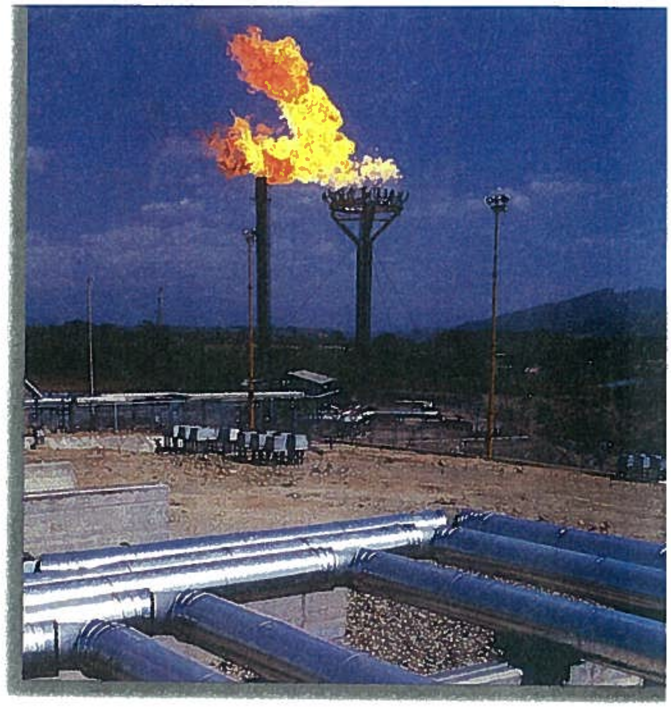
CHAPTER 9

ENERGY SOURCES



The three primary sources of energy are coal, oil, and natural gas. Natural gas pipelines connect production sites with industrial, commercial, and residential customers.

CHAPTER OUTLINE

OBJECTIVES

After reading this chapter, you should be able to:

- Differentiate between resources and reserves.
- Identify peat, lignite, bituminous coal, and anthracite coal as steps in the process of coal formation.
- Recognize that natural gas and oil are formed from ancient marine deposits.
- Explain how various methods of coal mining can have negative environmental impacts.
- Explain why surface mining of coal is used in some areas and underground mining in other areas.
- Explain why it is more expensive to find and produce oil today than it was in the past.
- Recognize that secondary recovery methods have been developed to increase the proportion of oil and natural gas obtained from deposits.
- Recognize that transport of natural gas is still a problem in some areas of the world.
- Explain why the amount of energy supplied by hydroelectric power is limited.
- Describe how wind, geothermal, and tidal energy are used to produce electricity.
- Recognize that wind, geothermal, and tidal energy can be developed only in areas with the proper geologic or geographical features.
- Describe the use of solar energy in passive heating systems, active heating systems, and the generation of electricity.
- Recognize that fuelwood is a major source of energy in many parts of the less-developed world and that fuelwood shortages are common.
- Describe the potential and limitations of biomass conversion and waste incineration as sources of energy.
- Recognize that energy conservation can significantly reduce our need for additional energy sources.

ENERGY SOURCES

Chapter 8 outlined the historical development of energy consumption and how advances in civilizations were closely linked to the availability and exploitation of energy. New manufacturing processes relied on dependable sources of energy. Technology accelerated in the twentieth century. Between 1900 and 2007, world energy consumption increased by a factor of about 16 and economic activity increased by more than 70 times, but population increased only slightly more than four times. (See table 9.1.)

The energy sources most commonly used by industrialized nations are the fossil fuels: oil, coal, and natural gas, which supply about 80 percent of the world's energy. Fossil fuels were formed hundreds of millions of years ago. They are the accumulation of energy-rich organic molecules produced by organisms as a result of photosynthesis over millions of years. We can think of fossil fuels as concentrated, stored solar energy. The rate of formation of fossil fuels is so slow that no significant amount of fossil fuels will be formed over the course of human history. Since we are using these resources much faster than they can be produced and the amount of these materials is finite, they are known as **nonrenewable energy sources.** Eventually, human demands will exhaust the supplies of coal, oil, and natural gas.

In addition to nonrenewable fossil fuels, there are several renewable energy sources. **Renewable energy sources** replenish themselves or are continuously present as a feature of the solar system. Some forms of renewable energy can also be referred to as *perpetual energy.* For example, in plants, photosynthesis converts light energy into chemical energy.

$$\text{Carbon dioxide} + \text{Water} + \text{Sunlight energy} \rightarrow \text{Biomass (Chemical energy)} + \text{Oxygen}$$

This energy is stored in the organic molecules of the plant as wood, starch, oils, or other compounds. Any form of biomass—plant, animal, alga, or fungus—can be traced back to the energy of the sun. Since biomass is constantly being produced, it is a form of renewable energy. Solar, geothermal, and tidal energy are renewable energy sources because they are continuously available. Anyone who has ever lain in the sun, seen a geyser or hot springs, or been swimming in the surf has experienced these forms of energy. Progress has been made in the use of renewable sources of energy, as in heating and cooling homes and businesses with solar energy. However, technical, economic, and cultural challenges must be addressed before renewable energy will meet a significant percentage of humans' energy demands. Figure 9.1 shows the proportions of renewable and nonrenewable energy sources used in the world today.

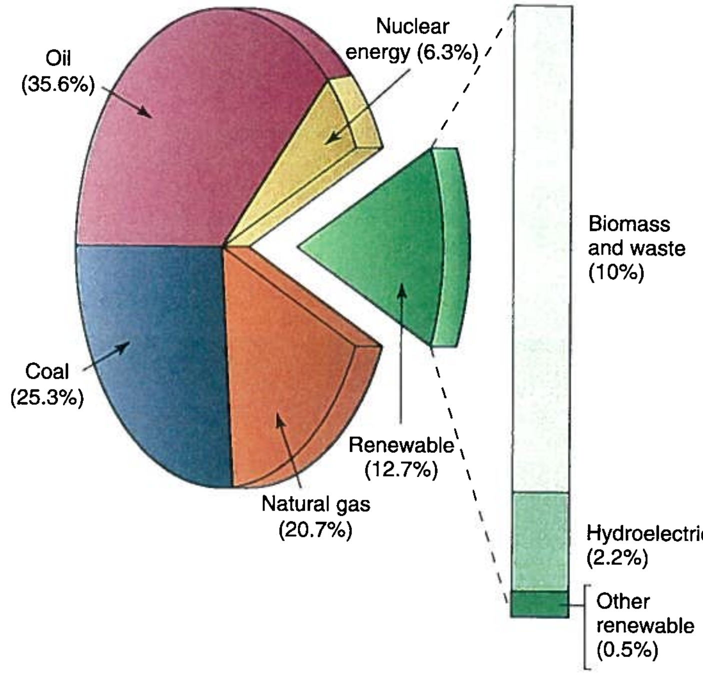


FIGURE 9.1 All Energy Sources The use of nonrenewable energy sources, including fossil fuels and nuclear energy, far outweighs the use of renewable sources in the industrialized world today.
Data from International Energy Agency, 2007.

