative appears on the horizon, fossil fuels—especially oil and natural gas—will account for the vast bulk of world energy use for the foreseeable future. Although the oil and gas industry will remain an integral part of the Oklahoma economy, its health depends on price, and price is controlled by nations in the developing world where reserves and productive capacity are high but consumption is low. Thus the volume of Oklahoma oil and gas remaining in the ground is less important than how much will be economic to produce in a global market. In spite of Oklahoma's standing as a major producing state, we will experience at least as much price volatility in the future as in the past. A predicted rise in long-term energy prices will aid the State's energy industry, but the negative impact on other areas of the economy leaves the net effect uncertain.

Meanwhile, the world is producing (and consuming) more oil than is being discovered, and projections show that productive capacity will be overtaken by demand before the end of the decade. After that, prices will rise, demand will fall, and, where possible, consumers will switch to other fuels. Natural gas is the fastest growing component of world energy supply and has far more remaining reserves than oil, but major sources for both fuels tend to be concentrated in unstable areas of the world. In the U.S., demand for natural gas is met by domestic production and imports from Canada. However, North American resources can now barely meet demand, and rising consumption will depend increasingly on imports.

Despite pronouncements by ambitious politicians, U.S. energy independence in a world dominated by oil and natural gas is not possible. We can extend the life of domestic reserves by opening new areas to exploration and development, and conservation can reduce our vulnerability to shortages. However, neither the U.S. nor Oklahoma can ever reach old production highs, nor is a significant reduction in demand likely through voluntary conservation. With demand expected to increase substantially even as our domes-

tic production declines, we will become increasingly dependent on external resources.

Even so, the future holds much promise. As our primary energy source has evolved from wood to coal, then oil, and eventually to natural gas, we have become increasingly efficient and less polluting in our energy consumption. Because energy resources are still vast, we have been able to rely mainly on the reserves that are most easily produced. The market forces of supply and demand ensure that we will never run out of energy from any source; it will simply become more expensive as the accumulations that are more difficult to produce are forced to satisfy a progressively larger share of demand.

WORLD OIL: PAST AND PRESENT

During most of human history, wood was the principal energy source. Initially abundant, cheap, and easily obtainable, it carried many societies through their pre-industrial age. Unfortunately, the legacy of large-scale wood burning is a landscape marred by clear-cut forests. In the 1800s, as wood became increasingly scarce, the United States and world energy economies gradually converted to coal (Fig. 1). An unintended benefit of this conversion was that, as dirty as coal burning was, it allowed forests to re-establish themselves in areas not committed to agriculture (Fisher, 2002). Coal assumed the bulk of the energy load from the late 1800s through the early 1900s, and, although its use remains high, throughout the developed world it was overtaken by petroleum in the mid-1900s.

For thousands of years, oil seeps and associated tar sands and asphalt deposits have been used by mankind. They occur around the globe and in many of today's major petroleum-producing areas, including the Persian Gulf, the La Brea Tar Pits of Los Angeles, and seeps in Oklahoma. Oil, in the form of asphalt, has been used throughout human history, but mainly as an adhesive or sealant. This changed in the early 1800s when, as a result of spreading prosperity, large numbers of people had the money to substitute expensive whale oil for the vegetable oil or animal grease previously used in lamps. Increased demand decimated local whale populations, forcing whalers to hunt farther afield and pushing the price for premium sperm whale oil to over $2.50 per gallon (Yergin, 1992). High prices precipitated a search for alternatives, and in the late 1840s and early 1850s it was discovered that "rock oil," now better known as crude oil, made an excellent substitute for whale oil in lamps. Rock oil had the additional advantage that it made a high-quality lubricant for machines powering the industrial revolution.

It was against this backdrop that "Colonel" Edwin Drake drilled the first producing oil well in 1859 near Titusville, Pennsylvania. He showed that high-quality crude oil could be obtained from the Earth's subsurface and that wells could produce the oil in commercial quantities. As refining techniques improved and the variety of products made from crude oil grew, uses multiplied and demand increased substantially. A major increase in demand came with the advent of the internal-combustion engine and its need for gasoline. Technological advances and improvements in refining techniques added more products and uses for crude oil. In addition to a variety of transportation uses, heating and the generation of electricity also became major uses of crude oil.

A similar sequence of events occurred throughout the Western world, spawning a global market for petroleum. Prices rose and fell, often sharply, as supply and demand sought balance. The production side included many notable discoveries: 1873, Russia (Baku); 1885, Indonesia (Sumatra); 1897, Oklahoma (Bartlesville-Dewey); 1901, Texas (Spindletop); 1905, Oklahoma (Glenn Pool); 1908, Iran; 1910, Mexico (Golden Lane); 1912, Oklahoma (Cushing); 1920, Oklahoma (Burbank); 1922, Venezuela; 1930, Texas (East Texas); 1932, Bahrain; 1938, Kuwait and Saudi Arabia; 1956, Algeria and Nigeria; 1968, Alaska (Prudhoe Bay); 1969, North Sea. Because of the petroleum industry's success in finding oil, prices remained low and oil was able to fill a progressively larger share of the world's demand for energy. Between 1949 and 1972, world energy consumption tripled, but petroleum demand rose 5.5 times (Yergin, 1992).

Petroleum in the U.S. became prominent in the early 1900s, due largely to early discoveries in Oklahoma (Boyd, 2002a), and since then both demand and production have grown rapidly if somewhat irregularly (Fig. 1). To prevent catastrophic drops in crude-oil price that could result from over-production, a group of organizations in the U.S.—then the world's largest producer and consumer—curtailed production to help balance supply and demand. The cartel, sanctioned by the government, was the precursor of the Organization of Petroleum Exporting Countries (OPEC) and was led by the Texas Railroad Commission, the Oklahoma Corporation Commission, and the Louisiana Conservation Commission. Although not sounding as threatening to Americans as OPEC, which includes two charter members of the current "Axis of Evil," this cartel performed the same function. It maintained the price of crude oil at a level high enough to sustain the petroleum industry, yet low enough to keep demand robust.

Throughout most of the 20th century the productive capacity of the United States sufficed to make up for any sud-

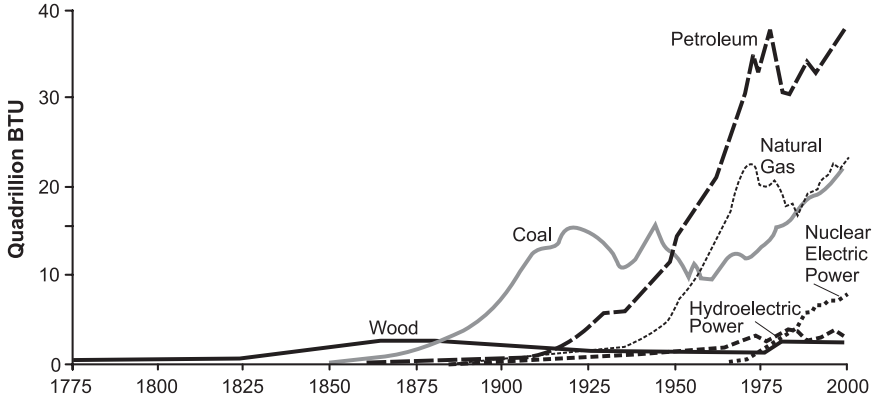

Figure 1. United States energy consumption by source, 1775–2000. From Energy Information Administration (2003).

den loss of imports. This permitted a balance of petroleum supply and demand that lasted through the early 1970s. The loss of some imports resulting from the 1967 war in the Middle East was the last major supply interruption to be overcome without a large increase in price. The shortage was made up largely by increased production in Ward and Winkler Counties in the Delaware Basin, authorized by the Texas Railroad Commission (Deffeyes, 2001). Similarly, in 2003, Saudi Arabia increased production to overcome U.S. shortages caused by strife in Venezuela. Because refineries are designed to process specific types of crude oil, this entailed the production of a crude (Arab Heavy) that matched the missing Venezuelan oil.

To reduce the negative effects from interrupted imports, the U.S. has stored about 550 million barrels of oil (MMBO) in the Strategic Petroleum Reserve. Storage is mostly in hollowed salt domes along the coast of the Gulf of Mexico. The reserve is meant to be a stopgap in the event of a major shortage; however, transporting large crude volumes from storage facilities to refineries has posed problems. In addition, the entire reserve represents only 52 days of petroleum imports, further reducing its effectiveness as a temporary source of supply.

The vulnerability of the U.S. to supply interruptions dramatically increased between the late 1950s, when excess capacity was about 4 million barrels per day (MMBOPD), and 1970, when this shrunk to 1 MMBOPD. The turning point came in March 1971 when, for the first time, Texas went to 100% allowable, placing all oil production in the country at 100% of capacity. Between 1967 and 1973, U.S. imports increased from 2.2 MMBOPD, or 19% of consumption, to 6.2 MMBOPD, or 36% of consumption (Fig. 2). That is why the 1967 embargo had no effect on supply, price, or consumption, but the embargo of 1973 (in the Yom Kippur War) led to drastically reduced supply and increased prices, and forced Americans for the first time to wait in line for gasoline. The Middle East war of 1973 disrupted the entire world economy by raising the price of a barrel of oil from $5.40 in October to $16 a month later (Yergin, 1992). This incremental price increase was followed by yet another in early 1979, when the Shah of Iran fell (Fig. 3).

For many decades the U.S. was by far the world's leading producer of oil, reaching its peak in 1970 (Fig. 4). Note: natural gas liquids are liquid hydrocarbons that condense from gas as it is produced and brought to atmospheric pressure; they are not added to the crude-oil volumes in Figure 4. Although Oklahoma's peak oil production came in the 1920s, it reached a lesser peak in the late 1960s, after which its production curve closely matches that of the United States as a whole (Boyd, 2002a). Both show a production drop in the early 1970s, a rise and secondary peak in the mid-1980s, and since then a nearly continuous decline.

In the international realm, Russian production has fallen from historic highs reached in the Soviet era, and Saudi Arabia—as the swing producer in OPEC—is believed to produce about 2.5 million barrels per day less than its capacity. As a result, in 2001 the U.S. was the world's leading producer of oil and natural gas liquids (Fig. 5; World Oil Magazine, 2002). However, the relative maturity of the U.S. oil industry is highlighted by the fact that its production in 2001 required more than 560,000 wells, while Saudi Arabia's production and much greater capacity required only 1,560 (Deffeyes, 2001).

WORLD NATURAL GAS: PAST AND PRESENT

Throughout much of history, natural gas was an enigma. Where it seeped from the subsurface it was sometimes ignited by lightning and became a burning spring—a phenomenon perceived as evidence of supernatural forces. Often springs became religious centers, a famous example being the spring associated with the Oracle of Delphi in ancient Greece.

Humans were slow to make practical use of natural gas, but about 500 B.C. the Chinese harnessed the potential of burning springs. Where gas seeped to the surface, they constructed crude pipelines of bamboo and transported the gas to locations where it could be burned to boil sea water. This

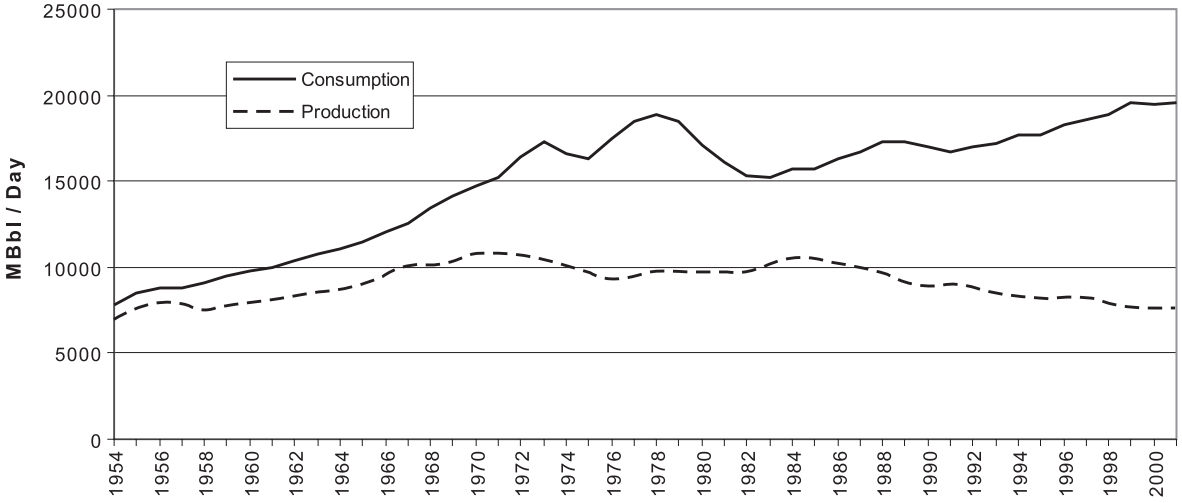

Figure 2. United States petroleum production vs. consumption, 1954–2001. From Energy Information Administration (2003).

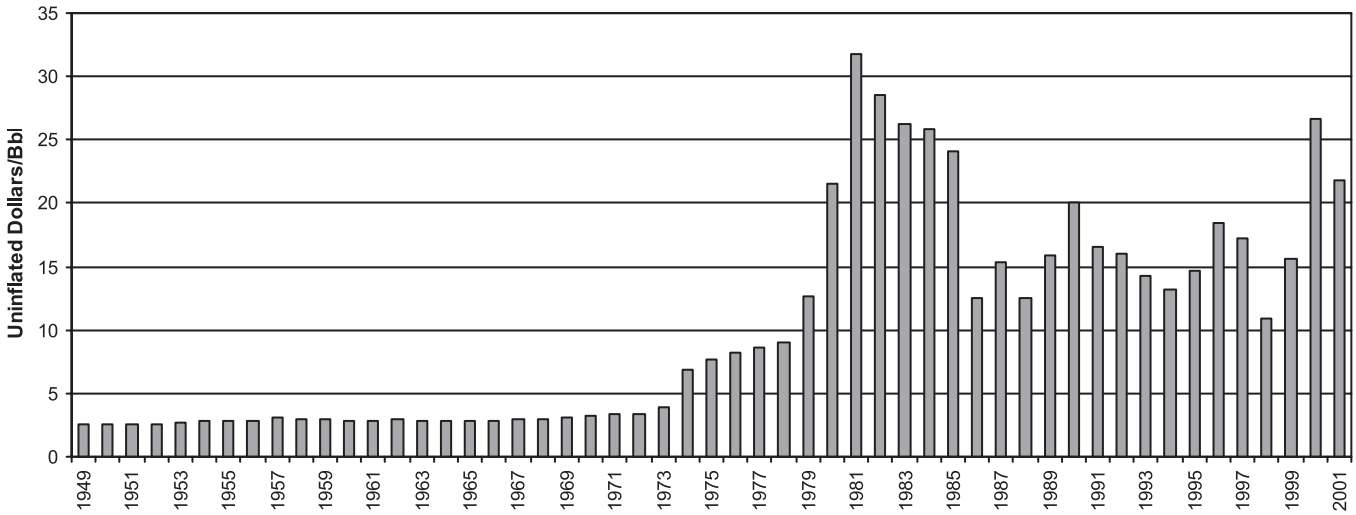

Figure 3. United States crude oil prices, 1949–2001. From Energy Information Administration (2003).

early distillation process removed salt from sea water, making it drinkable (NaturalGas.org, 2002).

Great Britain was the first country to commercialize use of natural gas, producing gas from coal in 1785 and using it for lighting. In North America, French explorers were the first to identify natural gas, observing natives in 1626 igniting seeps near Lake Erie. It was not until 1821 that the first well was dug with natural gas as the objective. In that year, William Hart (regarded by many as the father of natural gas in America) noticed gas bubbling to the surface of a creek at Fredonia, New York, and dug a 27-ft well to increase the flow (NaturalGas.org, 2002).

During most of the 19th century, natural gas was used almost exclusively for illumination in cities and businesses close to a source of supply. Demand remained low because, lacking pipelines, it was impossible to make gas widely available. Construction of large pipeline systems in the early 1900s led to a dramatic increase in demand. This led to the widespread home use of natural gas in heating and appliances, and its industrial use in manufacturing and processing plants (NaturalGas.org, 2002). Because gas is less expensive than oil as measured by equivalent heating capacity (or energy equivalence), it gradually replaced oil as a boiler fuel, and is now second only to coal in the generation of electricity.

Natural gas is found in conjunction with oil, and in the early days was usually considered a nuisance or a drilling hazard. Because gas had little value, when encountered it was commonly vented or flared until drillers determined whether oil was present in the reservoir below the gas (Boyd, 2002b). Difficulty of transport and the lack of local markets kept most early drilling focused on oil, and it was not until the late 1970s—with oil embargos, price deregulation, and the resulting increases in demand and price—that natural gas became a major exploration objective in many parts of the world.

