# 1 Overview of the Natural Gas Industry

## 1.1 INTRODUCTION

The Chinese are reputed to have been the first to use natural gas commercially, some 2,400 years ago. The gas was obtained from shallow wells, transported in bamboo pipes, and used to produce salt from brine in gas-fired evaporators. Manufactured, or town, gas (gas manufactured from coal) was used in both Britain and the United States in the late 17th and early 18th centuries for streetlights and house lighting The next recorded commercial use of natural gas occurred in 1821. William Hart drilled a shallow 30-foot (9-meter) well in Fredonia, New York, and, by use of wooden pipes, transported the gas to local houses and stores (Natural Gas Suppliers Association, 2004).

During the following years, a number of small, local programs involved natural gas, but large-scale activity began in the early years of the 20th century. The major boom in gas usage occurred after World War II, when engineering advances allowed the construction of safe, reliable, long-distance pipelines for gas transportation. At the end of 2004, the United States had more than 297,000 miles (479,000 kilometers) of gas pipelines, both interstate and intrastate. In 2004 the U.S. was the world's second largest producer of natural gas (19.2 trillion cubic feet [Tcf]*, 543 BSm$^3$) and the leading world consumer (22.9 Tcf, 647 BSm$^3$). (Energy Information Administration, 2005h and BP Statistical Review of World Energy, 2005)

Although the primary use of natural gas is as a fuel, it is also a source of hydrocarbons for petrochemical feedstocks and a major source of elemental sulfur, an important industrial chemical. Its popularity as an energy source is expected to grow substantially in the future because natural gas presents many environmental advantages over petroleum and coal, as shown in Table 1.1. Carbon dioxide, a greenhouse gas linked to global warming, is produced from oil and coal at a rate approximately 1.4 to 1.75 times higher than production from natural gas.

Both atmospheric nitrogen and nitrogen in fuel are sources of nitrogen oxides ($NO_X$), which are greenhouse gases and a source of acid rain. Because both oil and coal contain nitrogen compounds not present in natural gas, the nitrogen oxides formed from burning natural gas are approximately 20% of those produced

---

* Gas volumes are normally reported in terms of standard cubic feet (scf) at standard conditions of 60°F and 14.7 psia. In metric units, the volumes are given in either normal cubic meters, Nm$^3$, where standard conditions are 0°C, 1 bar, or standard cubic meters, Sm$^3$, where the standard conditions are 15°C, 1 bar. In the U.S. gas industry, prefix M represents $10^3$, and MM, B, and T represent $10^6$, $10^9$, and $10^{12}$, respectively. We use this convention for both engineering and SI units.

### TABLE 1.1
### Pounds of Air Pollutants Produced per Billion Btu of Energy

| Pollutant | Natural Gas[a] | Oil[b] | Coal[c] |
|---|---|---|---|
| Carbon dioxide | 117,000 | 164,000 | 208,000 |
| Carbon monoxide | 40 | 33 | 208 |
| Nitrogen oxides | 92 | 448 | 457 |
| Sulfur dioxide | 0.6 | 1,122 | 2,591 |
| Particulates | 7.0 | 84 | 2,744 |
| Formaldehyde | 0.750 | 0.220 | 0.221 |
| Mercury | 0.000 | 0.007 | 0.016 |

[a] Natural gas burned in uncontrolled residential gas burners.

[b] Oil is # 6 fuel oil at 6.287 million Btu per barrel and 1.03% sulfur with no postcombustion removal of pollutants.

[c] Bituminous coal at 12,027 Btu per pound and 1.64% sulfur with no postcombustion removal of pollutants.

*Source*: Energy Information Administration (1998).

when oil or coal is burned. Particulate formation is significantly less in gas compared with coal and oil, an important environmental consideration because in addition to degrading air quality, high levels of particulates may pose significant health problems.

The values reported in Table 1.1 for sulfur dioxide can be misleading. Many natural gases contain considerable quantities of sulfur at the wellhead, but specifications for pipeline-quality gas require almost total sulfur removal before pipelining and sale. Consequently, the tabular values for natural gas represent combustion after removal of sulfur compounds, whereas the tabular values for oil and coal are reported for fuels with no sulfur recovery either before or after combustion. Nevertheless, gas produces far fewer pollutants than its competitors, and demand for gas, the clean fuel, is expected to rise significantly in the near future.

### 1.1.1 WORLD PICTURE FOR NATURAL GAS

The current status of primary energy sources is summarized in Figure 1.1. Basically, dry natural gas (natural gas with natural gas liquids [NGLs] removed) is on a par with coal in importance.