TABLE 9.1 World Population, Economic Output, and Fossil-Fuel Consumption

	Population (Billions)	Gross World Product (Trillion 2000 US$)	Fossil-Fuel Consumption (Billion Metric Tons Coal Equivalent)
1900	1.6	0.6	1
1950	2.5	2.9	3
2007	6.6	43.3	16

RESOURCES AND RESERVES

When discussing deposits of nonrenewable resources, such as fossil fuels, we must differentiate between deposits that can be extracted and those that cannot. From a technical point of view, a **resource** is a naturally occurring substance of use to humans that can *potentially* be extracted using current technology. **Reserves** are known deposits from which materials *can* be extracted profitably with existing technology *under prevailing economic conditions.* It is important to recognize that the concept of *reserves* is an economic idea and is only loosely tied to the total quantity of a material present in the world. Therefore, reserves are smaller than resources. (See figure 9.2.)

Both terms are used when discussing the amount of fossil-fuel deposits a country has at its disposal. This can cause considerable confusion if the difference between these concepts is not understood. The total amount of a *resource* such as coal or oil changes only by the amount used each year. The amount of a *reserve* changes as technology advances, new deposits are discovered, and economic conditions vary. Furthermore, countries often restate the amount of their reserves for political reasons. Thus, there can be large increases in the amount of *reserves,* while the total amount of the *resource* falls.

When we read about the availability of fossil fuels, we must remember that if the cost of removing and processing a fuel is greater than the fuel's market value, no one is going to produce it. Also, if the amount of energy used to produce,

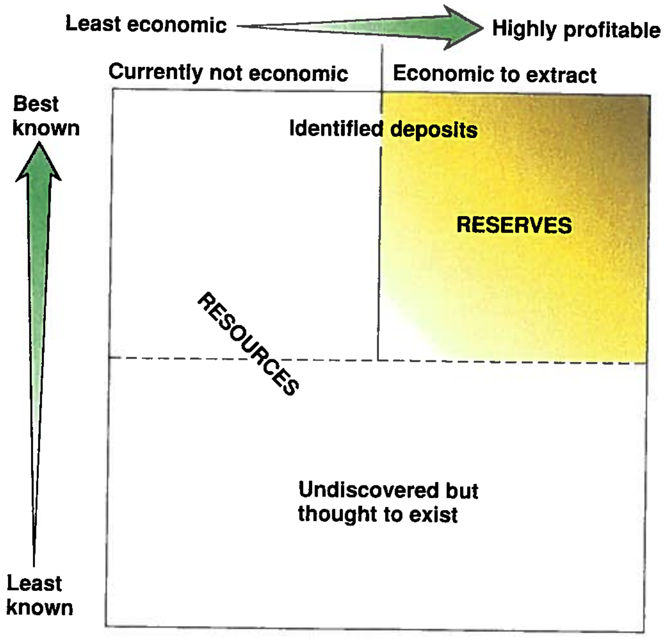


FIGURE 9.2 Resources and Reserves Each term describes the amount of a natural resource present. Reserves are those known deposits that can be profitably obtained using current technology under current economic conditions. Reserves are shown in the box in the upper right-hand corner in this diagram. The darker the color, the better known the deposit and the more profitable it is to extract. Resources are much larger quantities that include undiscovered deposits and deposits that currently cannot be profitably used, although it might be feasible to do so in the future if technology or market conditions change.

Source: Adapted from the U.S. Bureau of Mines.

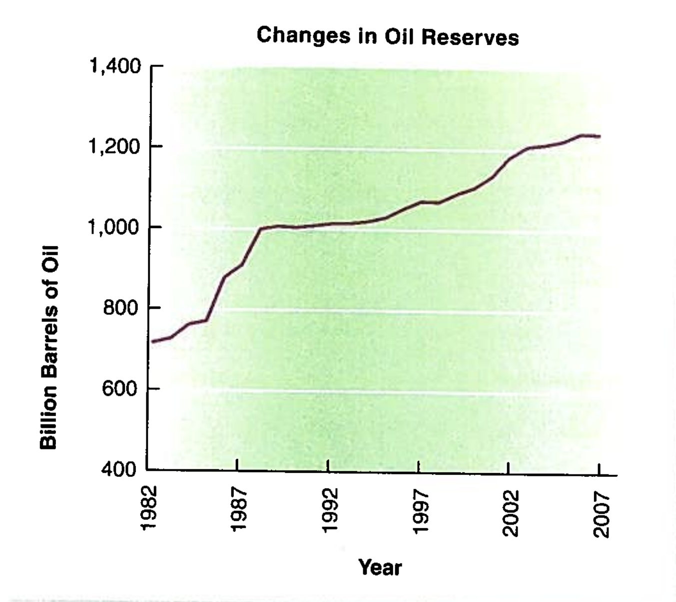


FIGURE 9.3 Changes in Proved Oil Reserves The figure shows the changes in proved oil reserves over a 25-year period. The major changes in the 1980s were primarily due to more accurate reporting rather than new discoveries.

Source: Data from *BP Statistical Review of World Energy,* June 2008.

refine, and transport a fuel is greater than its potential energy, the fuel will not be produced. A net useful energy yield is necessary to exploit the resource. However, in the future, new technology or changing prices may permit the profitable removal of some fossil fuels that currently are not profitable. If so, those resources will be reclassified as reserves.