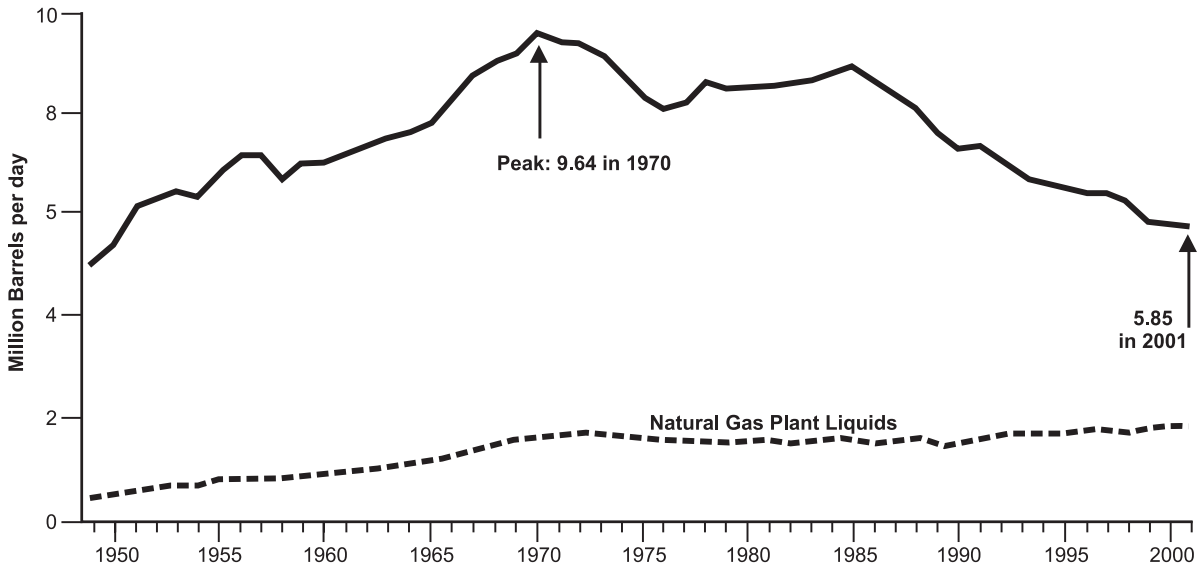

Figure 4. United States crude oil and natural gas liquids production, 1949–2001. From Energy Information Administration (2003).

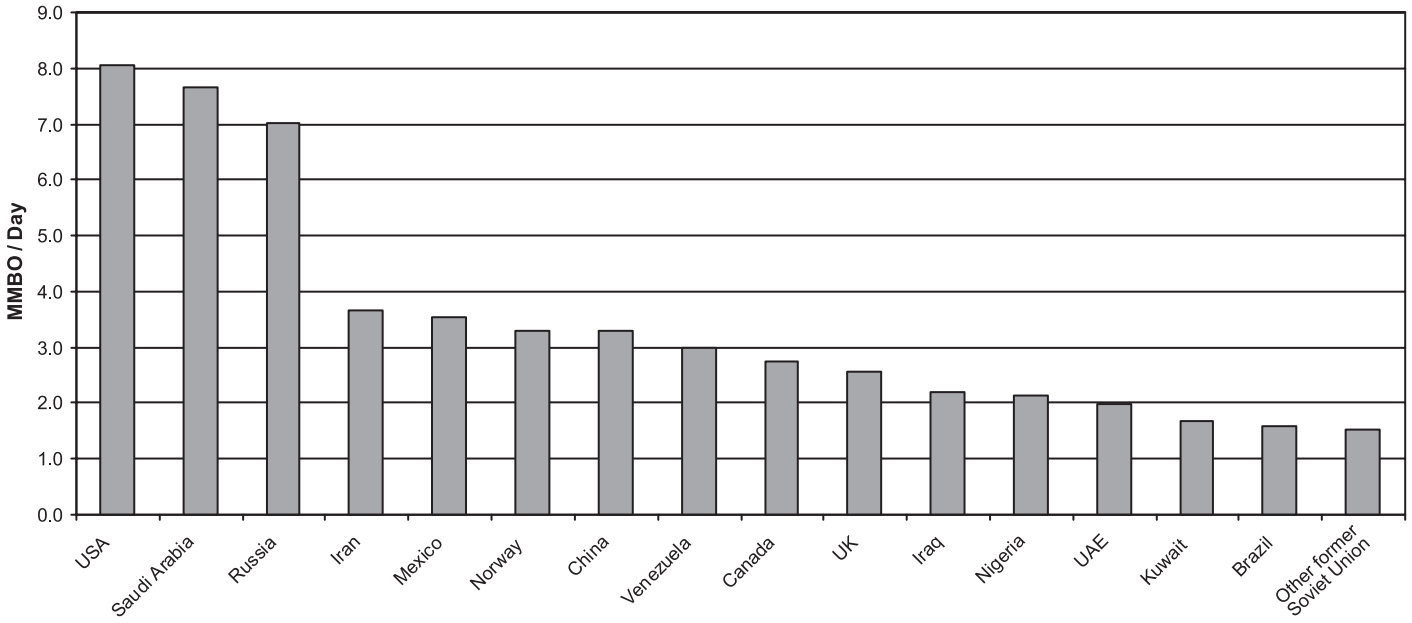

Figure 5. Daily national petroleum production (crude and natural gas liquids) for the top world producers. 2001 data from *World Oil*, from Energy Information Administration (2003).

In the same way that oil gradually supplanted coal in overall energy consumption, so natural gas began its rise to prominence 25–30 years later than oil. Although the uses of oil and gas differ, graphs of national consumption reveal parallel courses (Fig. 1), and with gas-price deregulation in the 1970s, the pattern is likely to continue. Deregulation has allowed the price to move with market demand; thus the correlation of oil and natural gas prices shown in Figures 3 and 6 (Boyd, 2002b). A similar parallel appears in graphs of U.S. production and consumption. Where the curves separate, imports begin rising rapidly. For oil the rise begins about 1967 (Fig. 2) and for gas 1986 (Fig. 7). Although it is not apparent in the figures, prior to 1958 the U.S. was a net gas exporter. The decline in production and consumption from 1972 through 1983 was due to rapid increases in gas price and the perception of a shortage, leading to government policies discouraging its use (U.S. Geological Survey, 2002).

The production of gas worldwide is—unlike oil—a function of access to a major market. Because the infrastructure for producing and transporting gas is expensive, long-term markets must be secured before development begins. If the market is overland, a pipeline system can be used to move the gas to market (for example, Russian gas exports to Europe via the Trans-Siberia Pipeline). If the market is overseas, the solution is usually shipment of liquefied natural gas (LNG) in the way that Indonesia supplies gas to Japan, South Korea, and Taiwan—from large LNG facilities in Sumatra and Kalimantan (Borneo). LNG is made by cooling natural gas until it liquifies. The supercooled liquid is then shipped in tankers that maintain the gas in a liquid state. Upon arrival at an offloading facility, the LNG is allowed to warm and revert to a gaseous state, whereupon it is sent via pipeline to consumers.

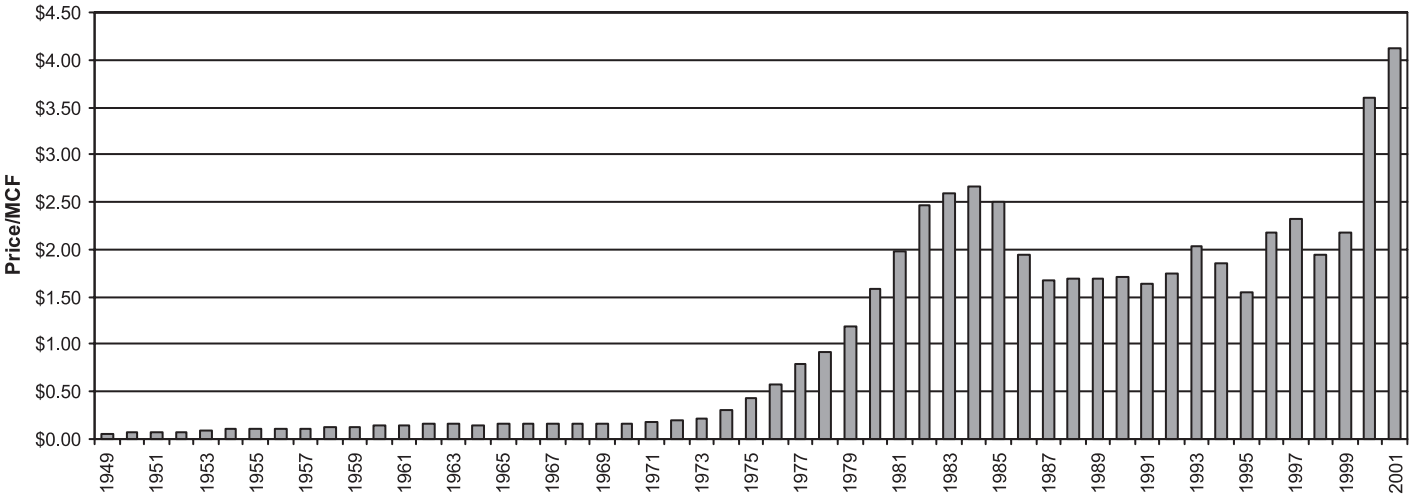

Figure 6. United States average wellhead natural gas price, 1949–2001. From Energy Information Administration (2003).

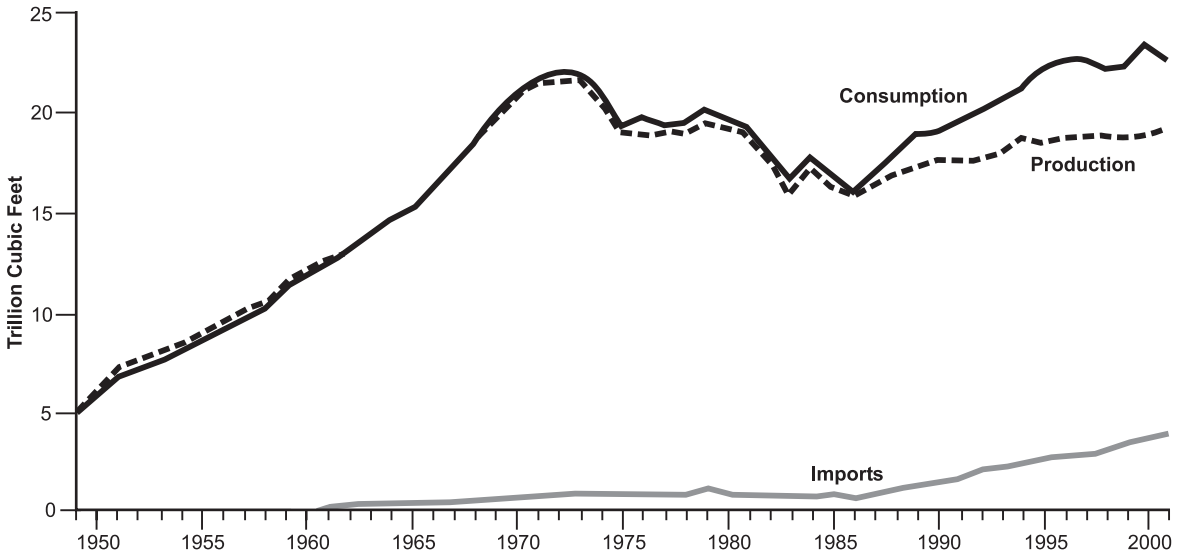

Figure 7. United States natural gas overview, 1949–2001. From Energy Information Administration (2003).

Because the up-front costs for both pipeline systems and LNG infrastructure are often measured in billions of dollars, the desire to insure that these investments are recouped is strong. To do so, a long-term gas market must be secured through contracts that are designed to protect both the buyer and seller. Under these the importer is committed to buy gas from the same facility for the life of the contract, but the price of the gas delivered is allowed to fluctuate with the market. (In most cases the gas price is based on a formula tied to the average world price of oil.) Because contracts are renewable and may span many years, large segments of the gas market are made unavailable to fields discovered in other areas. In addition, contracts are usually renewed until the seller no longer can meet demand, so the length of time that markets are dedicated is often measured in decades. Thus any gas inaccessible to existing gathering systems is stranded until additional demand justifies building another transportation system.

Countries that produced more than 2 trillion cubic feet (TCF) of gas in 1999 are shown in Figure 8 (Hinton, 2002). Russia and the U.S. continue to be the world's largest producers of natural gas. In Russia, gas development has paralleled both economic growth and the development of a large export market in Europe. In the U.S., where gas resources are smaller than in Russia, historically high demand has brought the development and production of gas much earlier than anywhere else. Gas production peaked in the U.S. in 1972 at 21.4 TCF (Fig. 7). Cumulative U.S. production is about 839 TCF (U.S. Geological Survey, 2002), of which Oklahoma has contributed 90 TCF, or 11% (Boyd, 2002b). Of the U.S. production total, about 64% was conventional, non-associated gas, 30% was gas associated with oil production, and about 6% was from non-conventional sources such as coalbed methane, shale gas, fractured reservoirs, and tight (low-permeability) reservoirs.

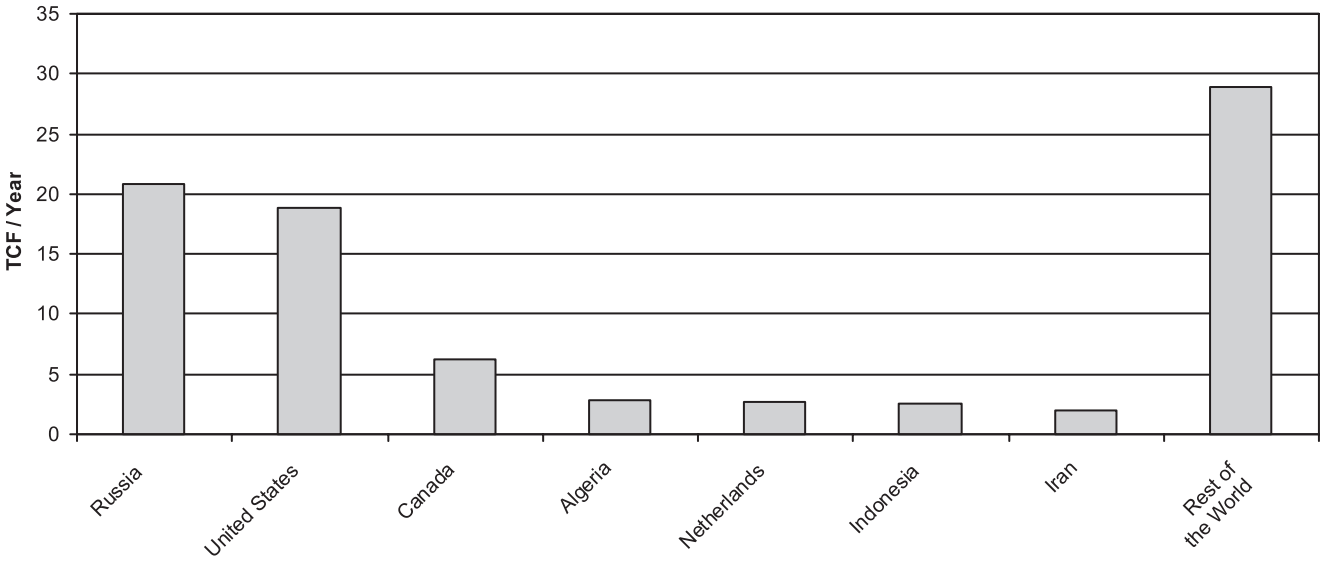

Figure 8. Countries producing >2 TCF of natural gas in 1999. From Energy Information Administration (2003).

THE OUTLOOK FOR OIL

Reserves

The most important variable in the analysis of any natural resource is proved reserves. For oil and gas, proved reserves are defined as the volume that geological and engineering data demonstrate, with reasonable certainty, to be recoverable from known reservoirs under existing economic and operating conditions. Their low technical and economic risk allows them to be assigned a monetary value. If reserves are divided by the annual rate of consumption (also known as the reserves to production or R/P ratio), one can estimate reserve life, which is the length of time that a given reserve volume can sustain the current rate of consumption (Boyd, 2002b). Reserve life is used as a yardstick in long-term planning, although it ignores future increases in demand resulting from economic growth.

It is convenient to categorize reserves by the world region in which they are found (Fig. 9). To clarify regional boundaries: (1) North America includes only Canada, the United States, and Mexico. (2) Asia/Oceania includes all countries east of Iran that are not former members of the U.S.S.R. (3) Greenland and Antarctica are assigned no reserves. The terms "developed country" and "developing country" refer to industrial development. In the broadest terms, developing countries are concentrated in the regions with the largest proved reserves of crude oil—the Middle East, Central and South America, and Africa. The industrialized countries are concentrated in North America, Western Europe, and Eastern Europe and the former U.S.S.R. Asia/Oceania comprises the developing economies of China, the Indian subcontinent, and Indonesia, as well as the industrial societies of Japan, South Korea, Australia, Taiwan, and Singapore.

Estimates of world oil reserves are relatively consistent. The value used here is the 2001 value of 1,028 billion barrels of oil (BBO), based on work by the *Oil and Gas Journal* (Fig. 10). As published by the Energy Information Association (EIA) of the U.S. Department of Energy (Hinton, 2001), it is very close to the value independently calculated by *World Oil Magazine* of 1,004 BBO for the same date, and is not far from a USGS estimate (based on 1996 data) of 891 BBO (U.S. Geological Survey, 2000). The similarity of these estimates reveals both a scarcity of the raw input data necessary to calculate reserves and a limited number of independent assessments for many of the countries involved. Note: oil's importance in the world economy has created conditions—in both developing and developed countries—in which political considerations commonly influence the size of reserve volumes reported.

As time passes, approximations of world oil reserves should converge. That does not mean that in a given economic environment there ever will be a precise and final estimate; rather, in a scheme in which 100 BBO has only a marginal effect, the range may be narrowing. The industry has matured, and the inventory of geologic basins that have been studied and explored has grown. In areas where exploration is allowed, the vast majority of promising basins have been evaluated. This is not to imply that they have been appraised to the level of many U.S. basins, but certainly large amounts of subsurface data have been acquired and the most promising areas have been drilled. Technology has advanced in the disciplines of well completion and evaluation, seismic acquisition and interpretation, and directional, horizontal, and deep-water drilling causing few prospective areas (in which drilling is permitted) to remain untested.

Because few frontier areas remain in the world, large future additions to reserves will be driven by technologies made economic through higher prices. One example is enhanced recovery operations in fields made after secondary (waterflood) recovery operations are completed. Another is in deep-water drilling (in more than 500 meters of water), where technological advances have made accessible large areas offshore. Deep-water discoveries account for an ever-increasing proportion of worldwide reserves, and have added roughly 21 BBO to the world total (Shirley, 2002b). In another realm, technological developments in producing oil from tar sands may greatly enhance proved reserves—as long as the long-term price of oil exceeds the cost of processing the tar. The tar sands in Canada (Athabasca) and Venezuela (Orinoco) will be the most important.