Six countries possess two thirds of the world's gas reserves (Figure 1.2), with almost half of the reserves located in Iran and Russia. The total reported natural gas reserves (~6,040 Tcf [171 TSm$^3$] at the beginning of 2005 [Energy Information Administration, 2005c]) do not include discovered reserves that are not economically feasible to bring to market. This "stranded gas" resides in remote regions, where the reserve size does not justify the cost of the infrastructure required to bring it to market. Note that proven reserve estimates are truly

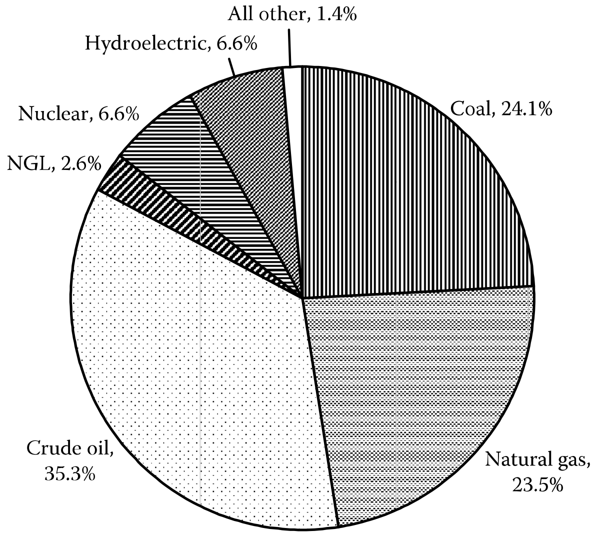

**FIGURE 1.1** Primary sources of energy in the world in 2003. Total energy used was 405 quadrillion Btu (Energy Information Administration, 2005b).

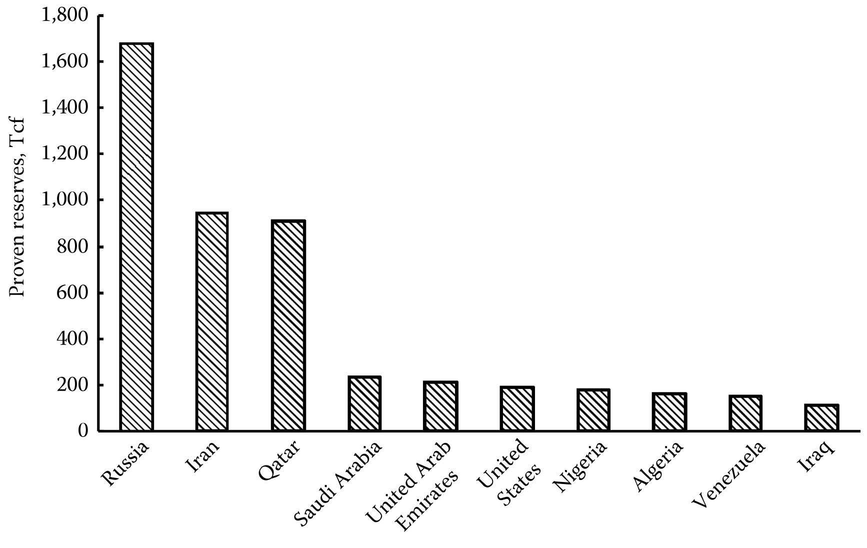

**FIGURE 1.2** Major proven natural gas reserves by country. Total proven reserves estimated to be 6,040 Tcf (Energy Information Administration, 2005c).

### TABLE 1.2
### World Natural Gas Production and Estimated Proven Reserves at End of 2002

| Region | Gross Production[a] | Vented or Flared[a] | Reinjected[a] | Marketed Production[a] | Dry Gas Production[a] | Proven Reserves[b] |
|---|---|---|---|---|---|---|
| North America | 33,060 | 176 | 3.895 | 28,487 | 26,893 | 255,800 |
| | (936) | (4.98) | (110) | (807) | (762) | (7,243) |
| | 29.5% | 6.3% | 31.0% | 29.5% | 29.2% | 4.6% |
| Central and South America | 5,983 | 350 | 1,404 | 4,229 | 3,722 | 250,100 |
| | (169) | (9.91) | (39.76) | (120) | (105) | (7,082) |
| | 5.3% | 12.5% | 11.2% | 4.4% | 4.0% | 4.5% |
| Western Europe | 12,333 | 135 | 1,236 | 10,963 | 10,548 | 191,600 |
| | (349) | (3.82) | (35.0) | (310) | (299) | (5,426) |
| | 11.0% | 4.8% | 9.8% | 11.4% | 11.4% | 3.5% |
| Eastern Europe and former U.S.S.R. | 27,047 | 253[c] | 1 | 27,046 | 27,046 | 1,964,200 |
| | (766) | (7.16) | (0.03) | (766) | (766) | (55,620) |
| | 24.1% | 9.1% | 0.0% | 28.0% | 29.3% | 35.7% |
| Middle East | 12,667 | 413 | 2,696 | 9,558 | 8,674 | 1,579,700 |
| | (359) | (11.69) | (76.34) | (271) | (246) | (44,732) |
| | 11.3% | 14.8% | 21.4% | 9.9% | 9.4% | 28.7% |
| Africa | 9,450 | 1,241 | 3,007 | 5,202 | 4,741 | 418,200 |
| | (268) | (35.14) | (85.15) | (147) | (134) | (11,842) |
| | 8.4% | 44.5% | 23.9% | 5.4% | 5.1% | 7.6% |
| Asia and Oceania | 11,637 | 224 | 331 | 11,083 | 10,528 | 445,400 |
| | (330) | (6.34) | (9.37) | (314) | (298) | (12,612) |
| | 10.4% | 8.0% | 2.6% | 11.5% | 11.4% | 8.1% |
| World total | 112,178 | 2,792 | 12,570 | 96,568 | 92,152 | 5,504,900 |
| | (3,177) | (79.06) | (355.94) | (2,735) | (2,609) | (155,881) |

[a] Data from Energy Information Administration (2005d).

