Chapter 9

NATURAL GAS

Natural gas is a domestically abundant source of clean energy. All price controls on natural gas at the wellhead will be eliminated by January 1993, under the Wellhead Decontrol Act of 1989. [...] The National Energy Strategy will remove regulation, except where necessary to protect consumers, while enabling all segments of the industry to expand by taking advantage of market opportunities. If fully implemented, the National Energy Strategy measures would increase U.S. consumption of natural gas by almost 1 trillion cubic feet (approximately 5 percent) over what it would have been in the year 2000 under pre-Strategy policies.

(*National Energy Strategy, Executive Summary*, 1991/1992)

The Administration's policy is to maximize the economic, environmental, and national security benefits of increased use of natural gas. To implement this policy, the Administration focuses on collaboration with industry to develop advanced natural gas technologies, provide incentives for increased exploration and production, stimulate end-use markets, and continue regulatory reforms that reduce costs and increase efficiency.

(*Sustainable Energy Strategy*, 1995)

Natural gas is a mixture of light hydrocarbons which exist in a gaseous state in a separate reservoir inside the earth's crust, or are dissolved in crude oil. (It is not to be confused with the term ‘gas’, often used in the media and in everyday language, which is of course the abbreviation for gasoline.) The principal component of natural gas is methane, CH_4. In many natural gas deposits, methane amounts to 80 to 90% of the gas.

Figure 9-1 summarizes the economically recoverable reserves of natural gas in the world. The proven world reserves of natural gas are about 3600 trillion cubic feet. Nations possessing large reserves of natural gas are the former Soviet Union (which has 37% of the world's supply), Iran (with about 25%), the United States, Algeria, the Netherlands, Saudi Arabia, Canada and Mexico. These same countries are among the leaders in natural gas production together with Indonesia and the UK, as illustrated in Figure 9-2. The United States and Russia account for 50% of today's production, while another 17 countries produce more than 1% of world's annual output for a total of 88% of world's production. Compare this distribution with that of coal (Review Question 7-2) and oil (Review Question 8-4). In the case of coal, 15 countries have 1% or more for a total of 97.1% of world's output. For petroleum, which is often considered to be a prototype of a monopolized resource (see Chapter 21), as many as 23 countries have 1% or more of world's annual output, for a total of 89.5%.

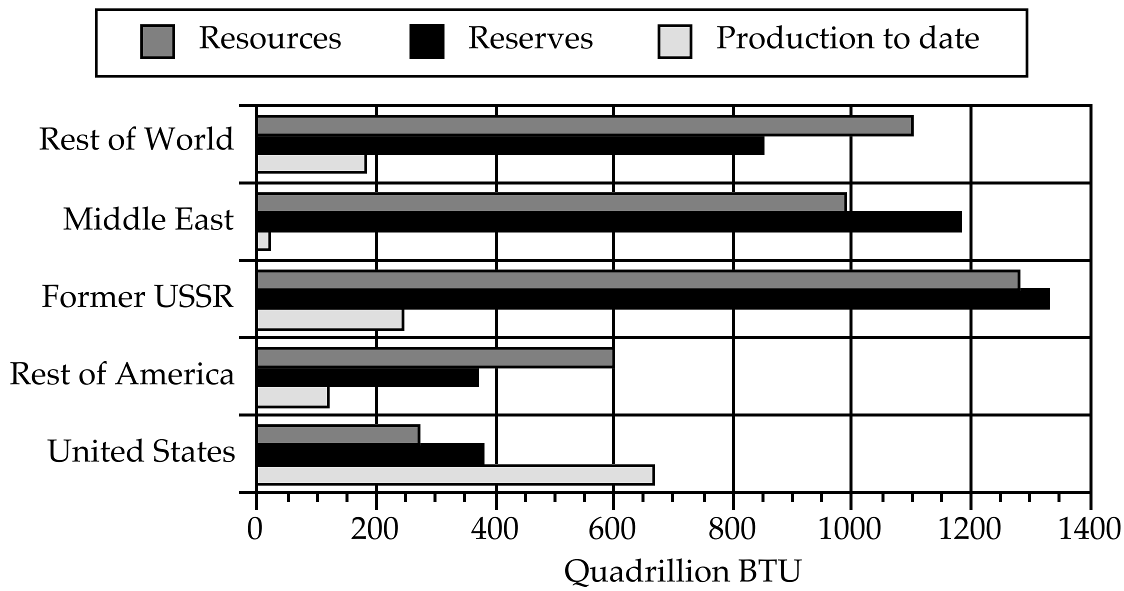

FIGURE 9-1. Summary of world's reserves and resources of natural gas.
[Source: W. Fulkerson et al., *Scientific American*, September 1990, p. 129)

Figure 9-3 shows the U.S. gas production and consumption trends in the last 65 years. In sharp contrast to the situation with petroleum (see Figure 8-3), and despite the dramatic increase in demand in the post-war era, domestic production has kept up with consumption. At the current consumption rate of 20 trillion cubic feet per year, the domestic reserves (see Figure 9-1) would be exhausted in less than two decades.