Except for the Middle East, the bulk of every region's reserves lie in one or two countries, each with at least 9 BBO of proved oil reserves. In North America, the U.S. and Mexico represent 91% of the region's total reserves; Venezuela contains 81% of the reserves in Central and South America; Norway, 54% of Western Europe; Russia, 83% of Eastern Europe and the former U.S.S.R.; Libya and Nigeria, 69% of Africa; and China, 55% of Asia/Oceania. In the Middle East, Saudi Arabia, Iraq, the United Arab Emirates (U.A.E.), Kuwait, and Iran each have at least 90 BBO reserves, and together account for 96% of the region's total. To complete the list of countries with more than 9 BBO of reserves, and to underscore the concentration of oil in the Middle East, the tiny nation of Qatar has reserves of 13.2 BBO. Qatar, whose land area is roughly the size of Connecticut, has reserves equal to 60% of the volume for the entire U.S.

One indication of disparity in the distribution of oil reserves around the globe is the two-tier system used by the American Association of Petroleum Geologists to classify fields as giants. In the Middle East, North Africa, and Asian Russia, a field must have an ultimate recovery of at least 500 MMB of oil or 3 TCF of gas to be considered a giant. For the rest of the world this hurdle drops to 100 MMB of oil or 1 TCF of gas (Fitzgerald, 1980). By the latter measure, Oklahoma has 26 oil fields (Boyd, 2002a) and 11 gas fields (Boyd, 2002b) classified as giants.

As one might expect, most of the world's future reserve additions probably will come from the areas with the bulk of today's proved reserves. Although analysts agree that OPEC countries still are the most promising areas for new reserves, some official estimates may be overstated, as member state's production quotas are determined in part by proved reserves. OPEC reserve estimates have risen dramatically in recent years, based largely on the expectation of higher recovery rates in existing fields. However, to be produced, much of these reserves will require huge capital investment (Sandrea, 2002).

Reserves are the part of a resource base (the total known supply) that is economically recoverable. As exploration around the world continues, the proportion of the resource

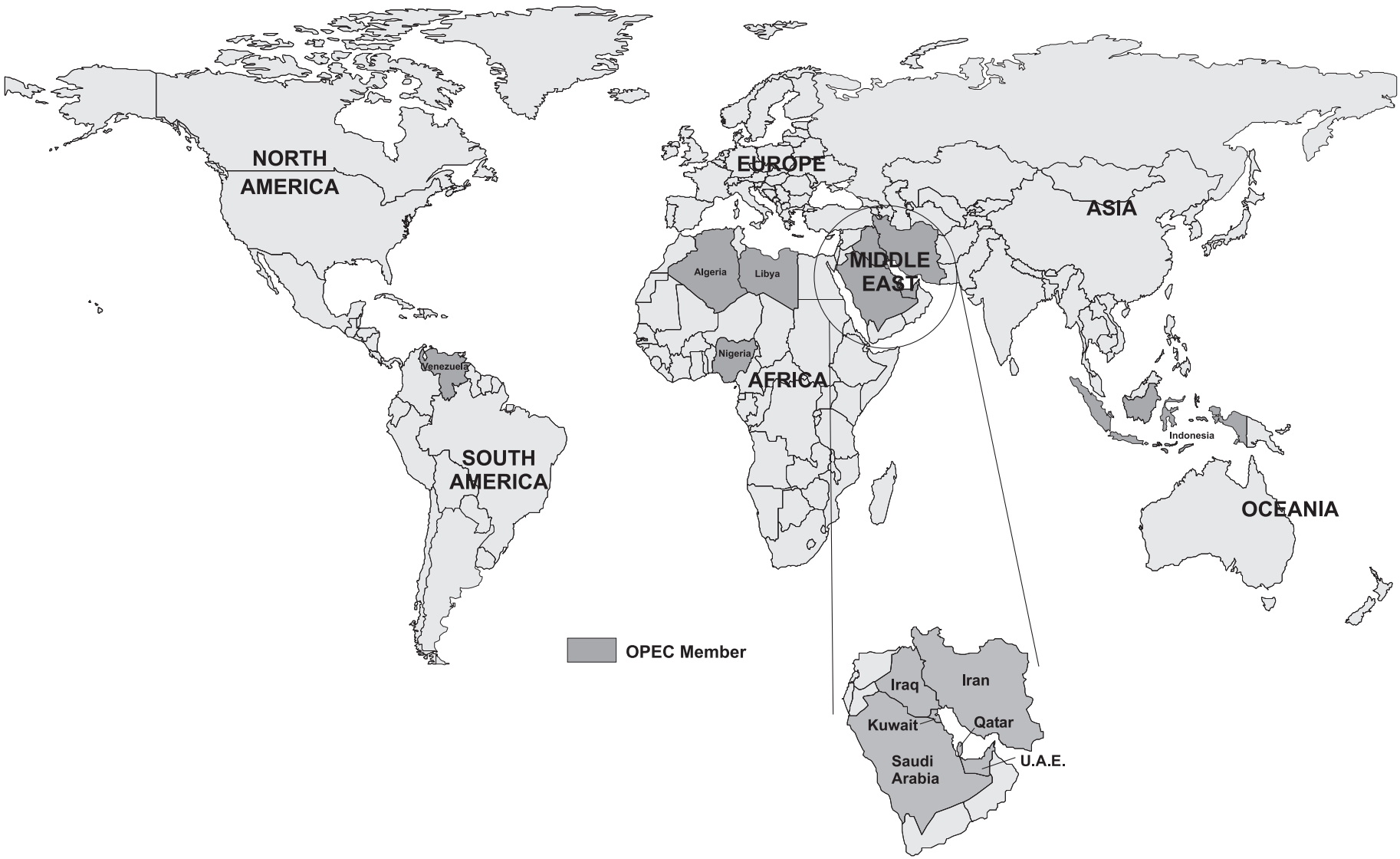

Figure 9. Map of world regions showing OPEC member states.

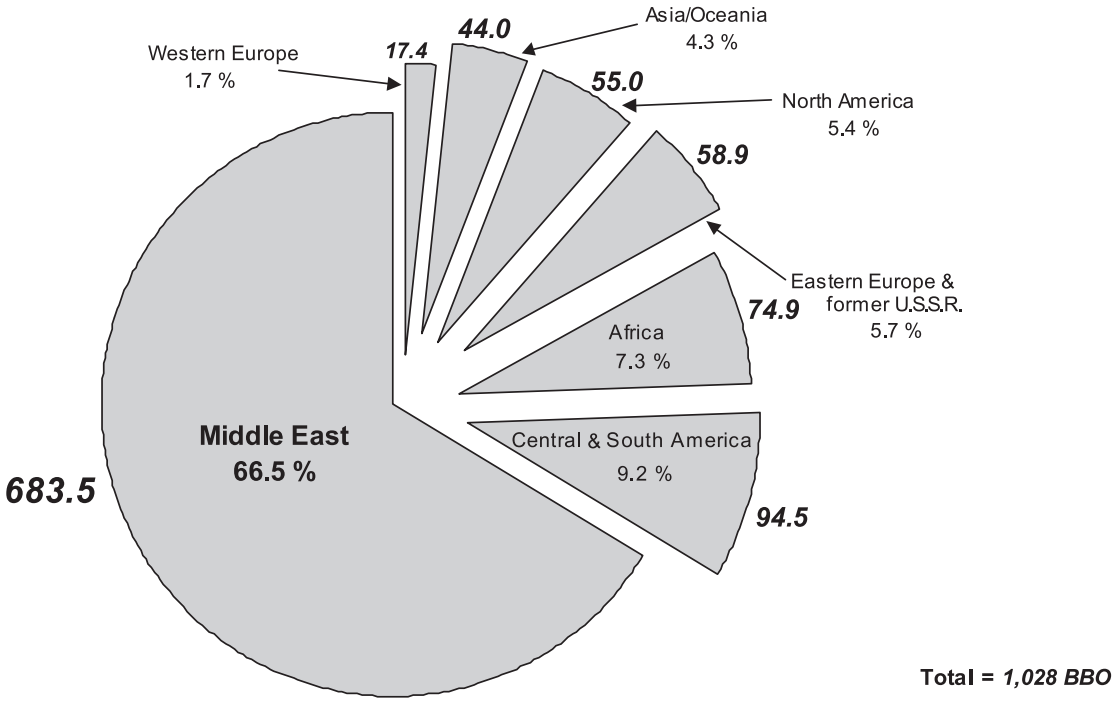

Figure 10. Proved oil reserves by world region (January 2001). Data from *Oil and Gas Journal*, from Energy Information Administration (2003).

base expected to be ultimately producible has grown. Historical reserve trends, advances in technology, and an ever-increasing volume of geological data have all been used to predict the size of additions to world reserves. Because these projected volumes are far less constrained than proved reserves, estimates can vary markedly. In order to avoid the problem of reserve volumes shifting categories through time (future reserves becoming proved reserves, and proved reserves being produced and becoming cumulative production), it is common to speak in terms of petroleum endowments. An endowment is the sum of all three categories (cumulative production, proved reserves, and future reserves) and is meant to represent the ultimate volume that will ever be produced.

Estimates of the world petroleum endowment range from about 1.8 trillion barrels of oil (Campbell, 1997) to 3.0 TBO (U.S. Geological Survey, 2000), with values clustering around 2.1 TBO (Deffeyes, 2001). Such calculations are not academic. The production curve for any large area tends to follow a bell-like shape, the peak of which can be determined, given enough historical data, based on ultimate recovery. Because much of the world's endowment has been produced, a realistic estimate of ultimate recovery should enable us to estimate a plausible date at which peak production will be reached. Because the world economy is based largely on petroleum, this prediction is very useful, as it marks the transition from a buyer's market to a seller's market.

Consumption

Consider the world's approximately one trillion barrels of remaining proved oil reserves in light of annual consumption, which an EIA assessment for the year 2000 places at about 28 BBO (Fig. 11). Most consumption is by industrialized countries that, as a result of early and rapid domestic production of oil, now find themselves at the bottom of the list in terms of reserves (Fig. 10). The world's top consumers of crude oil are the U.S., Japan, China, Germany, and Russia (Fig. 12; data begin in 1992 because no earlier statistics for Russia are available.)

U.S. consumption, at nearly 20 MMBO per day, is greater than that of the next six countries. The price shocks that began in 1979 reduced U.S. petroleum consumption below the peak reached in 1978 (Fig. 2). However, higher energy costs were absorbed by the economy, and demand began recovering in 1983. Except for minor, short-term declines, demand for oil in the U.S. has increased continuously. Nor does oil stand alone at the peak; nearly every other major energy source (natural gas, coal, nuclear energy, and hydropower) including wood is now used at record levels in the U.S. and the rest of the world (Fig. 1).

If one divides a proved reserve volume of 1,028 BBO by annual consumption of 28 BBO, one finds that reserves can sustain consumption at the current rate for about 37 years. This statistic is useful, but potentially misleading because it rests on many assumptions. It assumes no change in world demand (either up or down), although in the U.S., despite an ailing economy, demand has risen about 14% in the last 10 years. It presupposes that the petroleum industry will produce the remaining reserves as rapidly as those already produced. It also takes for granted that the proved reserve volume will remain static, though long-term revisions of worldwide reserves have always risen (but usually not enough to replace consumption). Finally, it assumes that all reserves (and the equipment necessary to produce them) will be continuously available to support demand—but think of recent news from Nigeria, Venezuela, and Iraq.

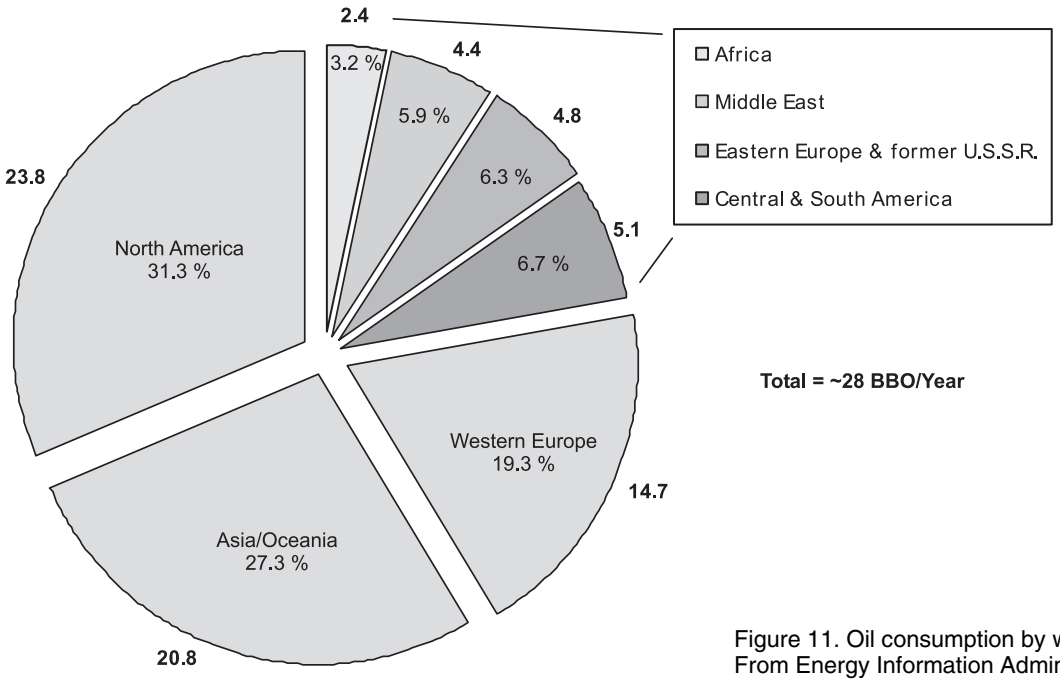

Figure 11. Oil consumption by world region (2000). From Energy Information Administration (2003).

Around the globe, as in the U.S., demand for energy is increasing continuously. Until recently this growth was confined almost exclusively to more developed and less populated regions. Now, industrialization has enlarged the proportion of world oil consumed in developing countries. Take China and India: their combined consumption in 2000 was a third that of the U.S.—but they had eight times the population. The point is not that our per capita use of energy is 24 times that of China and India; it is that in the last 10 years, while U.S. consumption was rising 14%, consumption in China and India rose 84% (Energy Information Administration, 2003). Their 2.2 billion people make up more than one third of the population of the planet. Although the developing world will never match per capita U.S. consumption, progressive industrialization will continue to push their energy demand higher.

The only factor that affects long-term oil consumption is price. Interruptions in supply are responsible for most major price increases, and, as a result, also the major drops in consumption. (These major supply interruptions are distinguished from those that are designed solely to keep oil within a price window that producers see as desirable.) Because the developed world has (by definition) an industrialized economy and the corresponding history of energy de-

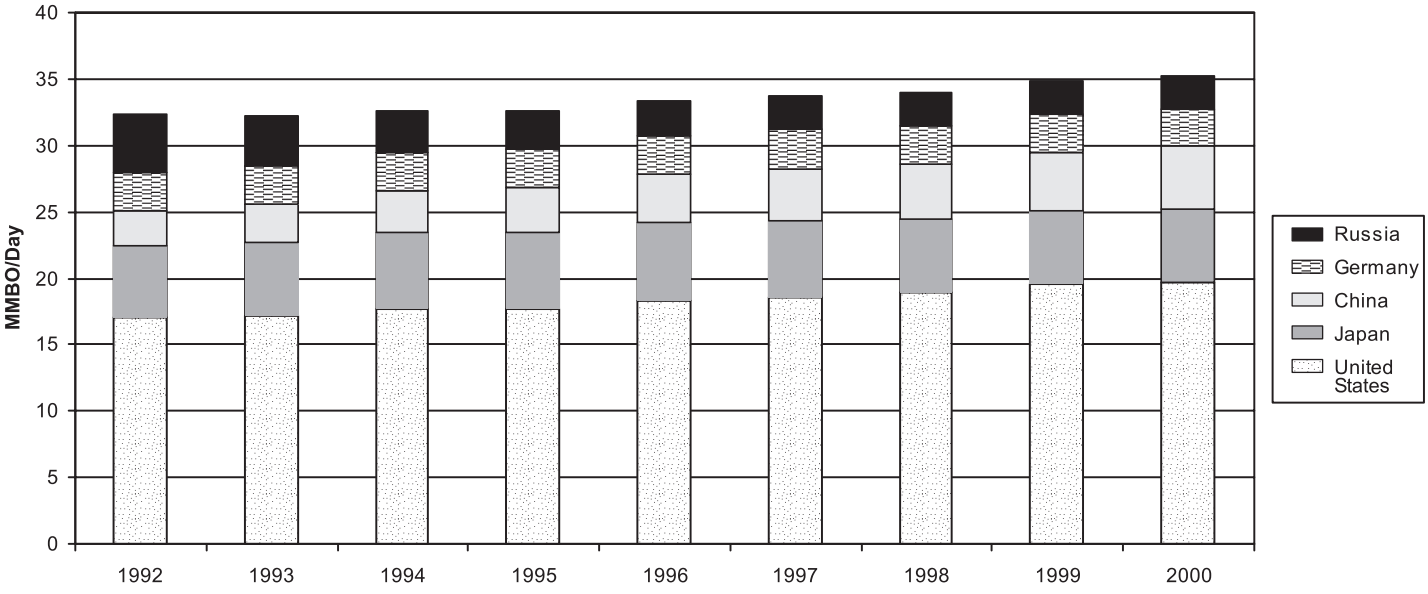

Figure 12. Countries consuming >2.5 MMBOPD (2000). From Energy Information Administration (2003).

mand, it has already produced the bulk of its oil reserves. As a result, an increasingly higher proportion of the remaining reserves reside in countries that have been slower to develop modern economies and the commodities that fuel them. Many developing countries are subject to all manner of internal and external disturbances that can disrupt their ability to produce oil. The world's excess production capacity is smaller than ever, so meeting today's demand requires sustained production from all major producers. In a precariously balanced market, a real or threatened interruption of supply anywhere inevitably leads to higher prices for everyone.