[b] Data from Energy Information Administration (2004a).

[c] Value given is for 1998 as an estimate because value for 2002 was unreported.

Values are in Bcf (BSm$^3$) and percentage values are percent of world total.

estimates and vary among sources. Also, proven reserves depend on gas prices; increased gas price causes reserve estimates to rise.

The world production of natural gas is summarized in Table 1.2. Noteworthy are the relationships between production and reserves in North America and Eastern Europe and the high percentage of gas flared or vented in Africa. North America (principally the United States) has the world's second largest production of dry gas and accounts for 29% of world production but possesses only 5% of the reserves. Eastern Europe slightly leads North America in dry gas production but has 36% of

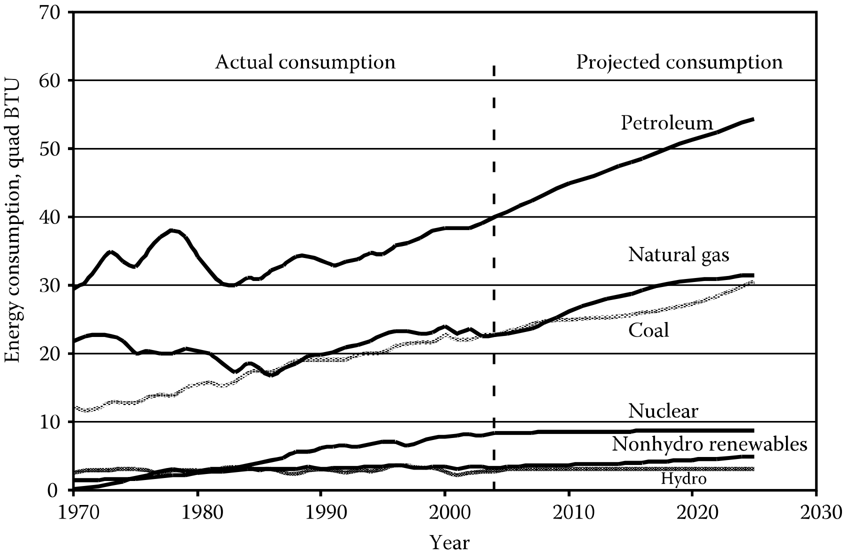

**FIGURE 1.3** United States energy consumption by fuel. (Adapted from Energy Information Administration, 2005a.)

the world reserves; three quarters of those reserves are located in Russia. Africa vents or flares 13% of gross production, an exceptionally high number considering that the world average, excluding Africa, is an estimated 2.3%. The disproportionately high loss in Africa is caused by the lack of infrastructure in many of the developing nations. Nigeria alone flares 2 MMscfd (56 $MSm^3/d$*), which is equivalent to the total annual power generation in sub-Saharan Africa. An effort is underway to reduce flaring and to convert much of the gas to LNG for export (Anonymous, 1999).

## 1.1.2 NATURAL GAS IN UNITED STATES

Natural gas plays an extremely important role in the United States and accounts for approximately 23% of the total energy used. Figure 1.3 shows the relationship among energy sources in the United States, as well as projected growth through 2025. Gas is presently second only to petroleum, and the difference in demand for gas over coal is expected to increase substantially with time. Of interest is the prediction that energy from nuclear and hydroelectric sources will be flat, and nonhydroelectric renewables are not expected to play a significant role through 2025.

The distribution of natural gas from the wellhead through consumption is shown in Figure 1.4. The numbers reveal some significant points. First, substantial amounts of the gross gas produced (14%) are returned to the reservoir for repressurization of the field. Second, the loss of gas because of venting or flaring is quite small,

---

* In this book the symbol M represents 1000 for both engineering and SI units.