To further illustrate the concept of reserves and how technology and economics influence their magnitude, let us look at the history of oil. When the first oil well in North America was drilled in Pennsylvania in 1859, it greatly expanded the estimate of the amount of oil in the Earth. There was a sudden increase in the known oil reserves. In the years that followed, new deposits were discovered. Better drilling techniques led to the discovery of deeper oil deposits, and offshore drilling established the location of oil under the ocean floor. At the time of their discovery, these deep deposits and the offshore deposits added to the estimated size of the world's oil resources. But they did not necessarily add to the reserves because it was not always profitable to extract the oil. With advances in drilling and pumping methods and increases in oil prices, it eventually became profitable to obtain oil from many of these deposits. As it became economical to extract them, they were reclassified as reserves. (See figure 9.3.)

FOSSIL-FUEL FORMATION

Fossil fuels are the remains of once-living organisms that were preserved and altered as a result of geologic forces. Significant differences exist in the formation of coal from that of oil and natural gas.

TABLE 9.2 Coal Formation—Changes in Carbon Content

	Carbon Content	Physical Characteristics
Peat	5%	Recognizable plant material
Lignite	25–46%	Brown and crumbly
Subbituminous	46–60%	Black and crumbly
Bituminous	60–86%	Black and soft
Anthracite	86–98%	Black and hard

COAL

Coal was formed from plant material that has been subjected to heat and pressure. Tropical freshwater swamps covered many regions of the Earth 300 million years ago. Conditions in these swamps favored extremely rapid plant growth, resulting in large accumulations of plant material. Because this plant material collected under water, decay was inhibited, and a spongy mass of organic material formed. Similar deposits are being formed today and are known as peat.

Due to geologic changes in the Earth, some of these organic deposits were submerged by seas. The plant material that had collected in the swamps was then covered by sediment. The weight of the plant material plus the weight of the sediment on top of it compressed it into coal.

Depending on the amount of time the organic matter has been subjected to geologic processes, several qualities of material are produced. (See table 9.2.) Most parts of the world have coal deposits. (See figure 9.4.)

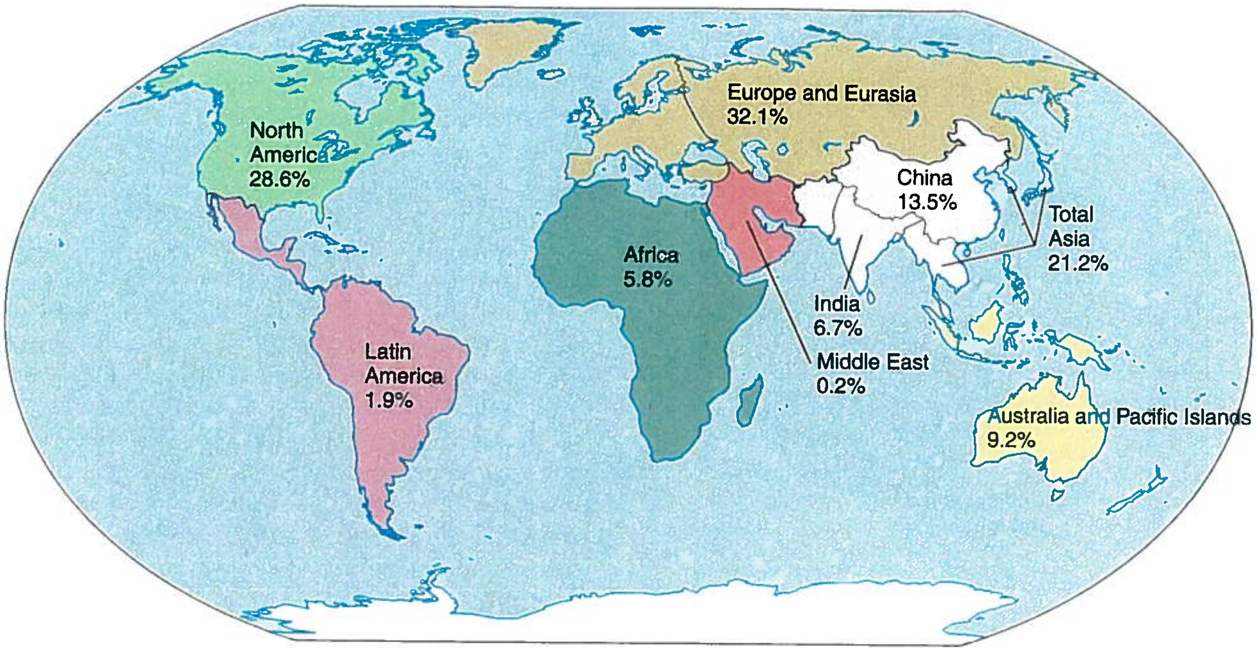


FIGURE 9.4 Recoverable Coal Reserves of the World 2007 The percentage indicates the coal reserves in different parts of the world. This coal can be recovered under present local economic conditions using available technology.

Source: Data from *BP Statistical Review of World Energy*, 2008.

OIL AND NATURAL GAS

Oil and natural gas, like coal, are products from the past. They probably originated from microscopic marine organisms. When these organisms died and accumulated on the ocean bottom and were buried by sediments, their breakdown released oil droplets. Gradually, the muddy sediment formed rock called shale, which contained dispersed oil droplets. Although shale is common and contains a great deal of oil, extraction from shale is difficult because the oil is not concentrated. However, in instances where a layer of porous sandstone formed on top of the oil-containing shale and an impermeable layer of rock formed on top of the sandstone, concentrations of oil often form. Usually, the trapped oil does not exist as a liquid mass but rather as a concentration of oil within sandstone pores, where it accumulates because water and gas pressure force it out of the shale. (See figure 9.5.) These accumulations of oil are more likely to occur if the rock layers were folded by geological forces.

Natural gas, like coal and oil, forms from fossil remains. If the heat generated within the Earth reached high enough temperatures, natural gas could have formed along with or instead of oil. This would have happened as the organic material changed to lighter, more volatile (easily evaporated) hydrocarbons than those found in oil. The most common hydrocarbon in natural gas is the gas methane (CH_4). Water, liquid hydrocarbons, and other gases may be present in natural gas as it is pumped from a well.