Production

World oil production, except in the Middle East, is about equally divided among the seven world regions (Fig. 13). Their shares vary from about 9 to 16%, with the Middle East accounting for roughly a third of the world total. However, this analysis understates the leverage that Middle Eastern oil production exerts on the world market. North America, Asia/Oceania, and Western Europe use all of their own oil and import large volumes of crude. Eastern Europe and the former U.S.S.R., and Central and South America, produce significant amounts of oil, but they use most of it themselves. Thus Africa and the Middle East, with their tiny share of the consumption pie, remain the largest exporters of crude oil. The Middle East produces three times as much oil as Africa, and also contains most of the world's remaining excess productive capacity. This explains the enormous influence that news from this region has on world energy markets. The situation is unlikely to change, because in addition to proved reserves, projected future oil reserves are also concentrated in the Middle East.

In almost every petroleum province the distribution of field size is asymmetrical, with the larger and easier-to-find fields making up a disproportionate share of total production and reserves. Oklahoma follows the worldwide trend with 5% of the fields responsible for about 83% of the State's oil production and reserves (Boyd, 2002a). Because most of the largest fields are found early in the life of a petroleum province, initial production in a given region tends to increase rapidly. This increase continues until the first of the large fields peak and begin to decline. Early discovery of most of Oklahoma's largest fields led to the State's production peak in 1927 (Boyd, 2002a). If the decline in big fields cannot be overcome by production from later discoveries (which must be large to have much impact), the overall production curve begins to decline. Because even small percentage declines in large fields are large volumes, as more fields mature the overall effect snowballs. As average discovery sizes become progressively smaller, even concerted drilling programs usually can only reduce the rate of decline. Secondary and enhanced recovery operations combined with many smaller discoveries can extend the length of time that high production rates are maintained, which often leads to lesser, intermediate peaks. However, by this stage only the rate of the long-term decline can be affected.

The sequence just described creates a production curve conforming to a general bell-shape. Such a curve is seldom symmetrical, for peaks vary in duration, and intermediate highs are sometimes quite large. Lesser peaks may be caused by price fluctuations resulting from wars, embargoes, economic booms and busts, or anything that affects supply or demand. The opening of new areas to exploration late in the productive life of a given region also can generate bumps in the overall production curve. Such events can magnify intermediate highs, and if the timing is right they can extend the period of maximum production.

An example of both effects may be found in the U.S. oil production curve. It peaked in 1970, but production from the Prudhoe Bay Field and a nationwide drilling boom enabled it to stay near its maximum through the mid-1980s. (Note that Figure 14 shows only crude oil and not liquids derived from natural gas production, which do appear in Figure 5.) If production from Alaska is omitted, the 1970 peak is far more pronounced and the curve becomes far more bell-shaped.

Prudhoe Bay Field, the last supergiant (>10 BBO) found in North America, is the largest field in the U.S. Before the field's 1968 discovery the North Slope of Alaska had been drilled only sparsely. Its recognition was greatly facilitated by the use of early reflection seismology (Jamison, 1980).

Although the effect is not as dramatic, in recent years the decline in national production has been noticeably slowed by the addition of oil from deep-water fields in the Gulf of Mexico. Much of the oil in the Gulf had been out of industry's reach until new drilling technology enabled drilling in water depths of several thousand feet. This development has brought essentially all prospective offshore areas within reach of the drill bit.

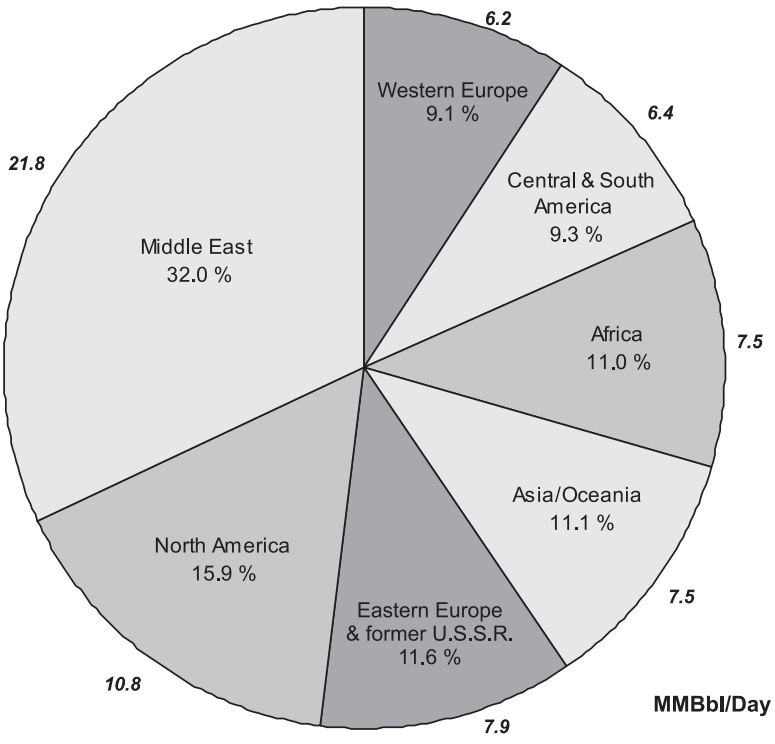

Figure 13. Oil production by world region (2000). From Energy Information Administration (2003).

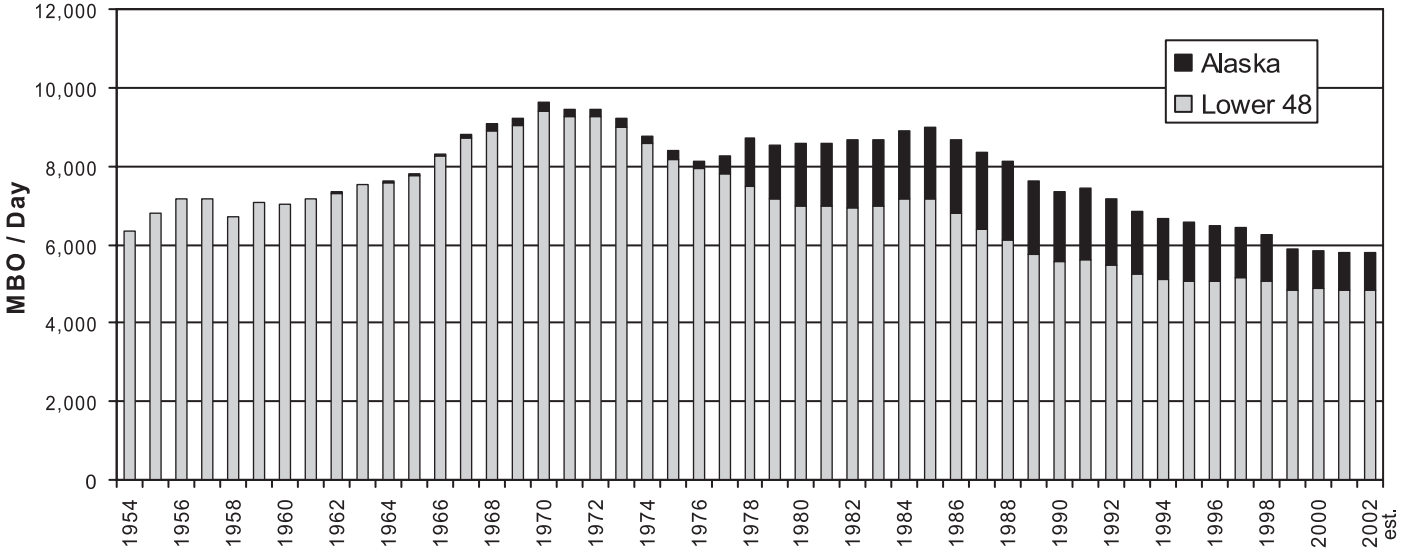

Figure 14. United States crude oil production, 1954–2002. From Energy Information Administration (2003).

Giant fields like Prudhoe Bay hold not only reserves, but also most of the world's capacity for oil production. The world has 583 giants (defined as having at least 500 MMBO of reserves plus production). The giants constitute 0.1% of all fields, but account for roughly 85% of global reserves (Fitzgerald, 1980). Not surprisingly, most of the largest oil giants were found early and have been producing for decades. Their increasing age is demonstrated by production rates: in 1986, 15 of the giants could produce more than 1 MMBO per day, but now only four can make this rate. The survivors are Ghawar in Saudi Arabia, Kirkuk in Iraq, Burgan in Kuwait, and Cantarell in Mexico (Petzet, 2001). Many other major producing fields are declining or soon will be, even in the Middle East. Two of Iran's four largest fields are in secondary recovery, and the U.A.E.'s two largest fields are about to begin secondary recovery operations. OPEC's overall peak production capacity of 40 MMBO per day was reached in the mid-1970s, when the largest fields were still young. Although massive spending on infrastructure could increase OPEC production, old highs are unlikely to be matched (Bakhtiari, 2002).

For Oklahoma and the U.S. as a whole, nothing can return production to historic highs. Oklahoma is 75% (573 MBO per day) below its peak rate, and the U.S. is down by 40% (4 MMBO per day). Although the declines in both have flattened in recent years, as a result of higher prices, their long-term slides continue (Boyd, 2002a). The U.S., unlike Oklahoma, has many promising areas off limits to exploration. They include the Arctic National Wildlife Refuge on the North Slope, the eastern Gulf of Mexico, offshore areas along the entire East Coast and most of the West Coast, and areas in the Rocky Mountains. However, even if all of these were opened today production still could not approach previous highs.

North Slope production remains by far the most important to be found in the U.S. in decades. At their peak, Prudhoe Bay and its satellite fields represented 25% of the national output and even now about 17% (Fig. 14). Without the North Slope, U.S. imports today would account for about 75% of consumption. Although Prudhoe Bay production peaked at about 2 MMBO per day, that was 20 years after the discovery well was drilled. The decline for Prudhoe Bay and its satellites alone in the next 20 years is estimated at 400 to 700 MBO per day (Energy Information Administration, 2001). Adding the concurrent loss in production that is expected in the rest of the country during the same period (2.0–3.5 MMB per day) makes apparent the difficulty in just maintaining today's production level. Even in the most optimistic outlook, the American "snowball" has gathered far too much momentum to ever be pushed back to the top of the hill.

Over a century of world oil production, and the realization that production graphs (in statistically large samples) tend to yield a bell curve, makes possible certain predictions. These include broad estimates of the peak production rate and when this peak will occur. Critical variables include ultimate recovery and the precise shape of the curve. In a given area production inclines and declines are often irregular and may be steep or gradual on either side of the peak. Economic factors and the addition of new sources of supply can affect the duration of production peaks (Fig. 14).

If the curve used to predict the peak of world oil production is roughly symmetrical and encompasses an ultimate recovery of about 1.8 TBO, the world could reach the peak this year, in 2003. Clearly we have not yet reached the peak, for although OPEC production capacity is kept secret most analysts believe that excess production capacity for the world is still 4 to 5 MMB per day (Toal, 2002). However, with current daily consumption at 76 MMBO and this increasing to more than 118 MMBO per day by 2020 (Energy Information Administration, 2003), it is clear that we are working with little cushion. The low level of excess capacity explains why even a small, brief interruption of supply can have a major impact on price.

If the ultimate recovery volume is increased by 300 BBO (or about half the cumulative production to date) to 2.1 TBO,

world production should peak between 2005 and 2009 at an annual consumption rate of about 31 BBO (Fig. 15; Deffeyes, 2001). This is believed to be more realistic, and would show about 34% of the world's petroleum endowment as cumulative production, 42% as proved reserves, and 24% as future reserve growth. Different scenarios for reserve growth, discovery, infrastructure, and pricing could end with different dates and durations for peak production. However, even moderate economic growth leads to increases in world oil demand of 1–2 MMBO per day per year. So if the world's excess capacity is truly 4–5 MMBO per day, the supply-demand curves could easily cross in this decade.

An estimate by the U.S. Geological Survey (2000), of more than 3.0 TBO of ultimate recovery, has been used as evidence that peak oil production will not be seen for decades. However, this estimate is roughly 1 TBO higher than most others and requires a doubling of the current proved world oil reserves (Fig. 10). Some of this oil could come through improved recoveries in existing fields. However, most of it must come as a result of new discoveries. The discovery of so much economically producible oil so late in the life of worldwide oil exploration contradicts experience. Huge, prospective, and hitherto unexplored regions would have to be opened. Some areas of the world do remain sparsely explored, but unrealistic success rates also must be invoked in order to find the equivalent of 100 Prudhoe Bay fields. The worldwide field-size distribution (where $^{1}/_{1000}^{th}$ of the fields represent 85% of reserves) and the trend in oil discovery size make it unlikely that ultimate recovery can be increased by a trillion barrels.

For reserves to significantly affect the date at which world oil production peaks, they must be found in large fields in reservoirs where high production rates can be established in the next few years. If they occur, for instance, in comparatively small pools in deep water, beneath Antarctic ice, or in low-permeability reservoirs that require intensive drilling to attain high production rates, they will not affect the point when demand exceeds supply. To delay the world's production peak much beyond the 2 to 6 years estimated requires bringing into production, every year, the equivalent of at least one field delivering 1–2 MMBO per day. Although nonconventional resources like tar sands and oil shale occur in very large volumes, they cannot approach such yields, and certainly not any time soon.

When demand is forced to match supply, the extreme price lows that prove ruinous to low-rate oil production (a situation dominant in Oklahoma) should become a thing of the past. Although volatility in price will undoubtedly persist, the lows will be higher than those of the recent past. Higher average prices will permit the use of new, more expensive recovery techniques in producing fields and will open to the world market some smaller accumulations now stranded by transportation costs. Exploration could become economic in less-hospitable environments, perhaps even in Greenland and the Antarctic. Many enhanced recovery projects with large up-front costs, which have been on hold for fear of prolonged periods of low prices, could become economically viable.

Higher oil prices also could make possible large-scale investment in extraction of oil from tar sands, in which potential reserves are huge but production and environmental costs are high. Processing tar sands requires great amounts of water as well as the disposal of up to 10 tons of solid waste per ton of oil produced (Energy Information Administration, 2002). Tar sands such as the Athabasca (in Alberta) and Orinoco (in Venezuela), although huge resources, will probably have little effect on when maximum world oil production will be reached. Their main value, like other sources that become economic in a high-cost environment, will be in providing a large (if expensive) source of petroleum for long-term demand.

The key point is that (transportation costs aside) similar types of oil sell for essentially the same price anywhere in the world, regardless of the political compatibility of buyer and seller. In this age of instant communication, the global market ensures that oil will be sold only to those who pay the going rate. When supply can no longer meet demand, prices will rise sharply until demand falls to a level that can be sup-

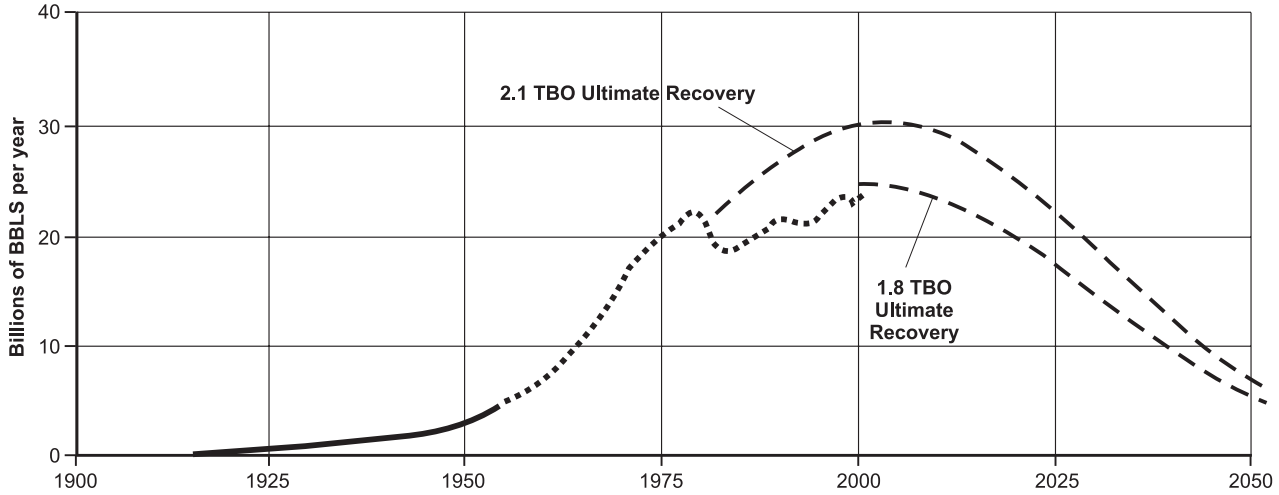

Figure 15. World oil production through 2000 (heavy dots) showing projected production through 2050 (dashed lines) for two possible ultimate recoveries. From Deffeyes (2001).

ported, usually through conservation and fuel switching. This relationship between supply and demand ensures that the world will never "run out" of oil.