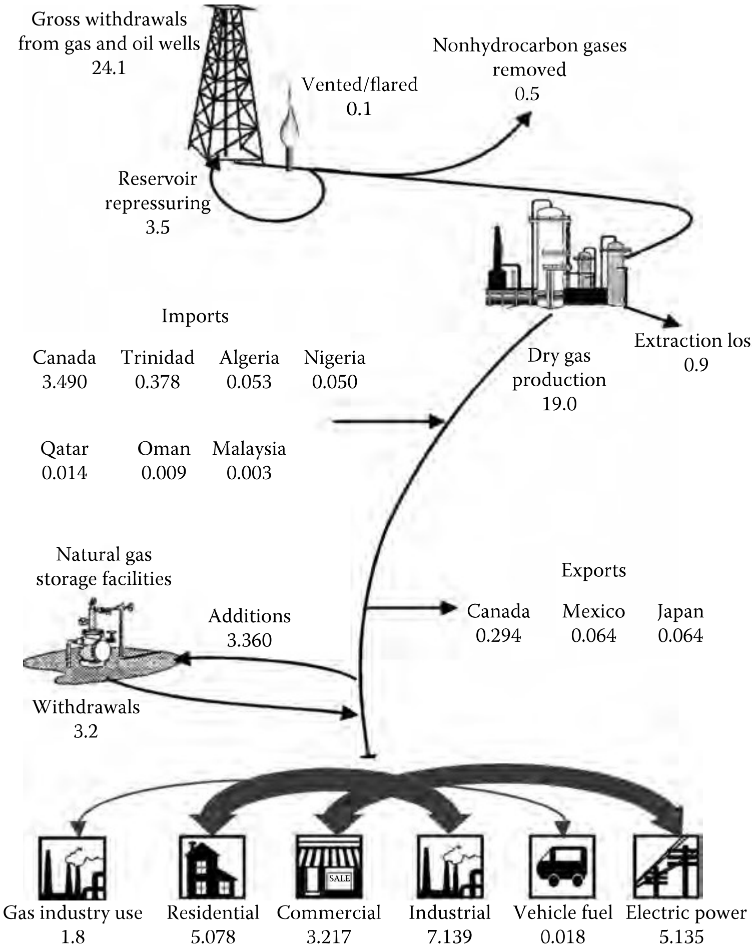

**FIGURE 1.4** Natural gas supply and disposition in the United States in 2003. Values shown are in Tcf. (Adapted from Energy Information Administration, 2005d.)

only 0.4% of the gross withdrawal. Third, the nonhydrocarbon gases removed (2.5% of gross) occur in sufficient quantities to render the gas unmarketable, and the extraction losses (4.1% of gross) refer to liquids (NGL) removed from the gas and sold separately. Fourth, the imports that account for approximately 18% of the consumption come predominately from Canada.

In November, 2005, the average wellhead, city gate, and residential prices were $9.84, $11.45 and $15.80 per thousand cubic feet, respectively (Energy Information Agency, 2006 i).

Table 1.3 shows that in the area of production and reserves, imports account for approximately 19% of consumption, but, of that amount, LNG imports are only 2.9% of total consumption. Also worthy of note is that proven reserves in 2004 constituted only an 8-year supply at the current rate of consumption.

**TABLE 1.3**
**Natural Gas in the United States, 2004**

| | |
|---|---|
| U.S. Production | 18 Tcf (510 BSm$^3$) |
| U.S. Consumption | 22.4 Tcf (634 BSm$^3$) |
| U.S. Imports | 4.2 Tcf (120 BSm$^3$) |
| U.S. Exports | 0.85 Tcf (24 BSm$^3$) |
| Wellhead price | $5.49/Mscf |
| Average city-gate price[a] | $6.65/Mscf |
| Average price to residential customers | $10.74/Mscf |
| Average price to commercial customers | $9.26/Mscf |
| Average price to industrial customers | $6.41/Mscf |
| Average price to electrical utilities | $5.56/Mscf |
| LNG imports | 0.65 Tcf (18 BSm$^3$) |
| Number of producing gas and gas condensate wells (2003) | 393,327 |
| Pipeline miles (2003) | 306,000 (492,000 km) |
| Pipeline capacity (2003) | 178 Bcfd (5 BSm$^3$/day) |
| Dry natural gas proven reserves | 189 Tcf (5.35 BSm$^3$) |

[a] City gate is the point where the gas is transferred from the pipeline to the distribution facilities.
*Source*: Energy Information Administration (2005g).

### 1.1.3 NONCONVENTIONAL GAS RESERVES IN UNITED STATES

At present, the two major potential nonconventional gas sources are coal bed methane (CBM) and naturally occurring gas hydrates. The United States Geological Survey (USGS) estimates 700 Tcf (20 TSm$^3$) of CBM in the United States, but only 100 Tcf (3 TSm$^3$) are recoverable with existing technology (Nuccio, 2000). The most active region is the Powder River Basin area of Wyoming and Montana. Environmental concerns may limit production (National Petroleum Technology Office, 2004).

Naturally occurring gas hydrates (see Chapter 3) form on the ocean bottom and in sediments of permafrost regions, such as northern Canada and Alaska. The USGS estimates about 320,000 Tcf (9,000 TSm$^3$) of methane in hydrates in the United States; one half of that reserve is in offshore Alaska (Collett, 2001). An estimated 45 Tcf (1.2 TSm$^3$) in gas hydrates is on the North Slope of Alaska, where oil is currently produced. These reserves would be the most economically attractive to produce because the hydrates are concentrated, and much of the infrastructure for gas processing already exists. However, for the gas to reach the market, a pipeline must be built.

## 1.2 SOURCES OF NATURAL GAS

Conventional natural gas generally occurs in deep reservoirs, either associated with crude oil (associated gas) or in reservoirs that contain little or no crude oil (nonassociated gas). Associated gas is produced with the oil and separated at the casinghead or wellhead. Gas produced in this fashion is also referred to as casinghead gas, oil well gas, or dissolved gas. Nonassociated gas is sometimes referred to as gas-well gas or dry gas. However, this dry gas can still contain significant amounts of NGL components. Roughly 93% of the gas produced in the United States is nonassociated (Energy Information Administration, 2004b). A class of reservoirs, referred to as gas condensate reservoirs, occurs where, because of the high pressures and temperatures, the material is present not as a liquid or a gas but as a very dense, high-pressure fluid.