The conditions that led to the formation of oil and gas deposits were not evenly distributed throughout the world. Figure 9.6 illustrates the geographic distribution of oil reserves. The Middle East has over 60 percent of the world's oil reserves. Figure 9.7 shows the geographic distribution of natural gas reserves. The Middle East and Eurasia (primarily Russia) have about 76 percent of the world's natural gas reserves.

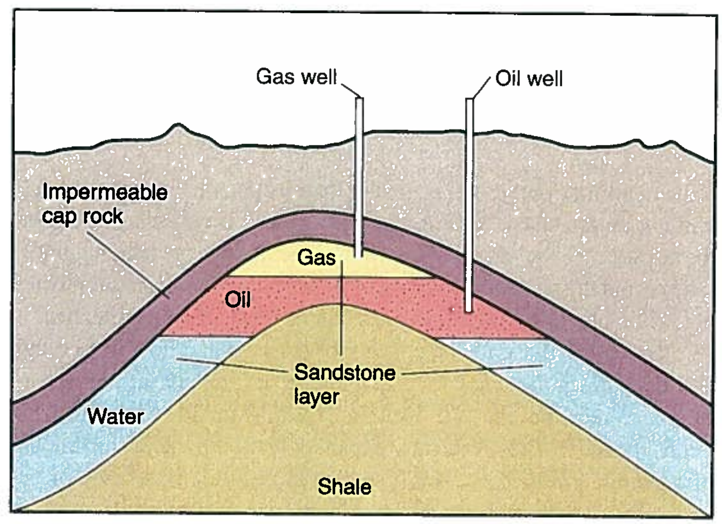


FIGURE 9.5 Crude Oil and Natural Gas Pool Water and gas pressure force oil and gas out of the shale and into sandstone capped by impermeable rock.

Source: Adapted with permission from Arthur N. Strahler, *Planet Earth*. Copyright © 1972 by Arthur N. Strahler.

ISSUES RELATED TO THE USE OF FOSSIL FUELS

As previously mentioned, of the world's commercial energy, about 80 percent is furnished by the three nonrenewable fossil-fuel resources: coal, oil, and natural gas. Coal supplies about 25 percent, oil supplies about 36 percent, and natural gas supplies about 21 percent. Each fuel has advantages and disadvantages and requires special techniques for its production and use.

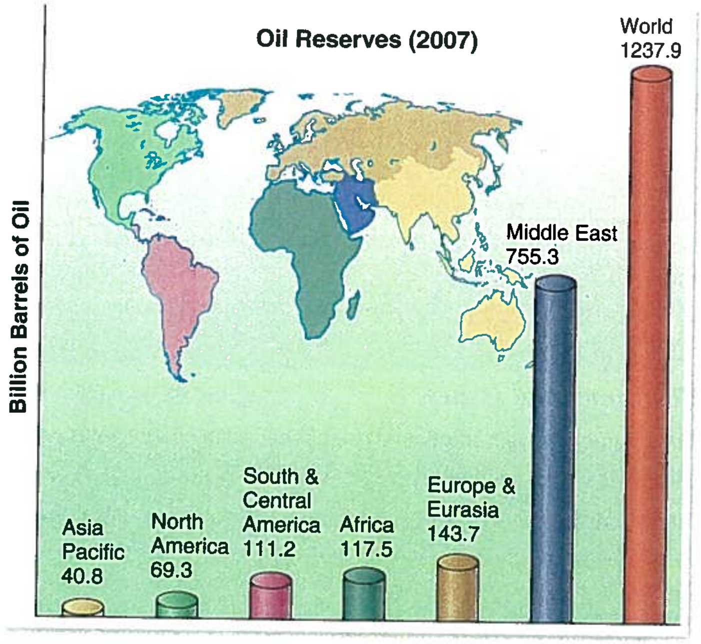


FIGURE 9.6 **World Oil Reserves 2007** The world's supply of oil is not distributed equally. The Middle East controls over 60 percent of the world's oil reserves.

Source: Data from *BP Statistical Review of World Energy*, 2008.

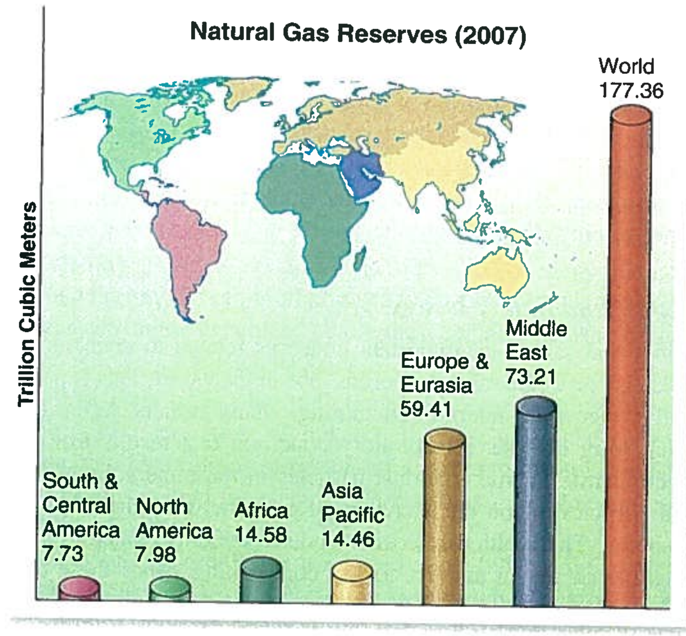


FIGURE 9.7 **World Natural Gas Reserves 2007** Natural gas reserves, like oil and coal, are concentrated in certain regions of the world. The Middle East and Eurasia have about 75 percent of the world's natural gas reserves.

Source: Data from *BP Statistical Review of World Energy*, 2008.

Coal Use

Coal is the world's most abundant fossil fuel, but it supplies only about 25 percent of the energy used in the world. It varies in quality and is generally classified in four categories: lignite, subbituminous, bituminous, and anthracite. Lignite (brown) coal has a high moisture content and is crumbly in nature, which makes it the least desirable form. It has a low energy content that makes transportation over long distances uneconomic. Therefore, most lignite is burned in power plants built near the coal mine. Over 60 percent of the lignite used is from Europe. Subbituminous coal has a lower moisture content and a higher carbon content (46–60 percent) than lignite and is typically used as fuel for electric power plants. Bituminous (soft) coal has a low moisture content and a high carbon content (60–86 percent). It is primarily used in electrical power generation but is also used in other industrial uses such as cement production and steel making. Bituminous coal is the most widely used because it is the easiest to mine and the most abundant. It supplies about 20 percent of the world's energy requirements. Anthracite (hard) coal is 86–98 percent carbon. It is relatively rare and is used primarily in heating of buildings and for specialty uses.