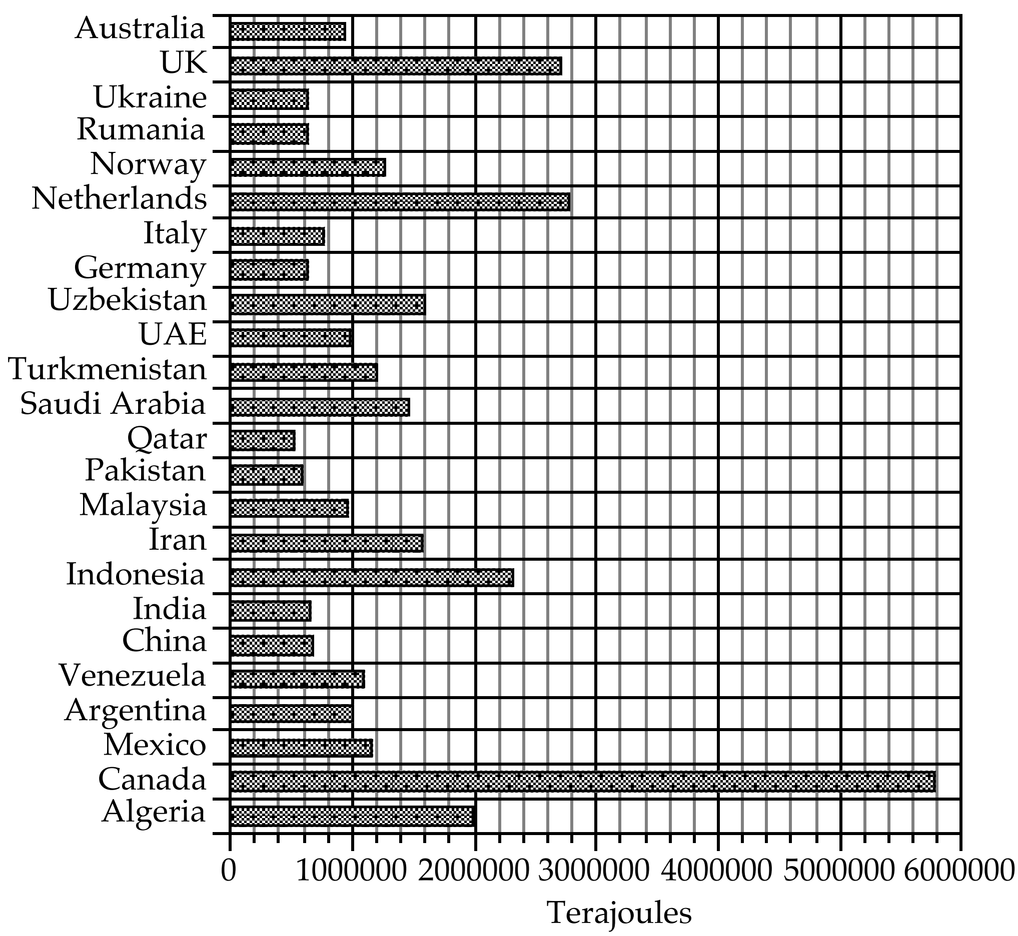

FIGURE 9-2. 1994 production of natural gas in selected countries.
[Source: 1994 Energy Statistics Yearbook, United Nations, 1996.]