Figure 1.5 shows a simplified flow of material from reservoir to finished product and provides an overall perspective of the steps involved in taking natural

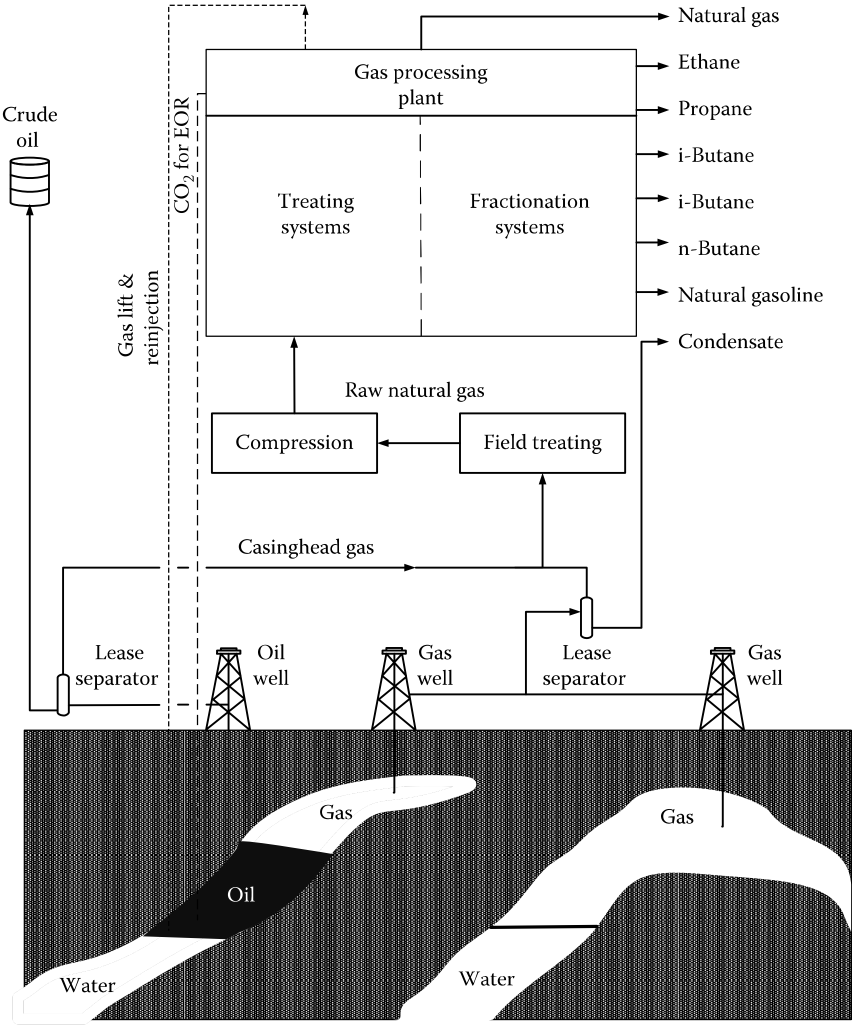

FIGURE 1.5 Schematic overview of natural gas industry. (Adapted from Cannon, 1993.)

gas from the wellhead to the customer. The chapters that follow provide more detail on the various steps. Note that Figure 1.5 oversimplifies the gas gathering systems. These systems typically are complex, and they bring gas from many fields and leases to gas plants.

Some gas plants receive feeds from refineries. These streams differ from natural gases in that they can contain propylene and butylene. They may also contain trace amounts of undesirable nitrogen compounds and fluorides. This book considers only the processing of gas and liquids coming directly from gas and oil leases.

## 1.3 NATURAL GAS COMPOSITIONS

### 1.3.1 Traditional Natural Gas

Traditional natural gases, that is, associated and unassociated gas from wells, vary substantially in composition. Table 1.4 shows a few typical gases. Water is almost always present at wellhead conditions but is typically not shown in the analysis. Some gas fields, however, contain no water. Unless the gas has been dehydrated before it reaches the gas processing plant, the common practice is to assume the entering gas is saturated with water at the plant inlet conditions.