FIGURE 9.8 **Surface Mining** Aerial view F&M Coal strip mining site, Preston County, West Virginia.

Extraction Methods

Because coal was formed as a result of plant material being buried under layers of sediment, it must be mined. There are two methods of extracting coal: surface mining and underground mining. **Surface mining** (strip mining) involves removing the material located on top of a vein of coal, called **overburden,** to get at the coal beneath. (See figure 9.8.) Coal is usually surface mined when the overburden is less than 100 meters (328 feet) thick. This type of mining operation is efficient because it removes most of the coal in a vein and can be profitably used for a seam of coal as thin as half a meter. For these reasons, surface mining results in the best utilization of coal reserves. Advances in the methods of surface mining and the development of better equipment have increased surface mining activity in the United States from 30 percent of the coal production in 1970 to more than 60 percent today. This trend toward increased surface mining has also occurred in Canada, Australia, and the former Soviet Union.

If the overburden is thick, surface mining becomes too expensive, and the coal is extracted through **underground mining.** The deeply buried coal seam can be reached in two ways. In the first, in flat country where the vein of coal lies buried beneath a thick overburden, the coal is reached by a vertical shaft. (See figure 9.9a.) In the second, in hilly areas where the coal seam often comes to the surface along the side of a hill, the coal is reached from a drift-mine opening. (See figure 9.9b.)

Health and Safety Issues

Health and safety are important concerns related to coal mining, which is one of the most dangerous jobs in the world. This is particularly true with underground mining. Many miners suffer from **black lung disease,** a respiratory condition that results from the accumulation of fine coal-dust particles in the miners' lungs. The coal particles inhibit the exchange of gases between the lungs and the blood. The health care costs and death benefits related to black lung disease are an indirect cost of coal mining. Since these costs are partially paid by the federal government, their full price is not reflected in the price of coal but is paid by taxpayers in the form of federal taxes and higher health insurance premiums.

Transportation Issues

Because coal is bulky, shipping presents a problem. Generally, the coal can be used most economically near where it is produced. Rail shipment is the most economic way of transporting coal from the mine. Rail shipment costs include the expense of constructing and maintaining the tracks, as well as the cost of the energy required to move the long strings of railroad cars. In some areas, the coal is transferred from trains to ships.

Environmental Issues

The mining, transportation, and use of coal as an energy source present several significant environmental problems.

1. ***Landscape Disturbance*** Surface mining (strip mining) disrupts the landscape, as the topsoil and overburden are moved to access the coal. It is possible to minimize this disturbance by reclaiming the area after mining operations are completed. (See figure 9.10.)

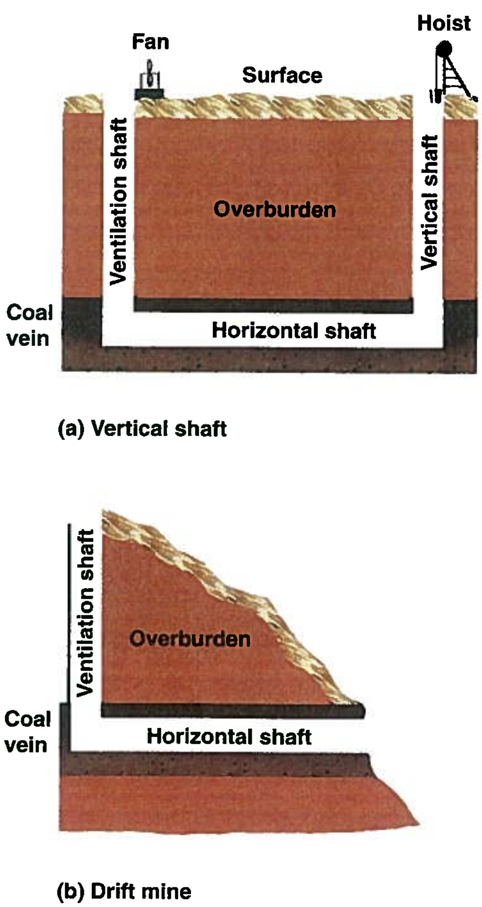
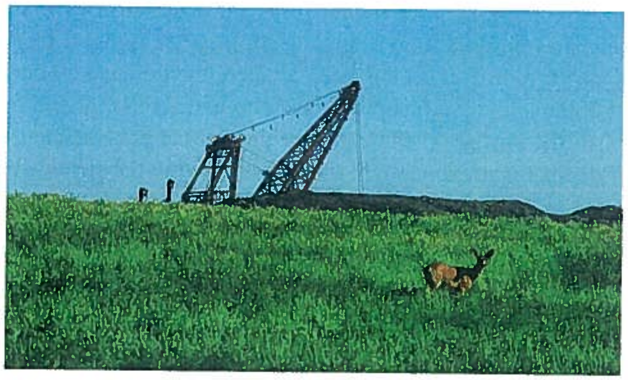


FIGURE 9.9 Underground Mining If the overburden is too thick to allow surface mining, underground mining must be used. (a) If the coal vein is not exposed, a vertical shaft is sunk to reach the coal. (b) In hilly areas, if the vein is exposed, a drift mine is used in which miners enter from the side of the hill.

(a) Unreclaimed stripmine



(b) Reclaimed stripmine

FIGURE 9.10 **Surface-Mine Reclamation** (a) This photograph shows a large area that has been surface mined with little effort to reclaim the land. By contrast, (b) is an example of effective surface-mining reclamation. The site has been graded and revegetated so that it provides wildlife habitat.

However, reclamation rarely, if ever, returns the land to its previous level of productivity. The cost of reclamation is passed on to the consumer in the form of higher coal prices. Underground mining methods do not disrupt the surface environment as much as surface mining does, but subsidence (sinking of the land) occurs if the mine collapses. (See figure 9.11.) In addition, large waste heaps are produced around the mine entrance from the debris that must be removed and separated from the coal.