THE OUTLOOK FOR NATURAL GAS

Reserves

There are many reasons to be optimistic about the long-term outlook for natural gas. Among them: (1) Gas remains a secondary target in many parts of the world, so it is comparatively under-explored. (2) When discovered in an area with no gas market, delineation wells (follow-up wells, to determine the size of the field) usually are not drilled, making reserve estimates cursory, and typically conservative. (3) If lacking a near-term market, an entire basin that is viewed as gas-prone may receive little attention from industry. (4) Gas can exist in deeper reservoirs than oil, and be produced from strata with much lower permeability than oil (Boyd, 2002b). (5) Many areas intensively drilled for oil have not been completely evaluated for deeper gas potential. (6) Non-conventional sources of natural gas, like gas hydrates, coalbed methane, and various types of low-permeability reservoirs, have huge resource potential; for them, even small changes in recovery estimates have a large impact on reserves. (7) In many areas of the world with large conventional gas reserves, little effort has been made to evaluate non-conventional resources.

Like oil, the world's proved reserves of natural gas are distributed unevenly (Fig. 16); Eastern Europe and the former U.S.S.R. and the Middle East contain nearly three-quarters of the world's proved reserves. On a national reserve basis, Russia has a large lead, but four of the top seven countries are in the Middle East (Fig. 17). A single huge accumulation in Qatar (the North Field) gives that tiny nation roughly three times the proved reserves of the U.S.

In the period from January 2000 to September 2002, according to IHS Energy (2002), 28 giant discoveries were made worldwide, with estimated reserves of more than 500 million barrels of oil equivalent (MMBOE). For gas, this is a reserve volume of at least 3 TCF (Fitzgerald, 1980). Two-thirds of these discoveries were gas, with all but one of the giant oil discoveries having a significant gas component. During the same period in North America, mirroring Oklahoma in recent years (Boyd, 2002b), 1,180 new fields were discovered. Most were small, but fully three-quarters were gas or coalbed methane (IHS Energy, 2002), indicating that industry's focus in North America has shifted strongly to natural gas. In the rest of the world, although oil may still be the primary objective, it is gas that is being found in the largest quantities.

Future additions to global reserves also are strongly skewed towards Eastern Europe and the former U.S.S.R. and the Middle East. Although the Northwest Shelf of Australia and offshore Norway hold promise, most new reserves are expected to come from Russia (Siberia, Barents, and Kara Sea) and the Middle East around the Persian Gulf (Ahlbrandt, 2002). These area's large conventional gas reserves have reduced the incentive to assess non-conventional resources, which are harder to produce and will not be needed for 60–100 years.

In North America, most easily produced gas already has been found, and large volumes of harder to produce gas are necessary to meet demand. Except for the many areas off limits to exploration, all possible sources of natural gas are being evaluated. Non-conventional sources such as coalbed methane and low-permeability reservoirs constitute a substantial part of both the resource base and daily production. For North America the resource volume of technically recoverable gas (proved reserves plus conventional and non-conventional resources) has been estimated at 2,500 TCF (Energy Information Administration, 2003).

Studies made in 1995–2001 of gas remaining in the U.S. (by private and federal organizations) project an average recoverable resource of 1,549 TCF—about nine times current

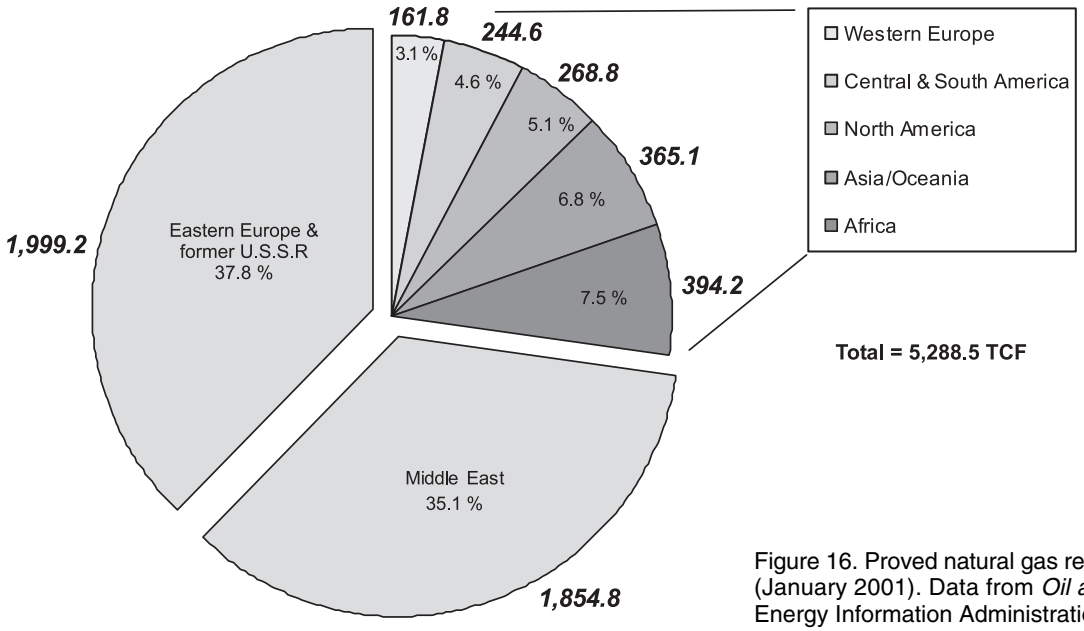

Figure 16. Proved natural gas reserves by world region (January 2001). Data from *Oil and Gas Journal*, from Energy Information Administration (2003).

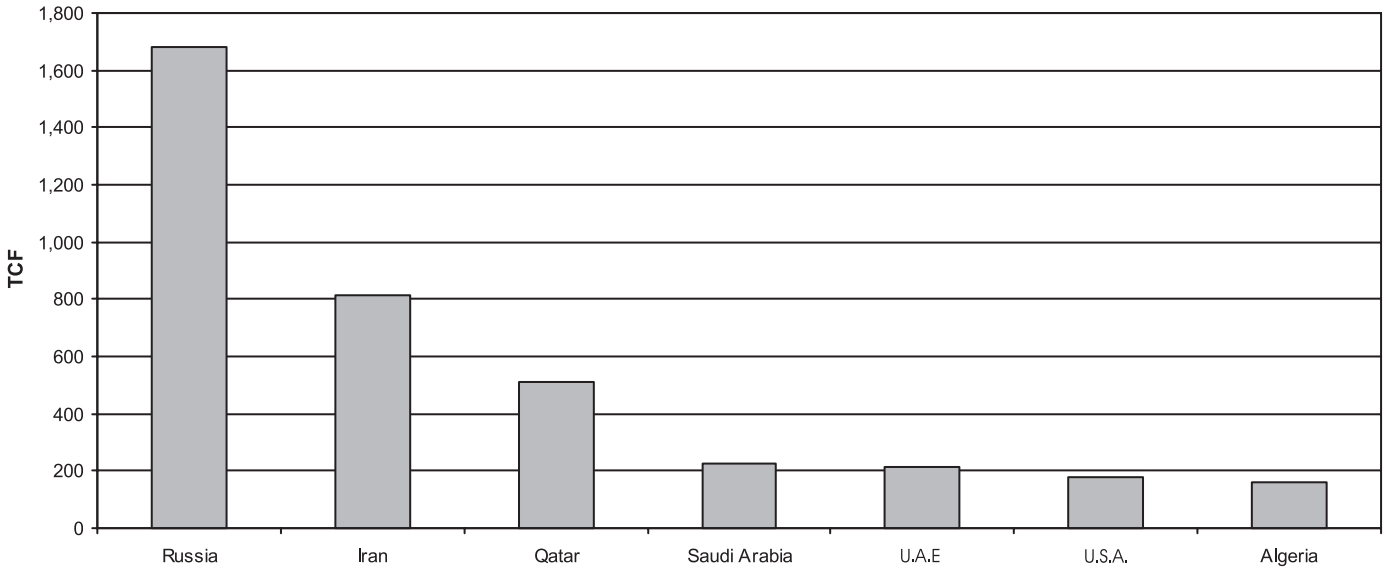

Figure 17. Proved natural gas reserves by nation (January 2002). Data from *Oil and Gas Journal*, from Energy Information Administration (2003).

proved reserves. This suggests that our reserve base can be greatly increased. The projected volume (assuming these resources all become reserves) amounts to a 67-year supply at the current rate of consumption. Non-conventional gas is a substantial component of the nation's resource base, so incremental improvements here could lead to large increases in reserves. For example, estimates of technically recoverable coalbed methane average 70 TCF, and for tight gas sands, 275 TCF. Although the non-conventional resource types are defined and assessed in different ways, and estimates vary considerably, the volume of potentially recoverable gas is clearly large (Curtis, 2002).

Proved gas reserves in the U.S. have remained fairly steady, averaging about 183 TCF over the last 25 years (Energy Information Administration, 2003), a volume equivalent to 8 years of current consumption. Year-end 2001 U.S. reserves were 183.5 TCF, but our ability to keep pace with production has not resulted from the discovery of large gas fields; in 2001, discoveries accounted for only 16% of additions to U.S. gas reserves. Most additions come from the expansion of old fields and upward revisions in recovery factors. Increasingly, additions are coming from non-conventional sources such as coalbed methane, tight gas, deep gas (>15,000 feet depth), shale gas, and offshore gas from deep water. These account for about 20% of U.S. reserves now, and this share is expected to grow to 50% by 2020. The coalbed methane component of gas reserves has grown since 1989 from less than 4 TCF to 18 TCF, or roughly 10% of total reserves (Energy Information Administration, 2003). In the Midcontinent (including Oklahoma) reserves are 16.9 TCF of recoverable tight gas, 5.8 TCF of coalbed methane, and 17.7 TCF of deep gas, mostly in the Anadarko Basin (Shirley, 2002a).

For gas, as for oil, endowments are the sum of cumulative production, proved reserves, and future reserves. They are meant to represent the ultimate volume of gas that will ever be produced and do not distinguish between associated and non-associated or conventional and non-conventional (Boyd, 2002b).

The USGS estimate of the world's natural gas endowment for the year 2000 is 15.4 quadrillion cubic feet (QCF), or 15,400 TCF. Of that endowment, 11% (~1,700 TCF) has been produced; 31% (~5,000 TCF) is proved reserves, and 58% (8,900 TCF) are reserves yet to be found. The volumes are huge, but in most parts of the world they include only conventional gas resources. Because this estimate could not include analyses for all prospective sedimentary basins, most consider the assessment conservative, despite its size (Ahlbrandt, 2002). In the last 20 years, as average prices have remained steady in real terms, consensus estimates of the world's remaining natural gas reserves have increased tenfold (Fisher, 2002), and discoveries and development show that this trend is likely to continue.

Any discussion of natural gas resources must include gas hydrates (also called methane hydrates). Hydrates are an enormous—but still uneconomic—non-conventional source of natural gas. They are solid, crystalline, ice-like substances composed of water, methane, and small amounts of other gases trapped in a water-ice lattice. Hydrates, which form at moderately high pressure at temperatures near the freezing point of water, are found in permafrost regions onshore and in ocean-bottom sediments in water depths below 450 meters (~1,500 feet). Some offshore hydrate deposits are exposed on the ocean bottom, but most are found in sediment beneath the seafloor. A growing body of evidence suggests that natural releases of methane from hydrates in the geological past have had major effects on the Earth's climate. How hydrate releases occur is not understood, but their production as an energy source could mitigate a long-term environmental hazard (Morehouse, 2001).

The volume of methane locked in natural gas hydrates around the world is staggering. Estimates vary widely, reflecting the early stage of research, but range from 35 QCF to >61,000 QCF. Compare these numbers to a resource esti-

mate of 15.4 QCF for gas worldwide, and reserves of about 5.3 QCF. In terms of oil equivalence, Lubick (2002) estimates that worldwide methane hydrate resources total 137.5 TBOE (825 QCF), a volume that dwarfs a 2.1 TBO petroleum endowment. Although gas hydrate volumes are colossal, the percentage that may be economically recoverable is unknown and could be very small. No technology is available for making hydrates a practical fuel. However, in the U.S. alone, the gas hydrate resource has been estimated at 250 times the conventional gas volume and almost 2,000 times current reserves (Morehouse, 2001).

If only a small percentage of the world's gas hydrates can be produced commercially, they would still represent a huge source of energy. This gas could be used in conventional applications, such as a boiler fuel or in heating. However, looking much farther ahead, methane from hydrates could become a source of hydrogen for fuel cells, which many view as the energy of the future. Technology and economics will ultimately determine whether the world's hydrate resource can be widely exploited. Meanwhile, extensive research is under way in Japan, Russia, India, Norway, Germany, Canada, and the U.S.

Consumption

In the year 2000, natural gas consumption worldwide was 87.4 TCF. As with other energy sources, gas consumption is at record levels and has increased 65% over the last 20 years (Fig. 18). However, in energy equivalence natural gas is still far behind that of oil (Fig. 1), mostly because its large-scale use started much later. The long-term share that gas takes of the world's energy budget will increase with time, and many variables will affect the rate of increase. However, fuel switching will be one of the most important, as global oil production peaks and prices rise accordingly.

Regional gas consumption resembles that of oil. The largest consuming region, North America, accounts for precisely the same share of the gas market as the oil—31.3% (Fig. 19). Natural gas reserves and infrastructure in Russia push Eastern Europe and the former U.S.S.R. into second place. Western Europe, with several moderate-size economies, is third. In gas, as with oil, the Middle East has the world's most favorable ratio of reserves to consumption, with 35.1% of gas reserves (Fig. 16), but only 7.7% of consumption.

Russia and the U.S. continue to be by far the world's largest consumers of natural gas (Fig. 20), together accounting for 42% of the world's consumption in 2000. Russia is self-sufficient in natural gas and a major exporter. The U.S. uses about 22 trillion cubic feet (TCF) of gas per year, produces about 18 TCF, and imports 4 TCF—nearly all from Canada. Production declines and the current level of imports (~18%) suggest that the U.S. gas market is roughly 25–30 years behind oil. Demand growth for gas parallels that of oil, forcing the U.S. to rely on ever-increasing gas imports. Although the import percentage for gas is still small relative to oil, the gap between production and consumption is headed in the same direction. Using these trends, Beims (2002) predicts that in 30 years the U.S. will import 50–60% of the gas it consumes.

The total North American gas endowment of 2,500 TCF (Energy Information Administration, 2003) can support current demand for more than 100 years, although it must use a great deal of non-conventional gas to do so. The challenge is that for these resources to be produced, they must be competitive with gas imports—ultimately meaning LNG. Hence, in North America what matters is not the size of the endowment but the economics of producing much of that endowment. Natural gas that does not eventually become economic to produce has no impact.

Analysts believe that prices approaching $4.00 per MCF will make economic the building of the infrastructure necessary to move large volumes of LNG into the U.S. market. Based on energy equivalency, this is also the same price at which the burning of coal can economically meet current environmental standards (Fisher, 2002). Natural gas prices will always be volatile, but when $4.00 per MCF is perceived to be the lower limit (or price floor), domestic gas production will face the same constraint as oil. This is a production cost competition in which hundreds or even thousands of U.S. wells are necessary to equal the production from a single well in an exporting country. Although the price of gas from

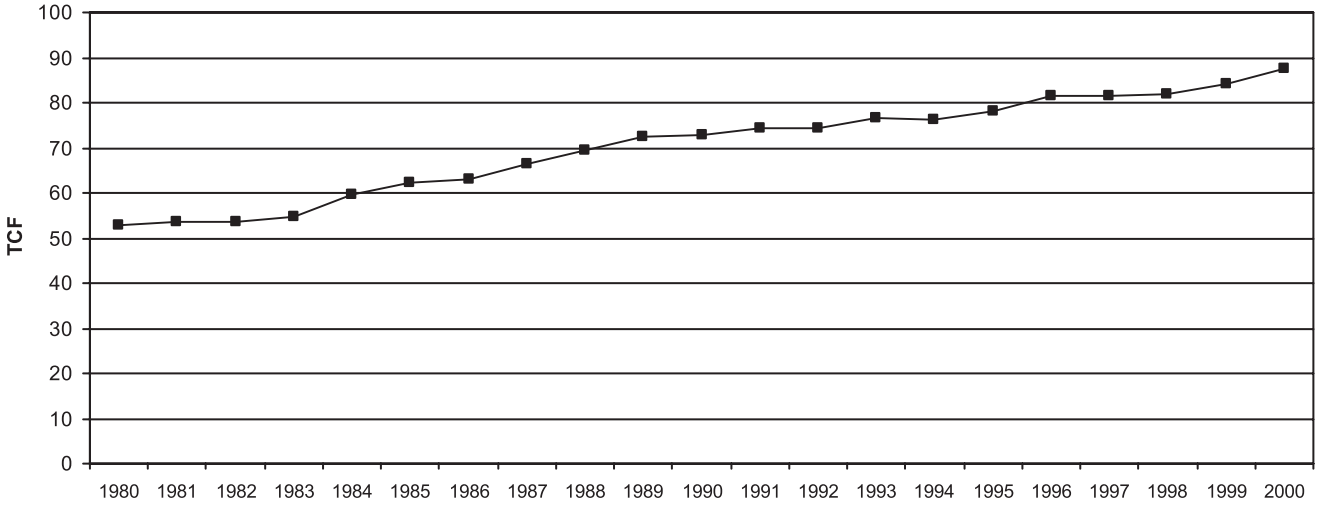

Figure 18. World natural gas consumption, 1980–2000. From Energy Information Administration (2003).