**TABLE 1.4**
**Typical Gas Compositions**

| | Canada (Alberta) | Western Colorado | Southwest Kansas | Bach Ho Field[a] Vietnam | Miskar Field Tunisia | Rio Arriba County, New Mexico | Cliffside Field, Amarillo, Texas |
|---|---|---|---|---|---|---|---|
| Helium | 0.0 | 0.0 | 0.45 | 0.00 | 0.00 | 0.0 | 1.8 |
| Nitrogen | 3.2 | 26.10 | 14.65 | 0.21 | 16.903 | 0.68 | 25.6 |
| Carbon dioxide | 1.7 | 42.66 | 0.0 | 0.06 | 13.588 | 0.82 | 0.0 |
| Hydrogen sulfide | 3.3 | 0.0 | 0.0 | 0.00 | 0.092 | 0.0 | 0.0 |
| Methane | 77.1 | 29.98 | 72.89 | 70.85 | 63.901 | 96.91 | 65.8 |
| Ethane | 6.6 | 0.55 | 6.27 | 13.41 | 3.349 | 1.33 | 3.8 |
| Propane | 3.1 | 0.28 | 3.74 | 7.5 | 0.960 | 0.19 | 1.7 |
| Butanes | 2.0 | 0.21 | 1.38 | 4.02 | 0.544 | 0.05 | 0.8 |
| Pentanes and heavier | 3.0 | 0.25 | 0.62 | 2.64 | 0.630 | 0.02 | 0.5 |

[a] Tabular mol% data is on a wet basis (1.3 mol% water)

*Source*: U.S. Bureau of Mines (1972) and Jones et al. (1999).

### 1.3.2 IMPORTANT IMPURITIES

A number of impurities can affect how the natural gas is processed:

Water. Most gas produced contains water, which must be removed. Concentrations range from trace amounts to saturation.

Sulfur species. If the hydrogen sulfide ($H_2S$) concentration is greater than 2 to 3%, carbonyl sulfide (COS), carbon disulfide ($CS_2$), elemental sulfur, and mercaptans* may be present.

Mercury. Trace quantities of mercury may be present in some gases; levels reported vary from 0.01 to 180 $\mu g/Nm^3$. Because mercury can damage the brazed aluminum heat exchangers used in cryogenic applications, conservative design requires mercury removal to a level of 0.01 $\mu g/Nm^3$ (Traconis et al., 1996)

NORM. Naturally occurring radioactive materials (NORM) may also present problems in gas processing. The radioactive gas radon can occur in wellhead gas at levels from 1 to 1,450 pCi/l (Gray, 1990).

Diluents. Although the gases shown in Table 1.4 are typical, some gases have extreme amounts of undesirable components. For example, according to Hobson and Tiratso (1985), wells that contain as much as 92% carbon dioxide (Colorado), 88% hydrogen sulfide (Alberta, Canada), and 86% nitrogen (Texas) have been observed.

Oxygen. Some gas-gathering systems in the United States operate below atmospheric pressure. As a result of leaking pipelines, open valves, and other system compromises, oxygen is an important impurity to monitor. A significant amount of corrosion in gas processing is related to oxygen ingress.

### 1.3.3 COAL BED METHANE

Coal beds contain large amounts of natural gas (usually referred to as coal bed methane, or CBM) that is adsorbed on the internal surfaces of the coal or absorbed within the coal's molecular structure. This gas can be produced in significant quantities from wells drilled into the coal seam by lowering the reservoir pressure. As is the case with conventional natural gas, the composition of the CBM produced varies widely. In addition to methane, these gases may contain as much as 20% ethane and heavier hydrocarbons, as well as substantial levels of carbon dioxide. However, a typical CBM analysis would reveal water saturation, up to 10% carbon dioxide, up to 1% nitrogen, no or very small amounts of ethane and heavier hydrocarbons, and a balance of methane. Because water is normally

---

* Mercaptans are highly reactive and odiferous, organic compounds with the formula RSH, in which R represents an alkane group. Natural gases typically contain methyl through amyl mercaptans. The ethyl and propyl mercaptans are added to natural gas and propane as odorants. They received their name from being reactive with mercury. The compounds readily oxidize in the presence of air and metal to form disulfides that are nearly odorless.

**TABLE 1.5**
**Quality of Proven Natural Gas Reserves of the Lower 48 United States in 1998**

| | Bcf (BSm$^3$) | % |
|---|---|---|
| High quality | 87,679 (2,464) | 59 |
| Subquality | 60,698 (1,699) | 41 |
| High $N_2$ only | 15,617 (424) | 11 |
| High $CO_2$ only | 17,932 (481) | 12 |
| High $H_2S$ only | 5 691 (161) | 4 |
| High $N_2$ & $CO_2$ | 1,577 (29) | 1 |
| High $N_2$ & $H_2S$ | 600 (17) | 0 |
| High $CO_2$ & $H_2S$ | 12,697 (340) | 9 |
| High $N_2$, $CO_2$, & $H_2S$ | 6,585 (170) | 4 |
| Total | 148,377 (4,191) | 100 |

*Source*: Meyer (2000).

present in the reservoir, it is produced in significant amounts along with the CBM, and this produced water can pose a significant problem because it may contain large quantities of dissolved solids that make it unfit for domestic or agricultural uses (National Petroleum Technology Office, 2004).

### 1.3.4 SUBQUALITY GAS

The Gas Research Institute (Meyer, 2000) classified natural gases from the lower 48 states as high quality and subquality. Subquality is divided into seven categories, depending on the amount of $N_2$, $CO_2$, and $H_2S$ present. For their definition of subquality. The gas contains more than 2% $CO_2$, 4%$N_2$, and 4 ppmv $H_2S$. Table 1.5 summarizes the evaluation for proven raw reserves.