2. ***Dust*** Coal mining and transport generate a great deal of dust. The large amounts of coal dust released into the atmosphere at the loading and unloading sites can cause local air-pollution problems. If a boat or railroad car is used to transport coal, there is the expense of cleaning it before other types of goods can be shipped. In some cases, the coal can be ground and mixed with water to form a slurry that can be pumped through pipelines. This helps to alleviate some of the air-pollution problems without causing significant water-pollution problems.

3. ***Acid Mine Drainage*** Since coal is a fossil fuel formed from plant remains, it contains sulfur, which was present in the proteins of the original plants. Sulfur is associated with **acid mine drainage** and air pollution. (See figure 9.12.) Acid mine drainage occurs when the combined action of oxygen, water, and certain bacteria causes the sulfur in coal to form sulfuric acid. Sulfuric acid can seep out of a vein of coal even before the coal is mined. However, the problem becomes worse when the coal is mined and the overburden is disturbed, allowing rains to wash the sulfuric acid into streams. Streams may become so acidic that they can support only certain species of bacteria and algae. Today, many countries regulate the amount of runoff allowed from mines, but underground and surface mines abandoned before these regulations were enacted continue to contaminate the water.

4. ***Acid Deposition*** Air pollution from coal burning releases millions of metric tons of material into the atmosphere and is responsible for millions of dollars of damage to the environment. The burning of coal for electric generation is the prime source of this type of pollution.

One of the problems associated with the burning of coal is acid deposition. Acid deposition occurs when coal is burned and sulfur oxides are released into the atmosphere, causing acid-forming particles to accumulate. Each year, over 150 million metric tons of sulfur dioxide are released into the atmosphere worldwide. This problem is discussed in greater detail in chapter 16.

5. ***Carbon Dioxide—Global Warming*** The release of carbon dioxide from the burning of coal has become a major issue in recent years. Increasing amounts of carbon dioxide in the atmosphere are strongly implicated in global warming. Environmentalists have suggested that the use of coal be decreased, since the other fossil fuels (oil and natural gas) produce less carbon dioxide for an equivalent amount of energy.

FIGURE 9.11 **Subsidence** When underground mines collapse, it changes the land surface. The holes and depressions shown in the photo are the result of subsidence.

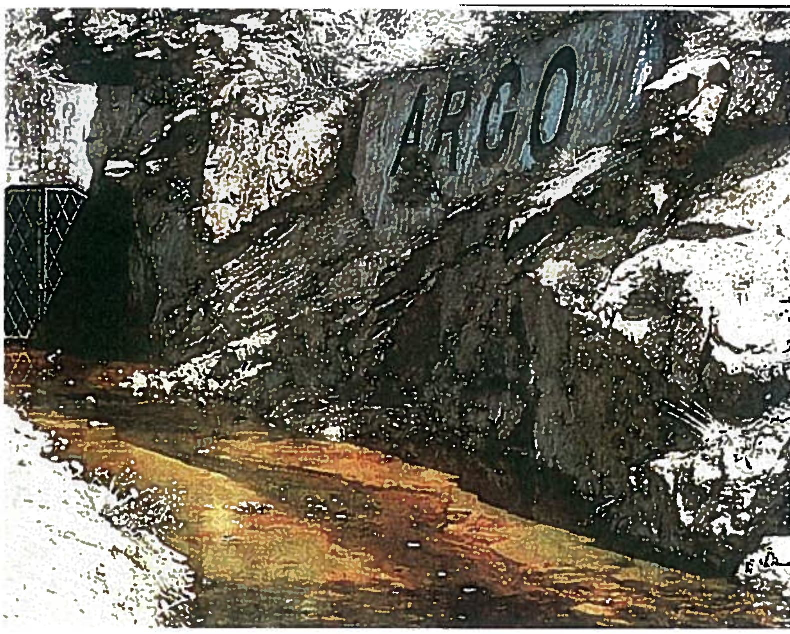


FIGURE 9.12 **Acid Mine Drainage** The red color of the river is a common characteristic of acid mine drainage.

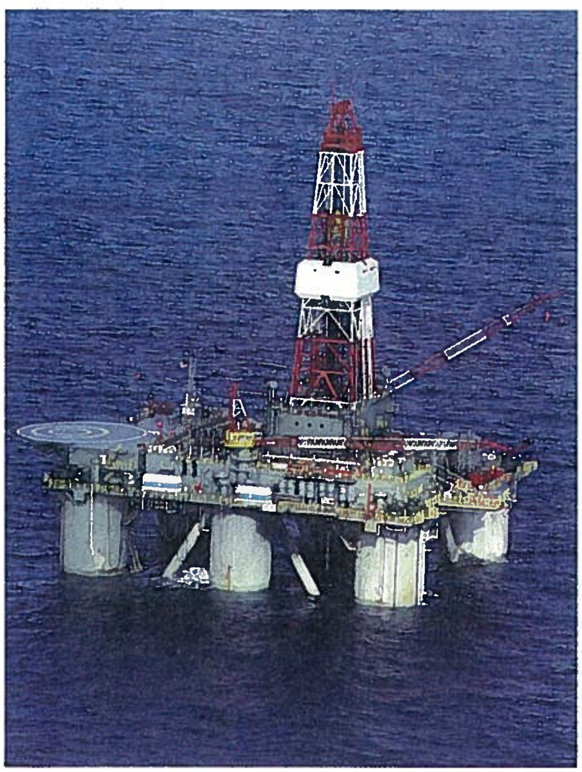
OIL USE

Oil has several characteristics that make it superior to coal as a source of energy. Its extraction causes less environmental damage than does coal mining. It is a more concentrated source of energy than coal, it burns with less pollution, and it can be moved easily through pipes. These characteristics make it an ideal fuel for automobiles. However, it is often difficult to find.

Extraction Methods

Today, geologists use a series of tests to locate underground formations that may contain oil. When a likely area is identified, a test well is drilled to determine if oil is actually present. Since the many easy-to-reach oil fields have already been tapped, drilling now focuses on smaller amounts of oil in less accessible sites, which means that the cost of oil from most recent discoveries is higher than that from the large, easy-to-locate sources of the past. As oil deposits located below land have become more difficult to find, geologists have widened the search to include the ocean floor. Building an offshore drilling platform can cost millions of dollars. To reduce the cost, as many as 70 wells may be sunk from a single platform. (See figure 9.13.)