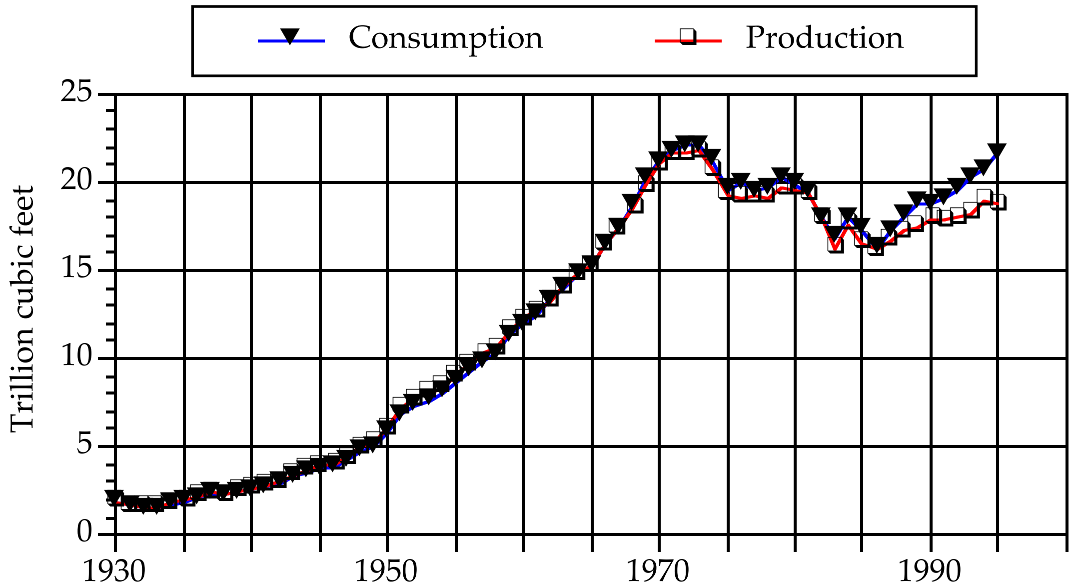

FIGURE 9-3. U.S. natural gas production and consumption.
[Source: Energy Information Administration.]

Formation of Natural Gas

Several processes result in the formation of methane. Some methane is produced by the bacterial degradation of organic matter, as in modern landfills. As petroleum was heated to high temperatures inside the earth, some of the molecules were split apart by heat, forming methane and other small hydrocarbon molecules. The deeper a crude oil was buried, the more cracking it had experienced because of the higher temperatures deep inside the earth (see Chapter 16). The repeated cracking of the hydrocarbon molecules resulted in the formation of shorter and shorter carbon chains, and eventually produced large amounts of molecules with one to four carbon atoms. These molecules are gases at ordinary temperatures. Hence, the deeper we drill for oil, the more likely we are to encounter substantial amounts of gas. In fact, at very great depths all of the hydrocarbons have cracked to gas, and we find no oil at all, only gas. The major commercial deposits of natural gas were formed in this way.

During the formation of coal, the increasing condensation of rings of carbon atoms into larger systems of rings can be accompanied by the breaking away of some single-carbon-atom fragments as methane. There is increasing interest in tapping into methane deposits in coal seams as a new source of natural gas. This gas is called *coalbed methane*. Doing so would be beneficial not only to provide a new gas supply, but also to lessen the hazards of gas accumulation in coal mines. Because methane is highly flammable, the accidental ignition of coalbed methane can cause devastating explosions in underground mines.

Natural gas is often found inside the earth's crust together with petroleum, as illustrated in Figures 8-4 and 8-9. In these cases, the gas is referred to as *associated gas*. At high underground pressures, natural gas might dissolve in crude oil and is then called *dissolved gas*. The gas is liberated when the pressure is released as the oil is brought to the surface. It is also possible for a pocket of natural gas to exist as a bubble over a pool of oil. Gas found in this way is called *gas cap gas.*

Gas can also migrate away from the oil until it becomes trapped by a layer of impervious rock in a reservoir of its own. This gas is known as *non-associated gas*. Roughly 65% of the gas recovered today in the U.S. comes from such gas wells, while the remaining 35% comes from oil wells.

Properties of Natural Gas

In addition to methane, natural gas usually contains small amounts of other small hydrocarbon molecules. These include ethane, C_2H_6, propane, C_3H_8, and butane, C_4H_{10}, all of which exist as gases at the ordinary pressures and temperatures of the earth's surface. In addition, small amounts of pentane, C_5H_{12}, and hexane, C_6H_{14}, may occur. At normal temperatures, pentane and hexane are liquids of low boiling points. However, at the elevated temperatures encountered inside the earth, they may be gases and form part of natural gas. In addition to these hydrocarbons, natural gas deposits may contain various amounts of inorganic compounds, including nitrogen, helium, carbon dioxide and hydrogen sulfide.

Illustration 9-1. Calculate the atomic carbon-to-hydrogen ratio in a Pennsylvania natural gas that contains 83.4% methane, 15.8% ethane and 0.8% nitrogen. Its elemental analysis is the following: 76.0% C; 22.8% H; 1.2% N.