## 1.4 CLASSIFICATION

Natural gases commonly are classified according to their liquids content as either lean or rich and according to the sulfur content as either sweet or sour. This section provides some quantification of these qualitative terms.

### 1.4.1 LIQUIDS CONTENT

Gas composition plays a critical role in the economics of gas processing. The more liquids, usually defined as $C_2$+, in the gas, the "richer" the gas. Extraction of these liquids produces a product that may have a higher sales value than does natural gas.

To quantify the liquids content of a natural gas mixture, the industry uses GPM, or gallons of liquids recoverable per 1,000 standard cubic feet (Mscf) of gas. (In metric units, the quantity is commonly stated as m$^3$ of liquid per 100 m$^3$

of gas.) The term usually applies to ethane and heavier components but sometimes applies instead to propane and heavier components. Determination of the GPM requires knowledge of the gas composition on a mole basis and the gallons of liquid per lb-mole. See Appendix B for the gallons per lb-mole for ethane and higher hydrocarbons. Note that ethane is not a liquid at 60°F (15.5°C), so the value is a hypothetical value accepted throughout the industry. Also, the actual volume of liquid obtained from a gas will be less than the GPM value because complete recovery of ethane and propane is impractical for two reasons:

1. Cost. The low temperature and high compression energy required generally makes recovery of more than about 90 to 95% of the ethane, 98% of the propane, and 99% of the butanes uneconomical. Higher ethane recovery plants also have higher recovery of propane and heavier components.
2. Heating value specifications. As discussed below, a specification applies to the heating value of gas. Unless the gas contains no nonflammable diluents (i.e., $N_2$ and $CO_2$), additional hydrocarbons must be in the gas to obtain the required heating value.

---

**Example 1.1** Calculate the GPM of the Alberta gas given in Table 1.4. Computation of the GPM requires summation of the product of the number of moles of each component in 1,000 scf of gas by the gallons of liquid per mole for that component.

**Basis:** 1,000 scf of gas.

A lb-mole of gas at standard conditions has a volume of 379.49 $ft^3$. This volume translates into 1,000/379.49, or 2.6351 lb-moles for 1,000 scf. This value is multiplied by the mole fraction of each component in the gas and by the gallons of liquid for each component. Table 1.6 summarizes the calculations.

### TABLE 1.6
### Calculation of GPM of Alberta Gas

| | Mole % | Moles | Gal/Mole | GPM |
|---|---|---|---|---|
| Helium | 0 | 0.0000 | 0 | 0 |
| Nitrogen | 3.2 | 0.0843 | 0 | 0 |
| Carbon dioxide | 1.7 | 0.0448 | 0 | 0 |
| Hydrogen sulfide | 3.3 | 0.0870 | 0 | 0 |
| Methane | 77.1 | 2.0317 | 0 | 0 |
| Ethane | 6.6 | 0.1739 | 10.126 | 1.761 |
| Propane | 3.1 | 0.0817 | 10.433 | 0.852 |
| Butanes | 2.0 | 0.0527 | 12.162 | 0.641 |
| Pentanes and heavier | 3.0 | 0.0791 | 13.713 | 1.084 |
| Totals | 100.0 | 2.6351 | | 4.338 |

For this example, the Gal/mole for butanes was taken as the average of isobutane and n-butane; the value for $C_5$+ was taken to be that of pure n-pentane. The resulting GPM for this gas is 4.34.

The rich and lean terms refer to the amount of recoverable hydrocarbons present. The terms are relative, but a lean gas will usually be 1 GPM, whereas a rich gas may contain 3 or more GPM. Thus, the gas described above is considered fairly rich.

### 1.4.2 SULFUR CONTENT

Sweet and sour refer to the sulfur (generally $H_2S$) content. A sweet gas contains negligible amounts of $H_2S$, whereas a sour gas has unacceptable quantities of $H_2S$, which is both odiferous and corrosive. When present with water, $H_2S$ is corrosive. The corrosion products are iron sulfides, $FeS_X$, a fine black powder. Again, the terms are relative, but generally, sweet means the gas contains less than 4 ppmv of $H_2S$. The amount of $H_2S$ allowable in pipeline-quality gas is between 0.25 and 1.0 grains per 100 scf (6 to 24 mg/$Sm^3$, 4 to 16 ppmv).

## 1.5 PROCESSING AND PRINCIPAL PRODUCTS

The two primary uses for natural gas are as a fuel and as a petrochemical feedstock, and consequently, the three basic reasons for processing raw natural gas are the following:

- Purification. Removal of materials, valuable or not, that inhibit the use of the gas as an industrial or residential fuel
- Separation. Splitting out of components that have greater value as petrochemical feedstocks, stand alone fuels (e.g., propane), or industrial gases (e.g., ethane, helium)
- Liquefaction. Increase of the energy density of the gas for storage or transportation

Depending on the situation, a process may be classified as either separation or purification. For example, if a small amount of $H_2S$ is removed, incinerated, and vented to the atmosphere, the process is purification, but if large amounts of $H_2S$ are removed and converted to elemental sulfur, often a low-priced commodity, the process is considered separation. Figure 1.6 provides an overview of the materials present in natural gas and the slate of possible products from the gas plant.