Once a source of oil has been located, the greatest technological problems involve techniques used to extract the oil and transport it to the surface If the water or gas pressure associated with an oil deposit is great enough, the oil is forced to the surface when



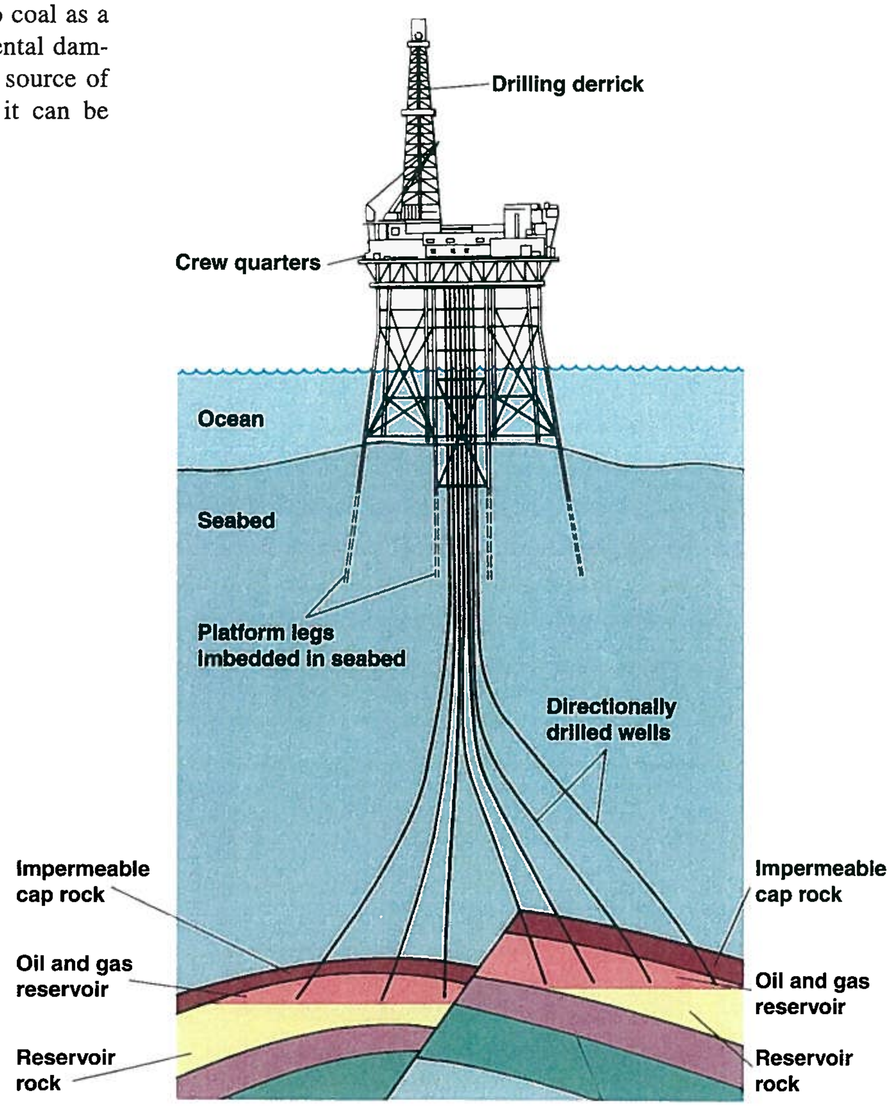
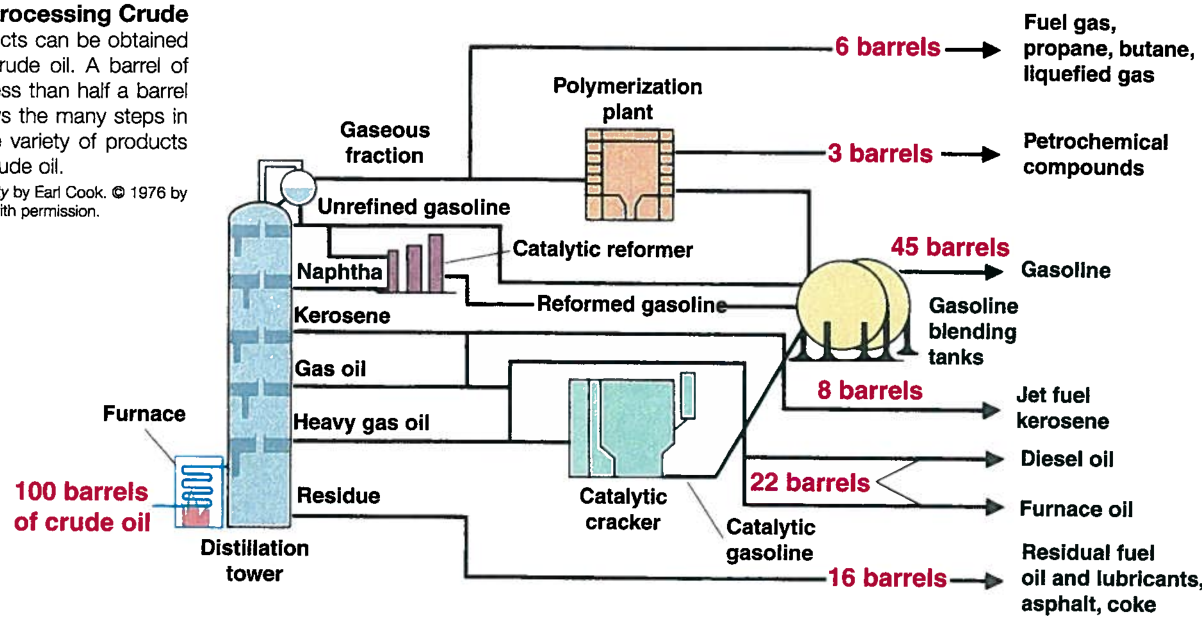


FIGURE 9.13 **Offshore Drilling** Once the drilling platform is secured to the ocean floor, a number of wells can be sunk to obtain the gas or oil.
Source: (line art) American Petroleum Institute.