Solution.

$$\frac{C}{H} = \frac{76.0\ g\ C}{22.8\ g\ H} = \left(\frac{76.0\ g\ C}{22.8\ g\ H}\right)\left(\frac{1\ g\ H}{1\ mol\ H}\right)\left(\frac{1\ mol\ C}{12\ g\ C}\right) = 0.28\,\frac{mol\ C}{mol\ H}$$

Thus, for every 100 H atoms there are 28 carbon atoms; this is almost the same ratio as in pure methane (CH_4, 1/4=0.25), as expected.

Utilization of Natural Gas

In many respects, natural gas is an ideal fuel, and there is not much more to be said about its use, if it is available. It has a relatively simple composition and a high calorific value. Compared to coal and especially petroleum, it requires very little processing before use. It is in a gaseous state, so its mixing with oxygen for efficient (complete) combustion is easy. It contains no minerals; therefore, upon combustion of natural gas, no ash residue is produced. In the discussion below we elaborate some of these statements.

Processing. When natural gas is brought to the earth's surface, pentane and hexane will condense to a liquid fuel called *natural gasoline*. Cooling the natural gas allows propane and butane to condense and form liquids. These compounds, along with ethane, are valuable materials for sale to the chemical industry, where they are converted to a myriad of synthetic products. For example, a propane-rich liquid is marketed as *liquefied petroleum gas*, almost universally known as *LPG*. The LPG is a very useful fuel, especially in rural areas not served by natural gas distribution networks. It is the fuel of choice for camper trailers and recreational vehicles and for gas-heated barbecue grills.

Natural gas that contains hydrogen sulfide, H_2S, is called *sour gas*. A sour gas is a highly undesirable commodity. Hydrogen sulfide has a vile odor – being responsible for the unforgettable odor of rotten eggs – and is also poisonous. When H_2S dissolves in water, it forms a mild acid that can corrode pipes, valves, meters and other components of the gas handling system. When the H_2S in the gas burns, it forms SO_2 and SO_3. As we shall see in Chapter 11, these gases contribute to air pollution, resulting in health problems and slowly corroding or destroying many materials. Before a sour gas can be sold, the H_2S must be separated. The relatively simple process of removing H_2S is called *sweetening*.

After most of the other hydrocarbons have been removed and the gas has been sweetened, it is ready for sale to consumers. At this point, the gas consists mainly of methane, with small amounts of ethane. Its heating value is about 1000 BTU/ft^3.

Transportation. Natural gas is mainly distributed by pipeline. A typical pipeline may contain gas at a pressure of about 65 atmospheres. The gas moves at about 15 miles per hour. Natural gas put into a pipeline in Texas on Monday morning would arrive in central Pennsylvania on Thursday night. There are about a million miles of gas pipelines in the United States, as compared with 200,000 miles of petroleum pipelines. Not only is the pipeline transportation an easy way to ship gas, but the large volume contained in a million miles of pipe also provides a great deal of gas storage capacity inside the pipeline system. Today there are some 7 trillion cubic feet of gas in underground storage in the U.S. This should be compared with the Strategic Petroleum Reserve; see Investigation 8-13.

International transportation of natural gas is usually done in refrigerated tankers. Low temperatures are used to reduce the volume of the material being shipped. Methane turns to liquid at -164 °C. The liquefied natural gas (LNG) requires only 1/600 of the volume of the same weight of methane gas at room temperature. The refrigerated-tank ships are, in a sense, large, floating thermos bottles. Algeria exports large quantities of LNG in this way.

In contrast to the situation with petroleum, imports of natural gas into the United States have never represented more than 7% of the total consumption (see Figure 9-2). But that may change if the consumption continues to increase and the trend of rising imports continues. The recently approved major gas pipeline from Canada to the northeastern U.S., with a projected capacity of 576 million cubic feet of gas per day, and the reopening of the Cove Point, Maryland, LNG terminal – idle since the 1979/1980 peak consumption years – could make this increase feasible (see Investigation 9-2).

Combustion. In many respects, therefore, natural gas is a premium fuel, particularly for residential use. It has the highest calorific value of any fossil fuel, 1000 BTU/ft^3 or 24,000 BTU/lb. It is easy to control the generation of heat, since natural gas burners offer instantaneous on/off capability. Natural gas is also a clean fuel. No ashes are produced upon combustion, and there is no mess in the home from handling or burning it. No fuel storage space is required at home. Space that would be used up by fuel oil tanks, a coal bin, or a wood pile can be put to better use. Normally gas is automatically available whenever the control valve to the furnace is opened. There is no need to make arrangements with a fuel company for periodic deliveries. Fluids (gases and liquids) are much more convenient to handle than are solids: compare shoveling snow or breaking ice cubes with pouring water or having it flow from a faucet.