Although the principal use of natural gas is the production of pipeline-quality gas for distribution to residential and industrial consumers for fuel, a number of components in natural gas are often separated from the bulk gas and sold separately.

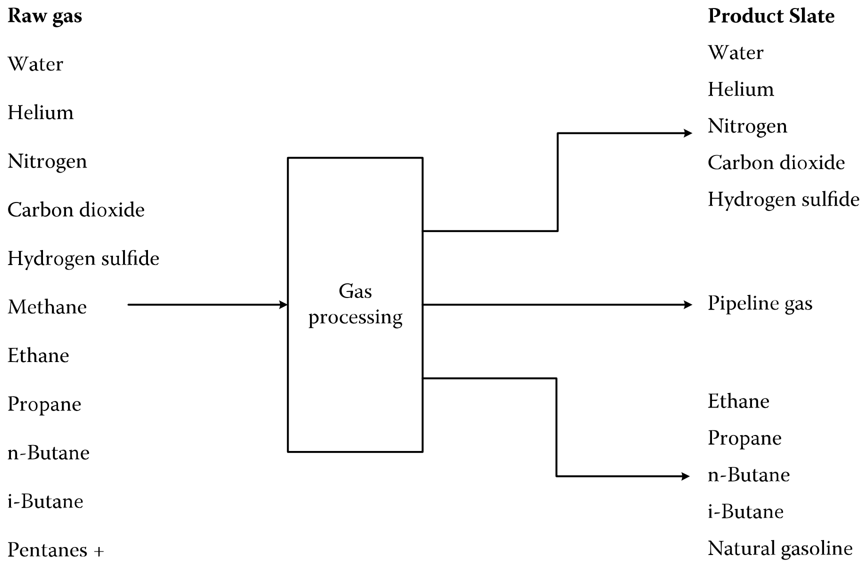

**FIGURE 1.6** Generic raw gas and product slate.

### 1.5.1 METHANE

The principal use of methane is as a fuel; it is the dominant constituent of pipeline quality natural gas. Considerable quantities of methane are used as feedstock in the production of industrial chemicals, principally ammonia and methanol.

### 1.5.2 ETHANE

The majority of the ethane used in the United States comes from gas plants, and refineries and imports account for the remainder. In addition to being left in the gas for use as a fuel, ethane is used for the production of ethylene, the feedstock for polyethylene.

### 1.5.3 PROPANE

Gas plants produce about 45% of the propane used in the United States, refineries contribute about 44%, and imports account for the remainder. The principal uses are petrochemical (47%), residential (39%), farm (8%), industrial (4%), and transportation (2%) (Florida Propane Gas Council, 2005). A special grade of propane, called HD-5, is sold as fuel.

### 1.5.4 ETHANE–PROPANE MIX

When NGL is fractionated into various hydrocarbon streams, the butanes along with part of the propane are sometimes separated for use in local markets because they are transportable by truck. The remaining light ends, an ethane–propane mix (E-P mix), is then pipelined to a customer as a chemical or refining feedstock.

### 1.5.5 ISOBUTANE

Approximately 42% of the United States supply of isobutene comes from gas plants, refineries supply about 5% (this percentage does not include consumption of isobutane within the refinery), and imports are responsible for about 12%. The remaining isobutane on the market is furnished by isomerization plants that convert n-butane to isobutane. The three primary markets for isobutane are as a feedstock for MTBE (methyl tertiary butyl ether) production (which is being phased out), as a feedstock in the production of reformulated gasoline, and as a feedstock for the production of propylene oxide.

### 1.5.6 n-BUTANE

Gas plant production of n-butane accounts for about 63% of the total supply, refineries contribute approximately 31%, and imports account for the remainder. Domestic usage of n-butane is predominantly in gasoline, either as a blending component or through isomerization to isobutane. Specially produced mixtures of butanes and propane have replaced halocarbons as the preferred propellant in aerosols.

### 1.5.7 NATURAL GAS LIQUIDS

Natural gas liquids (NGL) include all hydrocarbons liquefied in the field or in processing plants, including ethane, propane, butanes, and natural gasoline. Such mixtures generated in gas plants are usually referred to as “Y-grade” or “raw product.”

### 1.5.8 NATURAL GASOLINE

Natural gasoline, a mixture of hydrocarbons that consist mostly of pentanes and heavier hydrocarbons and meet GPA product specifications, should not be confused with natural gas liquids (NGL), a term used to designate all hydrocarbon liquids produced in field facilities or in gas plants.

The major uses of natural gasoline are in refineries, for direct blending into gasoline and as a feedstock for $C_5/C_6$ isomerization. It is used in the petrochemical industry for ethylene production.

### 1.5.9 SULFUR

Current sulfur production in the United States is approximately 15,000 metric tons per day (15 MMkg/d); about 85% comes from gas processing plants that convert $H_2S$ to elemental sulfur. Some major uses of sulfur include rubber vulcanization, production of sulfuric acid, and manufacture of black gunpowder (Georgia Gulf Sulfur Corporation, 2005).