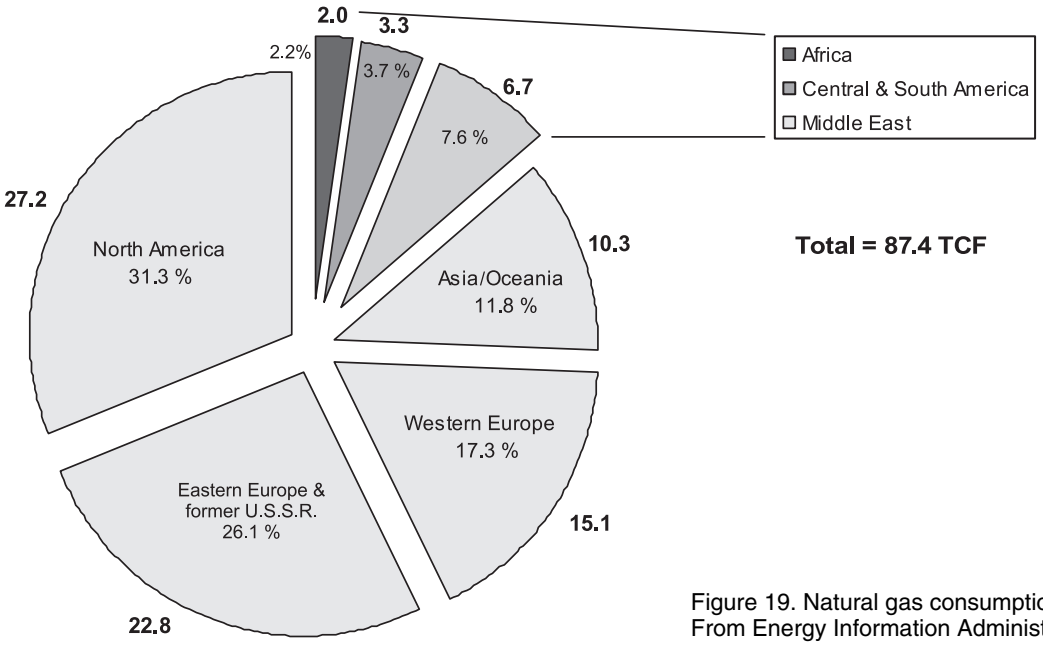

Figure 19. Natural gas consumption by world region (2000). From Energy Information Administration (2003).

an exporting country must include the cost of its conversion to LNG and transportation to our shores, this can be overcome by the disparity in production costs. Thus, when the infrastructure is in place to bring large volumes of LNG to the U.S. market, price will be beyond our control. Depending on where the global price settles, we could find a large part of our gas resource base inaccessible for the same reason that so much of our oil remains in the ground—namely, economics. Although various techniques can be used to produce more U.S. gas, it may cost more to produce than to buy from overseas. This could leave much of the North American gas endowment in the ground.

Gas prices have risen above $4.00 per MCF in the past, but only temporarily and usually during cold winters. To date, it is only the certainty that price lows would bring the average annual price well below winter highs that has kept international gas at bay. In fact, in the last 20 years the average price in the U.S. has been only $2.20 per MCF. Although the two most recent years of complete data (2000 and 2001) show record prices, averaging $3.60 and $4.12 per MCF, prices in the previous two years were only $1.94 and $2.17 (Fig. 6). The market for natural gas is delicately balanced, and a 2.5% change in supply or demand can lead to a 100%-plus rise in price. With a flat to declining production trend, price volatility is bound to remain high, but—barring a dramatic drop in demand (say in an economic depression) or an unexpected technological breakthrough—long-term prices seem sure to rise (Beims, 2002).

Natural gas has advantages over its major competitors, petroleum and coal. Gas is the most environmentally friendly of the three, and is so abundant that even conservative estimates show its reserves meeting increasing demand

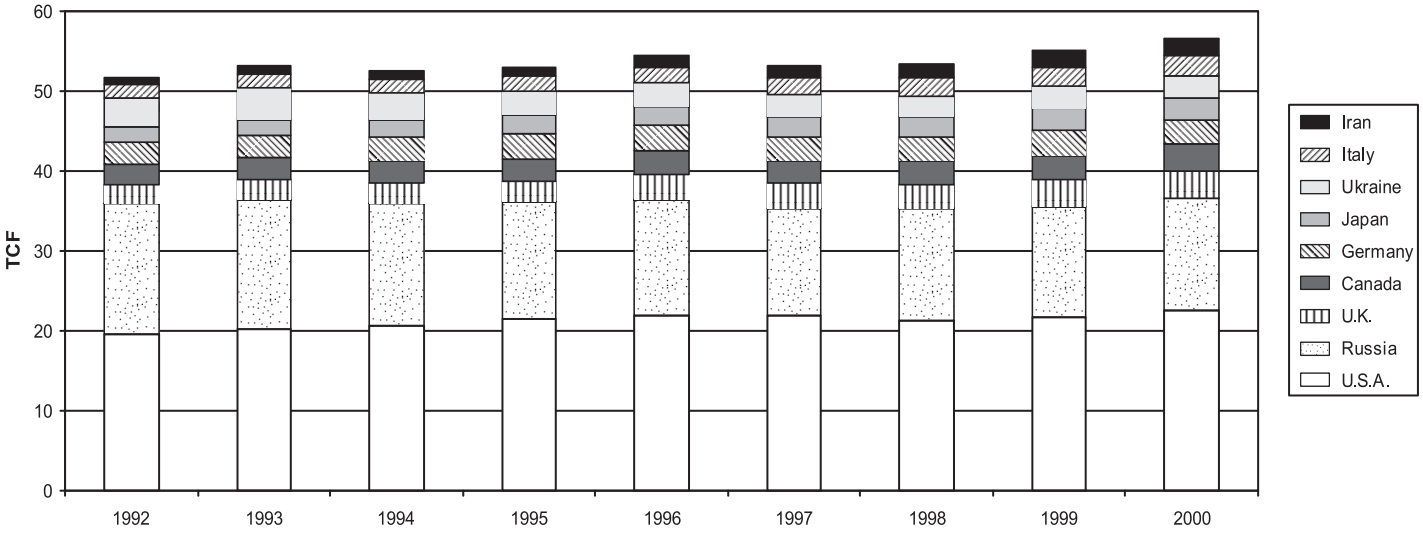

Figure 20. Countries consuming >2 TCF (2000). From Energy Information Administration (2003).

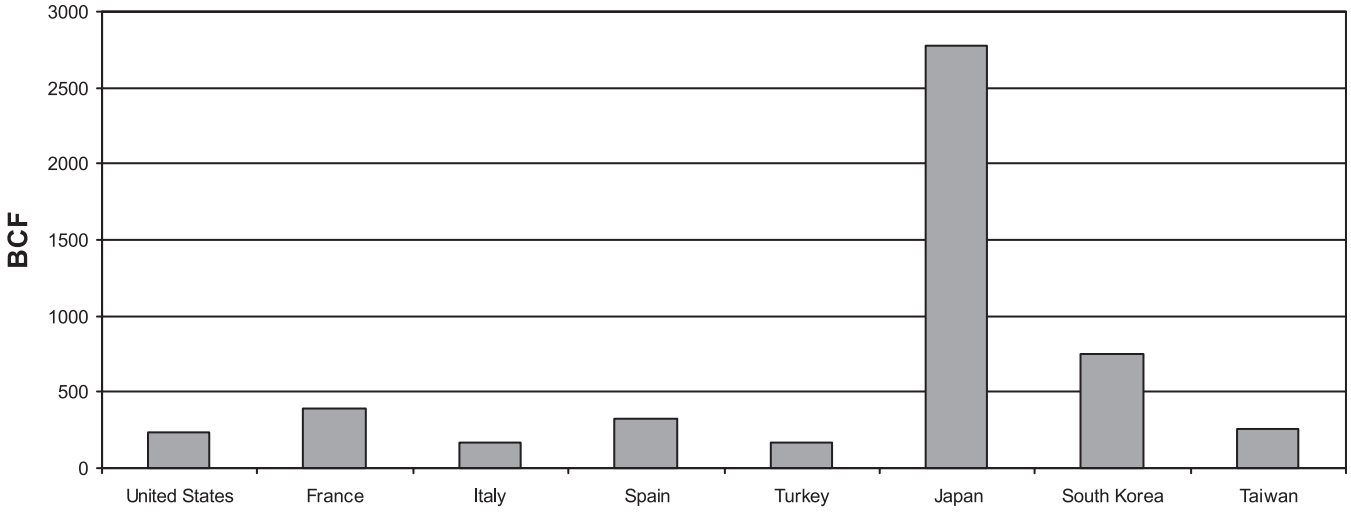

Figure 21. LNG importers of >100 BCF (2001). From Energy Information Administration (2003).

for several decades. The problem is that most of the reserves will be coming from the same regions as our imported oil. In addition, large imports will require a major investment in infrastructure and years of construction. This infrastructure will include a large number of LNG tankers, high-volume LNG off-loading and processing facilities, and pipelines for moving the gas inland. Today the largest LNG importers in the world are the hydrocarbon-poor nations of Japan and South Korea (Fig. 21). Only relatively minor volumes of LNG are consumed in other countries, including the U.S., but consumption is likely to increase substantially in the next few years.

The predicament for the U.S. is that much fuel-switching capability in the face of high oil prices involves increased use of natural gas. However, North America as a whole can barely keep pace with demand, and only when winters are mild. The point is illustrated by the abnormally cold winter of 2002–2003, when U.S. gas storage dropped to record lows, and prices increased four- to fivefold. If a problem with oil supply markedly increases gas demand, or if another cold winter comes, it is doubtful that enough gas will be available in the short term. Although this situation could starve some industries of energy so that homes could be heated, the problem is only temporary. A lasting solution will come when large-scale LNG imports are possible. Currently imported LNG meets only 1% of U.S. natural gas demand, and although this is a tenfold increase over 1995 LNG imports, maximum U.S. capacity for handling LNG is only about 4% of demand (Ziff Energy Group, 2001). If demand for natural gas grows faster than our capacity to import LNG, average prices should stay well above $4.00 per MCF until imported LNG can reach the market.

Despite North America's supply problems and high global consumption rates, the outlook for natural gas is good. Proved reserves and estimates of future additions are very large. Current proved reserves alone could support world demand for more than 60 years at current rates of use. If one adds the 8.9 QCF of future reserve additions predicted in 2000 by the USGS, consumption could be supported for a century more. A reserve life of 160 years, and the belief by most that even this estimate is conservative, explains why natural gas is seen as the bridge to sustainable energy sources.

Production

World gas consumption is balanced by gas production (Fig. 22). Even for non-exporting regions that are self-sufficient (e.g., North America), these volumes rarely match (Fig. 19), with small differences between production and consumption reflecting additions or withdrawals from storage. The U.S. and Russia dominate production as they do con-

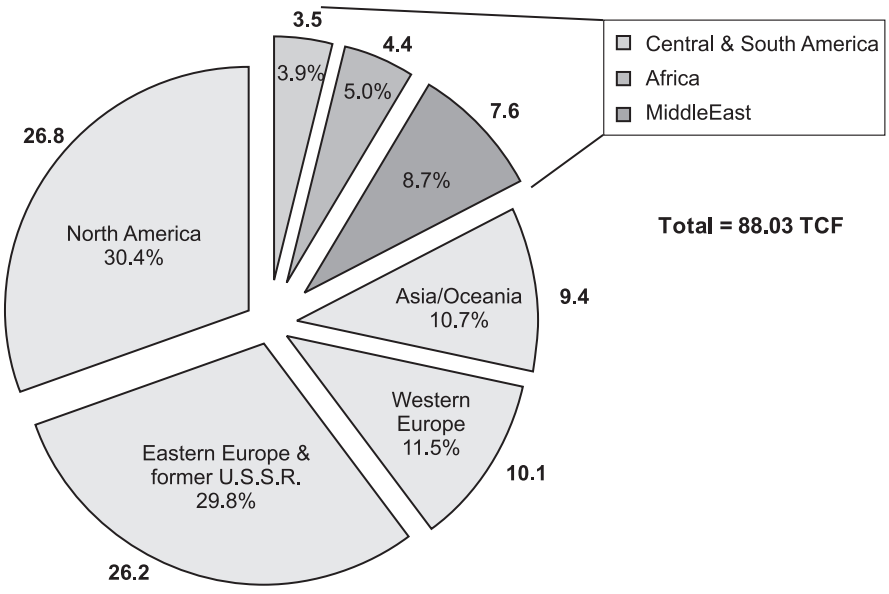

Figure 22. Natural gas production by world region (2000). From Energy Information Administration (2003).

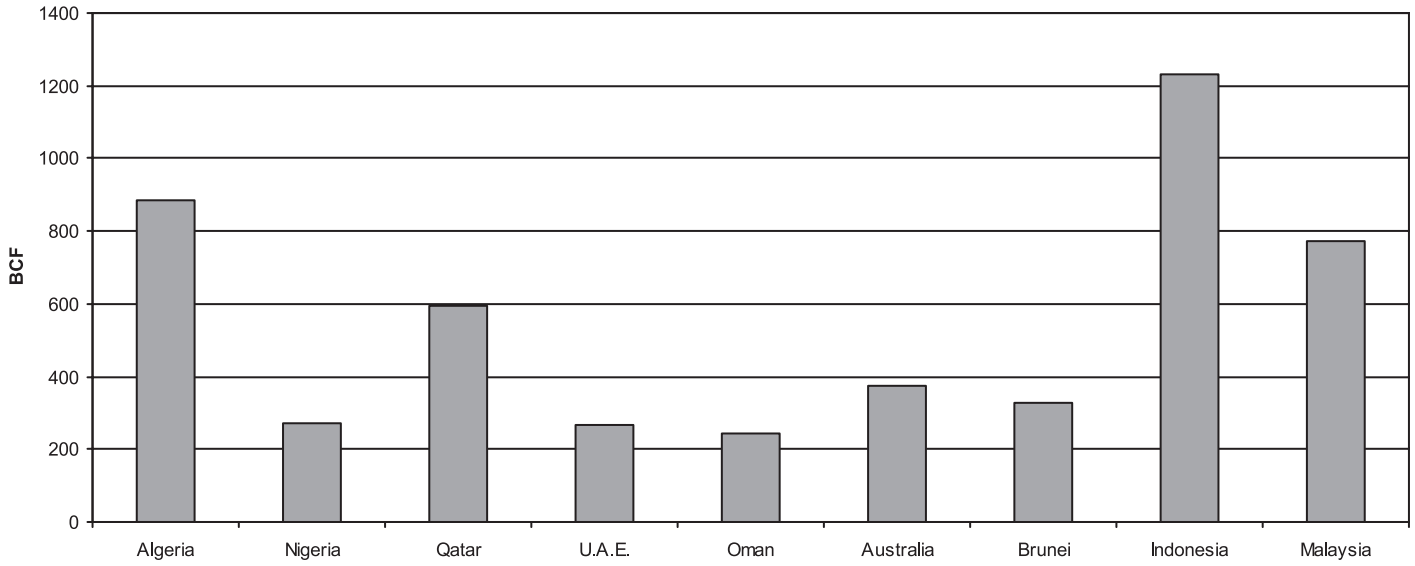

Figure 23. LNG exporters of >200 BCF (2001). From Energy Information Administration (2003).

sumption. However, production of gas (unlike oil) is not a direct indicator of the location of global reserves. It shows instead where reserves are connected to a market, which can be overland via pipeline or by seaborne LNG transport. Today only about 6% of the world's demand for natural gas is fed through LNG imports, but as reserves in the developed world are produced and consumption increases this percentage will grow markedly.

The largest LNG exporters are not the countries with the largest reserves but those that first met emerging demand from developed countries (Fig. 23). Many countries have larger gas reserves than Indonesia and Malaysia, but early drilling and reserve certification enabled them to obtain contracts with major Asian consumers—Japan, South Korea, and Taiwan (Fig. 21). Long-term contracts enabled them to build the infrastructure for shipping LNG to their markets, and later discoveries and additions to reserves have enabled the expansion of facilities to handle growing demand. Algeria's proximity to Western Europe has given it a decided advantage over other sources of LNG.

In the U.S., non-conventional resources such as tight gas and coalbed methane are taking a progressively larger share of production (Fig. 24), and conventional gas from deep water in the Gulf of Mexico and the U.S. and Canadian Arctic also will increase their contributions. However, the last three years in the U.S. have shown that even concerted gas drilling has not greatly increased our productive capacity. In fact, although demand continues to grow, we can barely maintain existing production levels. New volumes of conventional and non-conventional gas in North America are not large

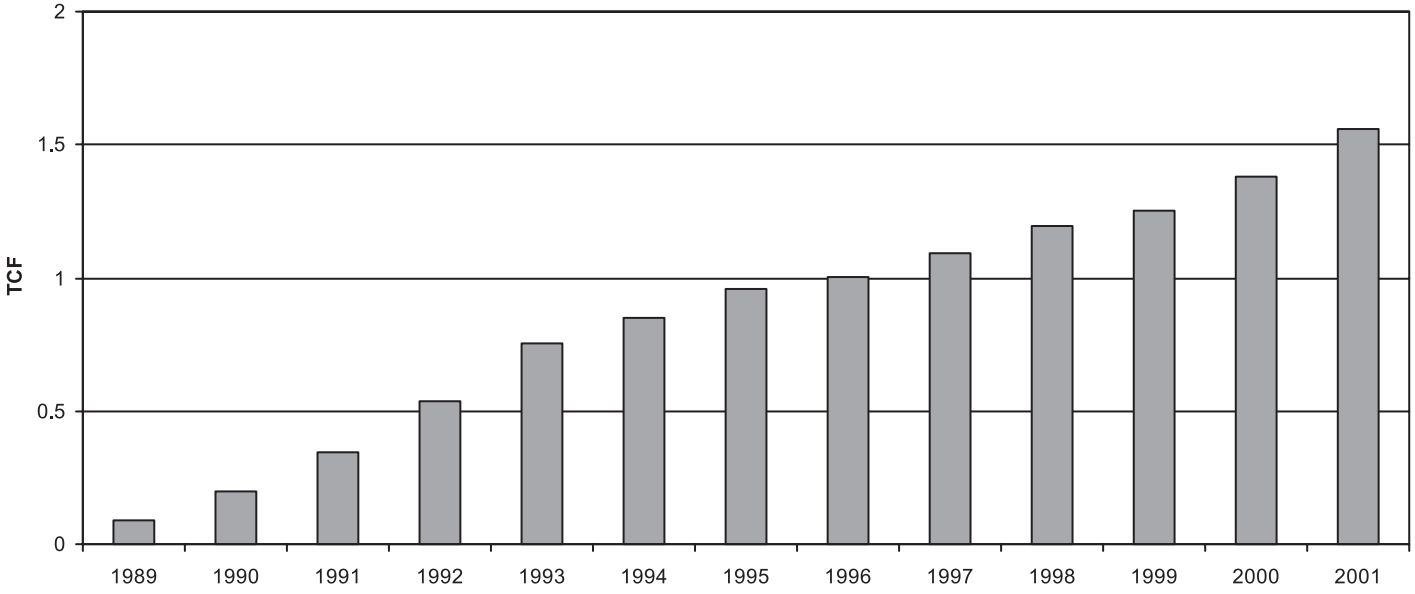

Figure 24. United States coalbed methane production, 1989–2001. From Energy Information Administration (2003).

enough, nor can they be produced fast enough, to prevent the need for large quantities of LNG in coming years. Although the U.S. is certain to be the largest emerging LNG market, of concern is the time needed to build the ships and facilities necessary to import it. With the delicate balance of supply and demand, it could take several years of progressively higher, roller-coaster prices before large volumes of LNG become available.