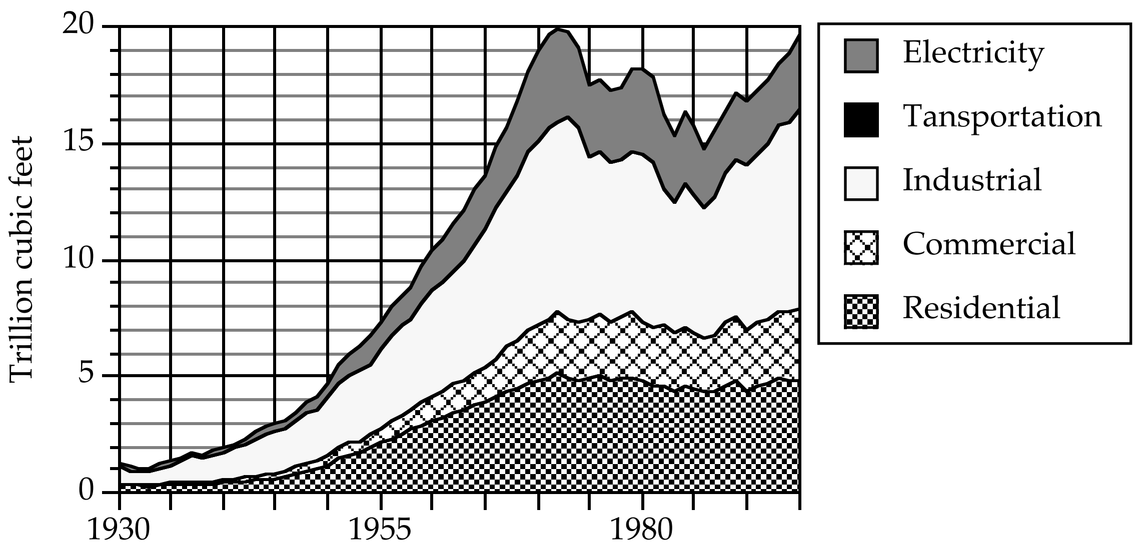

FIGURE 9-4. Natural gas consumption in the U.S. by economic sector. [Source: Energy Information Administration.]

The principal consumers of natural gas in the past 60 years are shown in Figure 9-4. Currently, about 44% of the natural gas used in the United States (some 8.6 trillion cubic feet) is burned for heating requirements in the various industrial processes. About 25% (4.8 trillion cubic feet) is consumed for residential heating, and another 15% (3.0 trillion cubic feet) for the heating of commercial buildings. Natural-gas-fired boilers in power plants consume some 16% of the natural gas used; this application consumes a premium fuel in a situation where a fuel of poorer quality, such as heavy fuel oils or coal, could possibly be used instead. A very small amount of natural gas (some 2.6 billion cubic feet) is currently used as transportation fuel, especially for fleet vehicles. This use is expected to undergo significant expansion in the future (see Chapter 20).

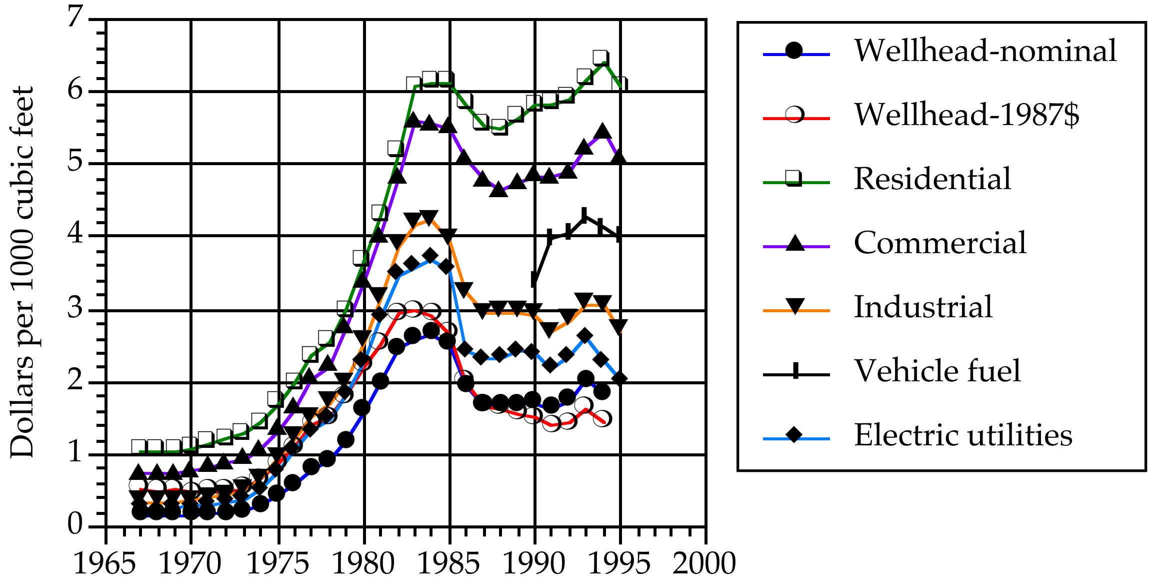

FIGURE 9-5. Historical trends in the average production and consumption prices of natural gas in the U.S. [Source: Energy Information Administration.]

The only big issues in natural gas use are its future availability and its price. The latter is shown in Figure 9-5. In the most recent past there has been a perception of an oversupply; this has led to both significant price decreases and a prevailing attitude that the oversupply is here to stay. Whether this is good news in the long term can be judged from detailed estimates of U.S. gas reserves. This information is summarized and contrasted to that for petroleum in Figure 9-6. The patterns are remarkably similar, except perhaps for the fact that the cumulative production of gas is not yet "peaking out" as much as that of petroleum. At annual production levels of 3 billion barrels of oil (Figure 8-3) and 20 trillion cubic feet of gas (Figure 9-4), the proven reserves of both would last less than 10 years, an even more alarming prediction than that made on the basis of information given in Figure 9-1.

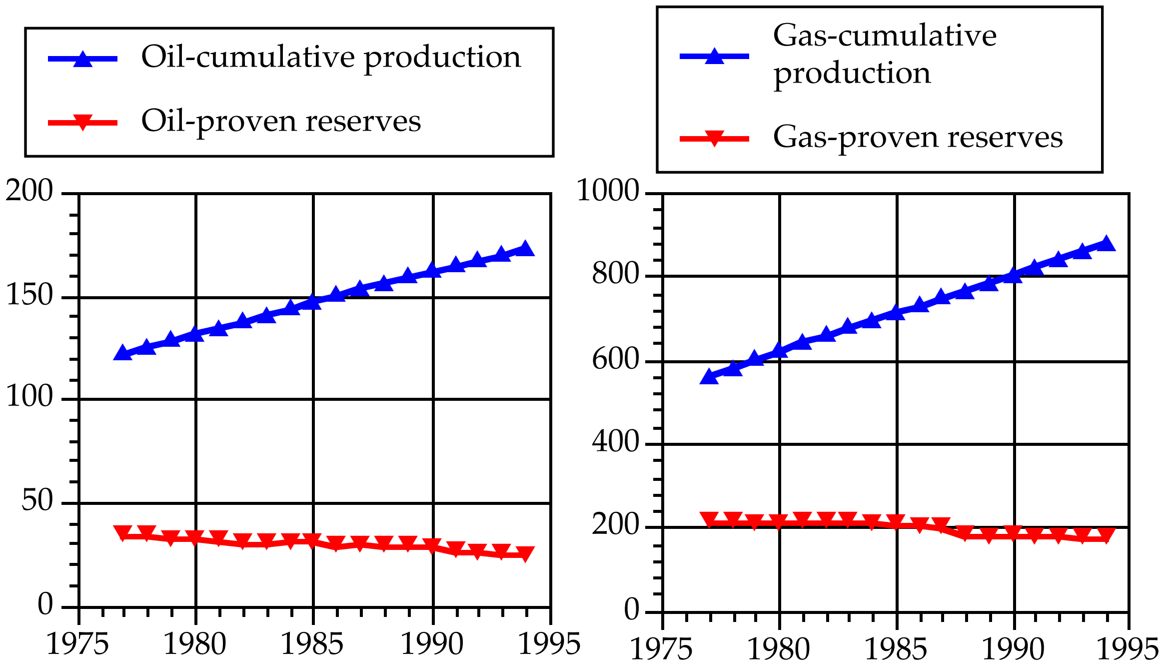

FIGURE 9-6. The future availability of fossil fuels is based on estimates of proven reserves and cumulative production trends such as these. The numbers for petroleum are in billions of barrels and those for natural gas are in trillion cubic feet.
[Source: Energy Information Administration.]