Ironically, many LNG facilities, which must be sited offshore and as close as possible to centers of demand, will be built over gas-prone basins that for political and environmental reasons are off limits to the petroleum industry. Examples include basins off the East Coast, adjacent to some of the nation's largest population centers.

The world's preoccupation with oil has often relegated natural gas to second-class status, especially in countries where oil is abundant. However, for both Oklahoma and the U.S. as a whole, it is gas that will largely be called upon to fill gaps left by reduced oil capacity. (A case in point is the conversion process of natural gas to liquid fuel, which will allow it to satisfy considerable oil demand.) The need for natural gas can only rise in the long run. Demand may temporarily fall as a result of conservation and fuel switching, but core demand—demand that remains whatever the price—will continue to increase. Core demand is being further augmented by gas-fired power plants built to meet increased electrical demand, most of which have no fuel-switching capability (Wright, 2002).

THE GLOBAL ENERGY FUTURE

As the world economy becomes more integrated, analysis of any one region in isolation becomes impossible. Thus, to understand Oklahoma's oil, gas, and larger energy picture one must first take into account the principal global and national issues. The overriding reality is that fossil fuels (oil, natural gas, and coal) will continue to fill the great bulk of the world's energy needs for a long time to come. As a result, the primary matter in the short to medium term is the degree to which supply (production) can meet the demand (consumption) for these critical commodities.

From 1975 though 2000, the volume of oil discovered every 5 years has been decreasing, and in the period from 1995 to 2000 an annual average of 3 BBO was discovered—while 27 BBO was consumed (Magoon, 2000). Estimates of discovered oil vary, but all agree that the world is living in the red. Only the vast reserves and productive capacity of the Middle East have allowed this situation to continue, but as time passes dwindling reserves must eventually result in reductions in supply and corresponding reductions in demand.

The dominant economies of North America, Asia, and Western Europe consume the bulk (78%) of the world's oil production, but they control only 11% of the reserves. In fact, the disparity between their proved oil reserves and their consumption is growing. For example, North America and Western Europe account for about 50% of world consumption and 25% of production, but a paltry 7% of world reserves. Thus, in addition to having smaller proved reserve volumes, these regions are producing their reserves proportionately faster. Compare this to the Middle East, which accounts for 6% of world consumption, 32% of world production, and 67% of world reserves. The inequity between the "haves" and "have-nots" will continue to accelerate because predictions of where future discoveries will be made also are skewed strongly towards developing regions. In order of importance, these are the Middle East, the Siberian and Caspian Sea areas of the former U.S.S.R., and the Niger and Congo River deltas in western Africa (Ahlbrandt, 2002).

A similar disparity exists for natural gas. Nations in Eastern Europe and the former U.S.S.R. and in the Middle East contain almost three-quarters of world reserves, yet account for only about one-third of consumption. These regions are also projected to contain the greatest volume of future reserves. In contrast, North America and Western Europe possess only 8% of the world's gas reserves, but consume about half the world's production.

The key producing regions of Central and South America, Africa, and especially the Middle East, are mostly the remnants of dismembered colonial empires, and not surprisingly some have been politically unpredictable. The concentration of oil reserves in countries that have only recently gained independence or are perhaps fledgling democracies means that instability in oil supplies will remain the norm, not the exception. These regions account for 83% of world reserves, with a fraction of the Middle East alone possessing two-thirds of the planet's proved oil volume. The resulting reserve geography makes the Middle East's stability especially important to the world economy, so news-making events in even the smallest of its nations often have international implications.

Many of the political, economic, and military issues confronting us today can be traced directly to the distribution of the world's oil reserves (Fig. 10). This linkage has made possible what would have been unthinkable until recently: U.S. reliance on Russia and previous members of the U.S.S.R. (the former "Evil Empire") to provide a stable source of supply to reduce dependence on oil from the Middle East (the center of the current "Axis of Evil"). Politics changes, as do our perceptions of the world, but trying to determine the level of U.S. oil security by calculating (often to 2 decimal places) the percentage of imported oil coming from sources considered "unreliable" misses the point (Fig. 25). Whether oil is imported from a close ally or a potential enemy, the market for oil is *global*: so aside from transportation charges, a barrel of oil from Iraq costs a U.S. refinery the same as a barrel of oil from Oklahoma. Any production added to the world market, regardless of origin, will push prices lower. Conversely, if a producing area goes down for any reason, its customers will seek oil from another source, whether that oil is spoken for or not. This drives prices higher.

The U.S. government has predicted that nuclear and hydroelectric energy will remain flat, and that the use of other renewable sources will increase only slightly through 2025 (Fig. 26). Coal, natural gas, and especially petroleum demand (fossil fuels) are expected to increase dramatically. Even as a percentage of total energy consumption, the U.S. dependence on fossil fuels is expected to grow from its current 85% to 88% by 2025.

Of the nation's top energy resources, only coal can meet demand from exclusively domestic sources. Both coal and

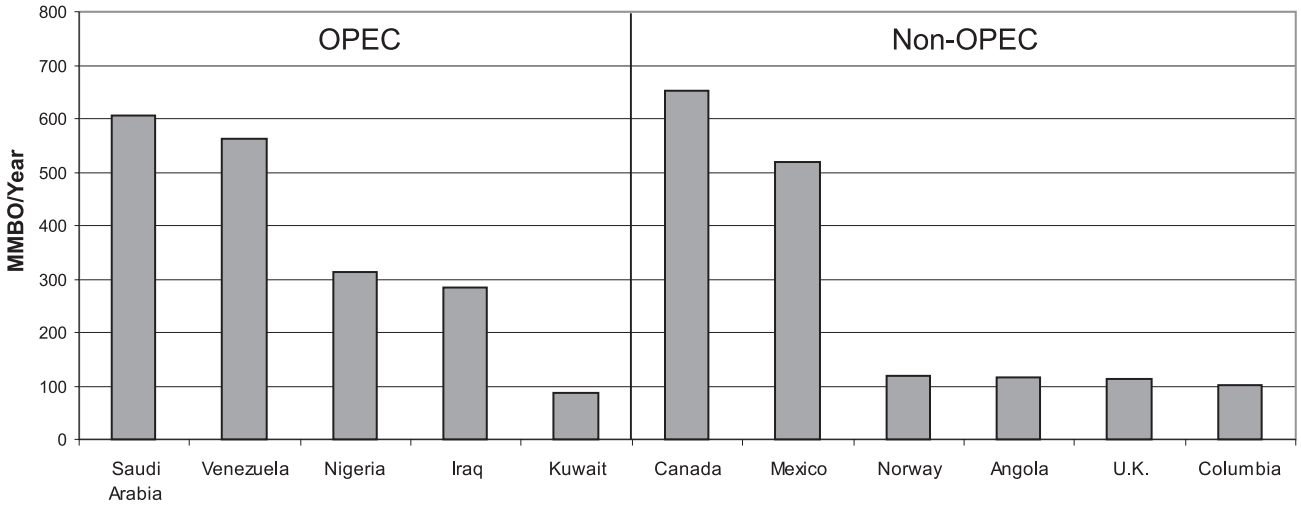

Figure 25. Major sources of United States crude oil imports (2001). From Energy Information Administration (2003).

nuclear energy, whose reserve lives (at current consumption rates) are 300 years and 100 years (Deffeyes, 2001), bear important environmental and political liabilities. As a result, it is unlikely that there will be a major shift in energy demand from oil into either of these. The fuel with the reserves and environmental qualities necessary to make up for any shortfalls in future oil supply is natural gas.

The peaking of world oil production, whenever it occurs, will lead to a considerable rise in price, and users that can shift to cheaper fuels will begin doing so. Coal, in which the U.S. is self-sufficient, is the least expensive, but on a Btu basis natural gas also has been cheaper historically than oil (Boyd, 2001). As fuel switching occurs, oil demand and prices will decline somewhat, but benefits from fuel switching are limited. Some petroleum products have no satisfactory substitutes. For example, about half of U.S. oil demand is in the form of gasoline and jet fuel, so for industries involved with transportation conversion may be too expensive or impossible.

Oil is America's number-one energy source, but a 50% increase in the current level of production and imports will be required to meet expected demand in 2025 (Energy Information Administration, 2003). As discussed previously, such an increase does not seem likely. In fact, under most scenarios, demand will exceed petroleum supply within years—not decades—and probably by 2009. When this occurs oil demand will be forced to match supply, with other energy sources taking up the slack. Whether demand exceeds production by one barrel or one million, the point where production and consumption curves cross will mark the beginning of the end of the age of oil.

Although market forces ensure that demand quickly balances supply, the range in which long-term oil prices will settle is impossible to predict. Price volatility probably will remain high, but the perception of scarcity should keep both price lows and average prices higher (in real terms) than they are today. The key to reducing turmoil is a gradual transition from an energy economy dominated by oil, to one in which a variety of long-lived resources can help shoulder the burden. To that end governments would be wise to plan for the long term, where possible using the most abundant domestic energy sources. Where economics dictate the use of less-expensive imported fuel, prudence demands formulating contingency plans involving fuel switching in favor of domestic resources. The goal is a smooth transition, with a minimum of price spikes. Reducing the speed at which prices rise is important, as it affords time to retool infrastructure and adapt to new economic constraints—an important task for developed and developing countries alike.

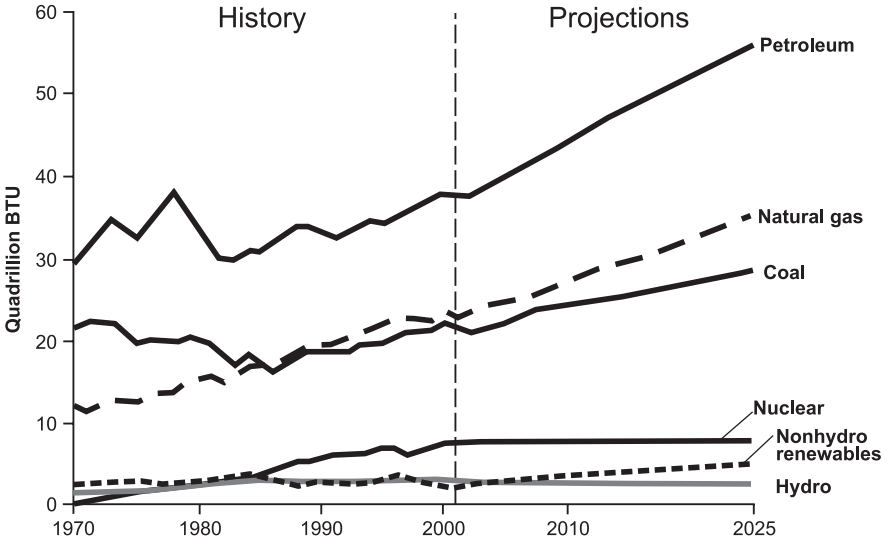

Figure 26. United States 2003 annual energy outlook—early release, 1970–2025. From Energy Information Administration (2003).

Apart from a decline between 1977 and 1982, resulting from sharply higher oil prices, U.S. consumption and dependence on imports have risen steadily. This trend will continue, as fully half of the 1.3 MMBO per day projected increase in worldwide demand in 2003 is expected to come from the U.S. (Wright, 2003a). A high level of national consumption is not surprising, as the American economy produces far more goods and services than any other country; however, we also have become more efficient in our energy usage. Between 1959 and 2001 the U.S. economy grew more than fourfold, but in 2001 we used half as much energy per dollar of gross domestic product as we did in 1959 (Radler, 2002).

The U.S. and the rest of the world depend on the free flow of oil and LNG from exporting countries. For their part, OPEC countries, excepting two embargoes intended to influence American policy in the Middle East, have provided oil in abundance. However, unforeseen events will continue to affect the flow of oil, forcing government planners to take precautions to ensure there are no interruptions. For instance, a primary mission of the U.S. Navy is to keep sealanes open to commerce, as our economic health, as well as that of the rest of the global community, depends on free access to energy supplies. The U.S. has fought one war over insuring access to oil and has recently completed another that, among other things, also will improve our long-term access to petroleum.

World events can lead to uncertainty in energy markets and create anxiety in the public mind. Our insecurity in energy matters is usually brought about by jumps in gasoline and natural gas prices. Complaints then become common, and conspiracies are alleged. However, with a myriad of uncontrollable factors that can affect prices, and an increasingly delicate balance between supply and demand, the wonder is that the average annual oil price has remained so steady in the $10–$20 per barrel range. Prices for oil (and gasoline) have, except for a jump in the early 1980s, remained nearly constant in real terms for 30 years (Fig. 27). Headlines may declare that the price of gasoline is the highest in history, but in constant dollars everything is more expensive. It is OPEC and the world's overcapacity in oil production that has largely kept energy prices independent of inflation. The price of natural gas in the U.S. has been proportionately more volatile than oil, but this is mostly because demand is more seasonal and we do not yet have large-scale access to overseas reserves. As a result, with the help of Canada, in natural gas we have been largely on our own.

What can America do to improve its lot? We are limited in our ability to maintain the uninterrupted flow of oil from producing countries, and for the same reason we have little control over price. Our options are to either reduce demand through some form of conservation, or enhance the supply of domestic oil and gas. Unfortunately, encouraging voluntary conservation of any kind is politically difficult, so only the supply side of the equation remains open. However, because of the maturity of our industry the only way to markedly increase long-term domestic oil and gas production is to open to leasing many areas that are now off limits. Popular sentiment also makes this course unlikely. For instance, gas-prone offshore areas (hence, with a minimal risk of oil spills) that are beyond sight of land have been placed off limits. (Bans have even been decreed retroactively through the denial of development permits after discoveries have been made.)

Although valid arguments exist both for drilling and for not drilling, it is important to understand that decisions to exclude areas from oil and gas exploration are as much philosophical as environmental. The industry's environmental track record is excellent, even in sensitive areas like the North Slope of Alaska where oil production has been under a microscope for more than 30 years. An environmental awareness that focuses on drilling restrictions tends to ignore the one element that would bring the greatest number of undeniable environmental benefits—reduced consumption. For example, 85% of the oil that enters North America's offshore environment (natural seepage excepted) results

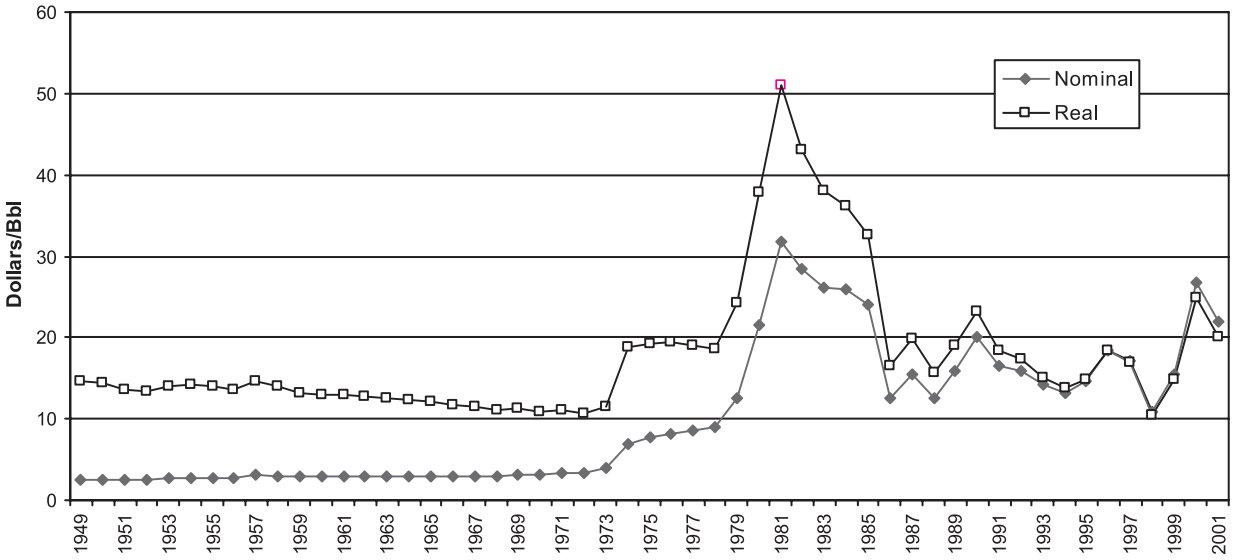

Figure 27. United States crude oil prices in 1996 dollars, 1949–2001. From Energy Information Administration (2003).

from consumption (runoff from urban areas and non-tanker shipping and boats). Transportation and refining account for an additional 11%, with only 4% entering the water through exploration and production activity (Wright, 2003b).