Of course, we have not yet run out of natural gas. It is true that the predicted lifetime can be estimated when the quantity of reserves is divided by the annual consumption rate. If the reserves are increased, or if the annual consumption rate is decreased, the predicted lifetime will become longer. As the apparent supplies of gas decrease, its cost will rise. An increase in cost will cause some consumers to switch to alternative fuel supplies, and other consumers will begin energy conservation measures (see Figure 21-3). In either case, the rate of consumption will drop. Furthermore, as the cost of gas increases, it becomes economically more attractive for gas companies to explore and drill to find new gas deposits or to better define existing gas fields. Hypothetical resources become conditional resources; conditional resources become possible or probable reserves; and possible or probable reserves become proven reserves (see Figure 5-8). Thus the reserve base increases. Both effects – decreasing use and increasing reserve base – stretch the anticipated lifetime of the reserves.

Even though all past predictions of the lifetime of natural gas reserves have been wrong, and even though changing economic conditions will increase the reserve base and decrease the rate of consumption, these predictions have been getting shorter and shorter over the past 40 years. A time is likely to come, perhaps sooner than expected, when traditional sources of natural gas will indeed become depleted. The many virtues of natural gas as a fuel, and the difficulty of switching all existing devices that burn natural gas to use other fuels, make it desirable to consider alternative sources of methane.

As mentioned previously, one such source is the methane produced as a by-product of the formation of coal. In current coal mining practices, this methane is considered a hazard because it can form explosive mixtures with the air inside the mine. However, coalbed methane is now known to be a valuable energy resource. According to the Department of Energy estimates, in 1992 it accounted for 5% of proved gas reserves. In the same year, nearly 5500 coalbed wells contributed 550 billion cubic feet of new natural gas supply. More than 90% of this supply came from the basins of San Juan in New Mexico and Black Warrior in Alabama. So the main technical issues of locating the methane and safely extracting it from the coal seam have now been resolved. The remaining issues are primarily economic. The surge in coalbed methane activity in the late 1980s and early 1990s has pretty much subsided for now, as the Section 29 tax credits expired in 1992. These tax credits (92 cents per million BTU for 1991 production) had been authorized by Congress to stimulate the development of clean domestic unconventional gas resources. It remains to be seen how soon coalbed methane will become competitive with conventional natural gas and with other energy sources. Stay tuned! (See Investigation 9-7).

In addition to coalbed methane, two other sources of unconventional natural gas need to be mentioned:

(a) Bacteria produce methane by acting on accumulating organic debris. This process can be accelerated and exploited in bacterial conversion of organic materials such as agricultural and forestry product wastes and municipal garbage. Doing so both generates useful methane and helps get rid of waste.

(b) As we shall see in Chapter 10, coal can be converted to *substitute natural gas*, thereby transforming a dirty, hard-to-handle fuel into a fuel that burns much cleaner and is easier to handle.

REVIEW QUESTIONS

9-1. Of all fossil fuels, combustion of natural gas will be shown in Chapter 11 to produce the least serious greenhouse effect. This conclusion is based on the calculation of the amount of carbon dioxide produced by burning these fuels (see Review Questions 6-4, 7-6 and 8-7. How many tons of CO_2 were produced in 1995 from natural gas combustion (see Figure 9-3)? Assume that natural gas is 100% methane and remember that the density of natural gas is 0.04 pounds per cubic foot (see Illustration 6-3).

9-2. Compare the natural gas production levels of Canada and the U.S. (Figures 9-2 and 9-3). Who produces more? By how much?

9-3. What was the total 1995 bill for residential gas consumption in the U.S.? Use the information provided in Figures 9-4 and 9-5.

9-4. An electric power plant produces 500 MW of electricity by burning natural gas. The efficiency of the plant is 35%. (a) How much gas does the plant consume every year? (b) How much did the utility pay for the gas in 1995? (Use the information in Figure 9-5.)

9-5. Indicate whether the following statements are true or false:
(a) More than 20% of the 1995 natural gas consumption in the U.S. was consumed in the residential sector.
(b) More than 10% of the 1972 gas in the U.S. was consumed for electricity generation.
(c) Ethane is the dominant hydrocarbon present in natural gas.
(d) It is difficult to separate sulfur-containing compounds from natural gas before its use.

INVESTIGATIONS

9-1. Asia is poised for rapid economic development in the 21st century. Do Asian nations have enough natural gas? Prepare a graph that compares their production and consumption of gas. See the *Economist* of 8/15/92 ("Asian energy: Quenching the tigers' thirst").

9-2. Increased utilization of natural gas is very much dependent on the existence of pipelines to transport it. Getting Alaskan oil to the energy-hungry Northeast is complicated. A gas pipeline from rich Canadian gas fields makes much more sense. Find out about the status of such a pipeline. See NYT of 1/21/92 ("Northeast Gas Pipeline Ready But Critics Still Doubt Need"), 1/26/92 ("Plenty of Gas Arrives, But at Shortage Prices"), 10/10/96 ("How to Make Pipelines Riskier" and "Democrats Urge Veto of Measure Easing Pipeline Regulations"), and 10/20/96 ("Energy: Playing With Fire").