The irony is that increased domestic production would have not only economic benefits, but would also reduce the environmental hazards inherent in transport. Unfortunately, the environmental consciousness that finds it easy to reduce activity in areas that are tightly regulated has no problem in allowing the developing world, with far less stringent environmental regulations, to suffer greater risks satisfying our energy demand. The bulk of the negative environmental impact resulting from use of any fossil fuel comes not from activity devoted to its discovery, production, refinement, or transport, but from its consumption. Minimal conservation, combined with increased industrial efficiency and domestic production would generate many benefits. These include a reduced reliance on external energy sources and the level of insecurity that we feel with every unsettling event that occurs worldwide. National economics would benefit from an improved balance of payments. Environmental risks of all kinds could be mitigated, an important one being a reduction in the number of tankers plying the nation's and the world's waterways.

The world will never "run out" of energy supplies. They will only become more expensive. However, inexpensive energy encourages waste and speeds the day when supply will no longer meet demand. Fuel economy in the average U.S. motor vehicle today is lower than it was in 1980, and for 20 years American energy consumption per capita has been more than 40 times the world average (Cloud, 2003). Although many Americans can afford higher energy prices, many others many cannot. Look beyond our borders: for many countries, especially those in the developing world that are resource poor, increasing energy prices will retard many aspects of development. More than affecting the size or horsepower of the vehicles driven, or whether homes and shopping malls can be air-conditioned to 65°F, in a poor country expensive energy has a major effect on industrial growth, jobs, food production and distribution, and ultimately social and regional stability.

When world oil production peaks it will signal not that we are running out of energy, only energy in a very convenient form. Natural gas can be brought to the U.S. in vast quantities in the form of LNG. It and our own gas reserves can be converted to liquid fuels, but this comes at a price. Even our abundant coal reserves can be converted to liquid fuels, but again at a price. All agree that the next major shift in energy usage will increase demand for natural gas at the expense of oil, coal, and nuclear energy. However, this shift is simply one in a long line of gradual changes in the history of energy consumption. The progression is characterized by increased energy efficiency as hydrogen-to-carbon ratios have increased (Fisher, 2002). The transition from wood to coal to oil to natural gas has not only increased overall energy efficiency, but each step has reduced the number and intensity of harmful side effects, such as clear-cut forests, acid rain, and greenhouse gases. Unfortunately, we cannot take credit for directing this evolution, because market forces (supply and demand) drove the development of the technology that made such improvements possible.

As we become more proficient technologically, the use of pure hydrogen may become the next logical step. Hydrogen has many potential applications and, although not yet viable, it may play an important role in developing sustainable transportation in the U.S. It does not pollute and can be produced in virtually unlimited quantities using renewable or abundant resources. Pure hydrogen and hydrogen mixed with natural gas have been used effectively to power automobiles. However, hydrogen's real value rests in its potential in fuel-cell vehicles. Fuel cells are essentially batteries that, constantly being replenished with fuel, never lose their charge (Alternative Fuels Data Center, 2003).

Hydrogen is produced by two methods: (1) electrolysis and (2) synthesis gas production by steam reforming (partial oxidation). Both methods need large amounts of energy to produce pure hydrogen, which is a major technical hurdle that must be overcome. Electrolysis uses electrical energy to split water molecules into hydrogen and oxygen. It is not efficient in producing hydrogen, and the U.S. Department of Energy has concluded that it is unlikely to become the dominant method for generating hydrogen in large quantities. Steam reforming, which separates carbon from the hydrogen in natural gas, is the dominant method used to create hydrogen fuel. If this method becomes economically viable, a large share of future demand for natural gas could come from the creation of hydrogen fuel (Alternative Fuels Data Center, 2003).

It is possible that a technological breakthrough will fundamentally change the world's energy budget by providing abundant, environmentally friendly, inexpensive energy that could substitute for oil and gas. Although the economic, environmental, and political benefits would be enormous, the likelihood of such an event occurring in the near-term is remote. Research continues in many areas, but nothing on the horizon promises to end our dependence on fossil fuels for decades to come.

OKLAHOMA'S OIL AND NATURAL GAS FUTURE

The energy future of Oklahoma, for both producers and consumers, is inextricably tied to the global marketplace. In that respect, our State is no different from any other. Its production of oil and especially natural gas is typified by large numbers of low-rate producers whose rates and long-term declines are tightly linked to drilling. Our reserves and production, although important nationally (Oklahoma ranks fifth in oil reserves and fourth in natural gas) are insufficient to affect, even in the slightest, the key variable influencing economics—world energy prices.

Price is especially important to Oklahoma's industry because our finding and development costs are higher, and production rates lower, than much of the rest of the world. This means when oil and gas prices slump, so do drilling and investment in infrastructure. In addition, during periods of low prices some wells become uneconomic to operate and, if low prices persist, many may be permanently abandoned (Boyd, 2002a).

The good news from a consumer's standpoint is that OPEC, like the state commissions before it, works hard to keep prices in a range that balances producers' income requirements with the world's economic interests. Unfortunately, this price range is barely enough to maintain Oklahoma's oil industry at a low level, and even this requires government programs designed to keep low-rate producers active (Boyd, 2002a). The relatively high cost of producing a barrel of Oklahoma oil is no one's fault, and there is no conspiracy to suppress U.S. drilling and production. The truth is that the oil price necessary to attract large investment (another drilling boom) in the State would also bring a global economic recession or depression. High prices would themselves soon reduce demand and bring on yet another round of falling prices. OPEC's balancing act is difficult, but must be judged as largely successful, for even as demand for oil has increased its price has remained reasonably stable. This factor, more than any other, has allowed the U.S. and other world economies to experience record growth.

World events make it all but impossible to entirely control energy prices, and short-term volatility will remain high. As long as the world's oil supply exceeds demand, the potential exists for prices to sink to levels ruinously low for Oklahoma's petroleum industry, although such drops should not last long. As demand continues to increase and oil production peaks—as is likely in the next few years—prices will rise. Then the balancing factor will cease to be the productive capacity of exporting countries, but the ability of consumers to reduce consumption. Volatility will continue, but both the peaks and valleys of price cycles should be higher than of those of the past. It is impossible to predict in what range oil prices will then move, but we can hope that the average will be high enough to encourage long-term investment in Oklahoma's oil industry. If so, it will be possible to concentrate on something that we can influence—how much oil is produced.

Any major increase in Oklahoma's oil reserves and production rate requires investment in concerted secondary and enhanced recovery work, especially in fields where recovery is substandard. The up-front costs are substantial for such projects, which require sustained higher prices in order to become economically attractive, but such prices could come in this decade. Regardless of how it is measured, the oil still residing in Oklahoma reservoirs is a staggering volume (44 to 82 BBO), all of which has already been mapped (Boyd, 2002a). Even a modest increase in the overall recovery factor for only the largest fields could yield huge rewards. A prudent strategy (in anticipation of the sustained oil price increase that seems inevitable) is to gather data and to rank candidate fields now, while interest in such projects is still relatively low.

Help could come as a result of studies (being sponsored by the U.S. Department of Energy) evaluating the feasibility of collecting carbon dioxide generated by industrial processes. The objective is to reduce greenhouse gases in the atmosphere, and this could be accomplished by pumping CO_2 into underground reservoirs from which it will never escape. The impact in this discussion is that CO_2 is very useful in enhancing oil recovery, and if the federal government decides that large-scale CO_2 sequestration is feasible, huge volumes of low-cost CO_2 could become available for enhancing oil recovery. If implemented, such a plan could dramatically increase ultimate oil recoveries in the eastern and southern parts of the State.

Higher oil prices will push natural gas demand and prices higher. However, unlike oil, the U.S. cannot yet import from overseas more than a tiny fraction (1–4%) of its gas requirements. Because our balance of supply and demand for gas is so tight, LNG capacity may be insufficient to satisfy all of the extra demand that may result from higher oil prices. Expensive oil, combined with a tight gas supply, could diminish our ability to reduce demand by switching fuels, and this may take prices for both to all-time highs. Higher prices would spur drilling, but there would certainly be negative repercussions for the overall State economy.

Drilling in Oklahoma is dominated by wells seeking gas. Nevertheless, major additions to gas reserves and production will require sustained drilling in areas that are still underdeveloped or underexplored. These include deep and low-permeability reservoirs that may be in areas of shallow, long-standing oil production. The continued development of coalbed methane resources also will remain critical to the State's gas industry. Oklahoma's location, geology, resource estimates, pipeline system, and the industry's strong history ensure that natural gas will be a key component of the State's economic future well into the 21st century. However, these strengths will avail us nothing without a steady stream of investment.

Petroleum products represent about a third (34%) of the State's energy consumption, nearly half of this as gasoline. Natural gas represents another 37% and coal 24%, bringing the total share for fossil fuels to 95%. The prices for all three tend to rise and fall together, but coal (as measured in Btu) is the cheapest and oil the most expensive. Unfortunately, coal use involves environmental issues that offset many of its advantages, and because most of Oklahoma's coal has high sulfur content, more than 90% of the coal burned here comes from Wyoming (Boyd, 2001).

Oklahoma's status as a major energy producer at the national level does not mean that the State's consumers are less affected by shortages or high prices. Even if we produced as much energy (oil, natural gas, and coal) as we use, prices in the global economy would remain beyond our control. (Local producers are obliged to maximize profits, and so cannot offer discounts to local consumers.) Ignoring taxes, transportation, and government subsidies, energy prices are the same everywhere on Earth. Oklahoma's production and nearby refineries reduce some transportation costs, but this price advantage is small and becomes less important as prices rise.

When prices for oil and gas swing widely, their value to the State depends far more on average price than on how much is produced (Boyd, 2002b). This is especially true for natural gas, which is the State's most abundant resource and its most important export. Two-thirds of Oklahoma's production of natural gas (roughly 1 TCF per year) is sold outside the State, and every dollar per MCF in gas price means $1.5 billion in gross revenue (1.5 TCF × $1.00/MCF). Building more gas-fired power plants will permit the conversion of some of these exports from gas to electricity, and the higher

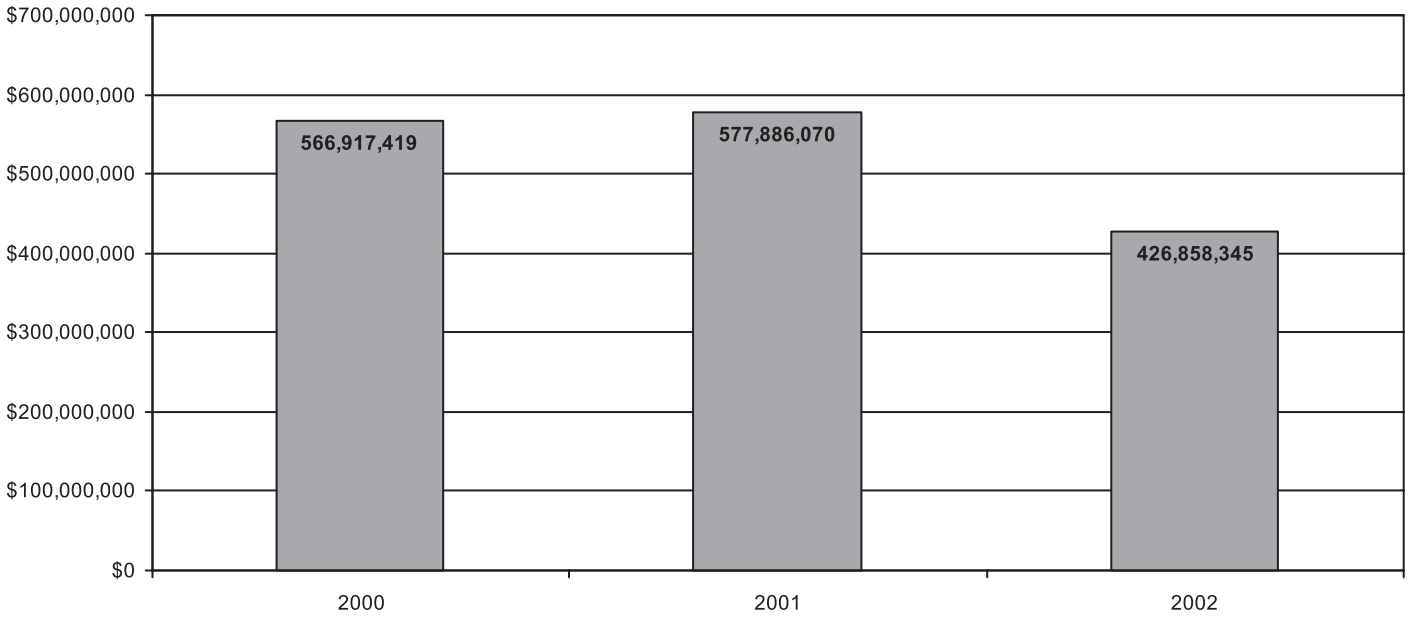

Figure 28. Oklahoma oil and gas tax revenues, 2000–2002. From Oklahoma Tax Commission.

price of electrical energy over raw natural gas should increase revenues to the State.

The annual decline in oil and gas production in Oklahoma has usually been less than 5%, but price can easily fluctuate 50–300% in a single year. This is why gross income and the resulting tax revenue to the State is so much more sensitive to price than the amount produced. Much of the shortfall in State revenue for 2002 can be directly attributed to lower prices for oil and gas—especially gas (Fig. 28). About three-quarters of the State's oil and gas tax revenue comes from gas production.

Oklahoma's Gross Production Tax has a sliding scale based on the average monthly price of oil and gas paid by the top three purchasers in the State. For oil the rate is 7% if the price is $17 per barrel or above, 4% from $14 to $16.99, and 1% if below $14. For gas the tax is 7% if the price is $2.10 per MCF or above, 4% from $1.75 to $2.09, and 1% if below $1.75 (Oklahoma Tax Commission, 2003). Such a variable tax is common among other States, but Oklahoma's scale is well below most others. For example, Kansas receives 8% of the revenue for oil and 15–17% for gas (Interstate Oil and Gas Compact Commission, 2003).

In light of recent tax shortfalls in Oklahoma, and the likelihood of substantially higher oil and gas prices in the future, an increase in our variable tax for prices well above $17 per barrel and $2.10 per MCF seems prudent. The negligible tax rate at low prices has done much to protect marginal producers, but State help given to producers in hard times should be balanced by higher rates when prices—and profits—are high. This is not a new idea, but it warrants consideration, especially as much of Oklahoma's royalty ownership is held by out-of-State residents (Dauffenbach, 2001).

Particularly important in the long term is the proportion of State resources that ultimately will become economic in an environment in which we cannot control price. How much of our oil and gas will be economically competitive with imports? Can we compete with LNG imported at $3.50 or $4.00 per MCF? Will long periods of low oil prices force abandonment of wells? Will new secondary and enhanced recovery projects become economic as world production plateaus and oil prices rise? In the more distant future, what proportion of reduced demand for oil will be met by natural gas? By coal? Hydrogen?

Our energy industry is important to the financial health of the State, and it certainly will benefit from higher energy prices. Higher prices will foster growth in energy-related businesses and increase State revenue, directly as production taxes and indirectly as a result of growth in the overall tax base through increased employment. However, because energy is an integral part of almost every business, the higher prices that help the oil and gas industry may not offset negative effects on other areas of the economy. No one can say whether the overall effect on Oklahoma will be positive or negative, but higher energy costs certainly will adversely affect much of the rest of the State's economy, and industries especially sensitive to energy prices will suffer disproportionately.

CONCLUSIONS

Oklahomans have no reason to be apprehensive about the energy future. The world will never run out of any source of energy. The question is how smoothly an energy market dominated by oil can change to one in which no single source dominates. Scenarios range widely. One is a gradual, seamless shift in energy consumption in the different parts of the world in which changes in demand and production balance and the required infrastructure is always at hand. This utopian vision is as unlikely as the other extreme, a sudden collapse of the global economy resulting in numerous

political and military confrontations.

Our future is far more likely to resemble the past, with supply disruptions continuing to cause volatile prices. A narrower gap between supply and demand will cause this volatility to increase in the long term and prices to spike more severely than in the past. It may take several years for this to happen, but as the world's excess productive capacity continues to shrink, flexibility of supply will be lost. The world will remain an unsettling place. The difference is that when there is no longer a Saudi Arabia that can quickly ratchet up production to cover supply shortages in Venezuela, West Africa, Kuwait, or Iraq, our sensitivity to supply interruptions will be magnified.

Society has progressed from a primary energy dependency on wood to one that is evolving to a combination of oil, natural gas, coal, and lesser resources. Although nothing on the horizon is capable of replacing fossil fuels, we still have plenty of time to prepare. The transition certainly will be bumpy, but the reserves remaining for each fuel are still large.

An individual can prepare for the coming transition and its uncertainties by factoring energy considerations into long-term decisions. A vehicle purchased today should last several years. However, if a 50% increase in gasoline prices in this timeframe is likely to be a financial burden, a reevaluation may be in order. In the same vein, a house 30 miles from the office may be appealing, but only if 300 miles of commuting per week with higher gasoline prices is not an economic strain. The same house also should be evaluated for its energy efficiency, because both the natural gas used to heat it in winter and the electricity used to cool it in summer are bound to become more expensive.

The American mindset tends to see any inducement designed to encourage conservation as restricting a basic freedom in our consumer society. As a result, we have arrived at this juncture sooner than was necessary. Only higher prices have ever led to appreciable conservation in the U.S., and as energy prices rise they will again curtail demand. It is impossible to predict exactly when prices will rise, or by how much, but energy inevitably will take an increasing share of everyone's budget. There are no guarantees concerning our energy future, but understanding the forces involved and taking simple precautions certainly will render us less vulnerable.

We have ample cause to be optimistic. The world economy and our average level of prosperity have grown dramatically, even as energy usage has become more efficient and less polluting. Although mankind will depend on fossil fuels for a very long time to come, history shows that we are adaptable. In spite of the many uncertainties that lie before us, the challenges ahead are no greater than those we already have overcome.

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