9-3. Europe's access to natural gas also depends to a large extent on gas pipelines coming all the way from Russia. Find out more about this mixed blessing. See WSJ of 10/27/92 ("Disruptions in Flow of Natural Gas From Russia Give Europe Jitters"), BW of 11/28/94 ("A Russian Gas Giant May Get Some Foreign Fuel"); and NYT of 10/29/96 ("Selling Shares, Gazprom Generates Its Own Energy").

9-4. One option for a brighter world market outlook for natural gas is LNG (liquefied natural gas), but the challenges of its transportation have yet to be resolved. Find out more about some of these challenges. See the *Baltimore Sun* of 11/13/92 ("Cove Point LNG terminal to reopen"), *Economist* of 12/19/92 ("Liquefied natural gas: Expansive profits"), and *Chicago Tribune* of 11/14/96 ("Egypt taps Amoco for big natural gas plant").

9-5. Where are companies drilling for gas these days? See NYT of 3/2/92 ("Collapse of Natural Gas Prices Shakes Producers"), 10/7/94 ("Tenneco Unit To Help Chile Energy Plan"), 11/17/94 ("U.S. Companies Sign Big Indonesia Gas Deal"), 5/11/95 ("Huge Gas

Rig Begins Journey in Norway"), 12/8/96 ("Gas Project Energizes The Critics of Burmese"). See also *Time* of 3/16/92 ("The Great Energy Bust").

9-6. Find out the basic facts about a gas and energy company that has been very much in the news lately, Enron Corp. See NYT of 5/19/91 ("Bottom-Fishing in the Gas Patch"), 12/4/92 ("U.S. Company Wins Stake in Argentine Pipeline"), 2/12/95 ("A Natural-Gas Man Has a Certain Something") and 1/14/97 ("Enron, seeking to be a household name, plans to start its campaign on Super Bowl Sunday"). Explore the Internet as well, both by visiting its Web site (www.enron.com) and using several Internet search engines.

9-7. The use of coalbed methane is a good example of an action that kills two birds with one stone. Find out about its recent past and its current status. See NYT of 12/26/90 ("Drillers Find Coalbeds Yield Gas and Profits") and 1/10/93 ("Capturing Methane From the Coal Mines"); and *USA Today* of 12/9/92 ("Mine's heat, smoke turn back rescuers").

9-8. When the price of an energy resource takes a dive, as that of natural gas did in late 1980s and early 1990s (see Figure 9-5), the independent producers are hit the hardest (see Investigation 8-21). Find out about one such family-owned company, Mitchell Energy & Development Corp. See NYT of 3/22/92 ("Keeping the Faith in the Gas Patch").

9-9. The price of natural gas is very sensitive to weather caprices such as hurricanes and mild or harsh winters. Find out why by reading about some of the recent such episodes. See WSJ of 9/21/92 ("Natural Gas Prices and Futures Gain Strength As Supply and Demand Create a Delicate Balance"), 10/16/92 ("Natural Gas Prices Surge Second Day in a Row On Supply Concerns and Forecasts of Cold Snap"), 1/16/96 ("Natural-Gas Prices Fall 13% as Weather Warms"); NYT of 9/28/92 ("Consumers Face Rise in Gas Heating Costs"), 6/6/95 ("Natural Gas Prices Rise Sharply On Storm-Related Supply Cuts").

9-10. What follows is a typical newspaper advertisement by a natural gas company (this one is from Columbia Gas, 1-800-866-4GAS). Do you 'buy' these arguments? Why or why not?
"(1) COMFORT. Warm heat is gas heat. Keeps your whole house comfy and cozy even on the most frigid days...and nights. (2) CLEANLINESS. Gas is better for the environment than any other fossil fuel. Only the sun, the wind and water are cleaner forms of energy. (3) VALUE. Gas has always been one of the most economical ways to heat, and gas increases the value of your home. (4) MADE IN THE U.S.A. We have enough gas reserves right here in the U.S. to last far into the future, without depending on foreign sources. (5) ADVANCED TECHNOLOGY. Modern gas furnaces are up to 96% efficient, using up to 30% less energy than models built just ten years ago. That saves energy *and* money."

9-11. Unlike the electric utilities (see Investigation 18-3), the natural gas industry has been 'deregulating' for years. Find out more about the new markets for gas producers, pipeline companies and gas utilities. See NYT of 10/23/96 ("Natural Gas, Unnatural Selection").