FIGURE 9.14 Processing Crude Oil A great variety of products can be obtained from distilling and refining crude oil. A barrel of crude oil produces slightly less than half a barrel of gasoline. This figure shows the many steps in the refining process and the variety of products that can be obtained from crude oil.

Source: From *Man, Energy, and Society* by Earl Cook. © 1976 by W. H. Freeman and Company. Used with permission.



a well is drilled. When the natural pressure is not great enough, the oil must be pumped to the surface. These techniques are often referred to as *primary recovery methods* and can extract 5 to 30 percent of the oil depending on geologic characteristics of the source and the viscosity of the oil. In most oil fields, secondary recovery is used to recover more of the oil. *Secondary recovery methods* include pumping water or gas into the well to drive the oil out of the pores in the rock. These techniques typically result in up to 40 percent of the oil being extracted. As oil prices increase, more expensive and aggressive recovery methods will need to be used. *Tertiary recovery methods* include pumping steam into the well to lower the viscosity of the oil and allow it to flow more readily. Other techniques include more aggressive pumping of gases or chemicals into wells. All of these methods are expensive and are only used if the price of oil is high and the likelihood of getting significant additional production is great.

FIGURE 9.15 Oil-Based Synthetic Materials These common household items are produced from chemicals derived from oil. Although petrochemicals represent only about 3 percent of each barrel of oil, they are extremely profitable for the oil companies.

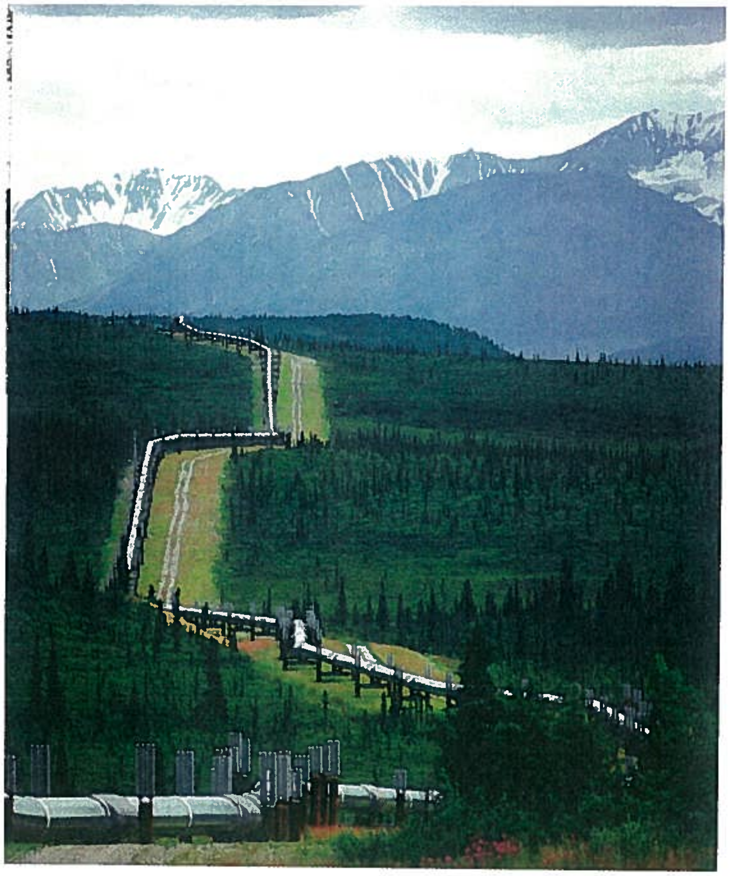
Processing Crude Oil

Oil, as it comes from the ground, is not in a form suitable for use. It must be refined. The various components of crude oil can be separated and collected by heating the oil in a distillation tower. (See figure 9.14.) After distillation, the products may be further refined by "cracking." In this process, heat, pressure, and catalysts are used to produce a higher percentage of volatile chemicals, such as gasoline, from less volatile liquids, such as diesel fuel and furnace oils. It is possible, within limits, to obtain many products from one barrel of oil. In addition, petrochemicals from oil serve as raw materials for a variety of synthetic compounds. (See figure 9.15.)

Environmental Issues

Liquids are much easier to transport than are solids or gases. Oil pipelines are the primary methods by which oil is transported on continents. When the oil must cross the ocean, giant supertankers carry huge amounts of oil. (See figure 9.16.) The primary problems associated with transportation are leaks and spills. All of the extraction, transportation, and refining activities create opportunities for accidental or routine releases that may cause air or water pollution.

Oil spills in the oceans have been widely reported by the news media. Because of new regulations, changes in tanker hull design, and greater attention to safety, the number of tanker spills has declined over the last few decades, while the amount of oil being transported has increased. (See table 9.3.) Although major shipping accidents are spectacular and release large amounts of oil, it is estimated that nearly 60 percent of the oil pollution in the oceans is the result of routine shipping operations unrelated to oil tankers.



(a) Trans-Alaska pipeline

(b) Oil tanker

FIGURE 9.16 **Transportation of Oil** (a) Oil pipelines and (b) c tankers are the primary methods used to transport oil. When accidents occur, c leaks contaminate the soil or water.

TABLE 9.3 Average Annual Oil Spills (over 7 metric tons) from Tankers

Years	Metric Tons of Oil Spilled per Year	Number of Spills per Year
1970s	314,200	25.2
1980s	117,600	9.3
1990s	113,800	7.8
2000–2007	24,000	3.6

Oil spills on land can contaminate soil and underground water. The evaporation of oil products and the incomplete burning of oil fuels contribute to air pollution. These problems are discussed in chapter 16.

Natural Gas Use

Natural gas, the third major source of fossil-fuel energy, supplies about 21 percent of the world's energy.

Extraction Methods

The drilling operations to obtain natural gas are similar to those used for oil. In fact, a well may yield both oil and natural gas. As with oil, secondary recovery methods that pump air or water into a well are used to obtain the maximum amount of natural gas from a deposit. After processing, the gas is piped to the consumer for use.

Transport Methods

Transport of natural gas still presents a problem in some parts of th world. In the Middle East, Mexico, Venezuela, and Nigeria, well are too far from consumers to make pipelines practical, so much o the natural gas is burned as a waste product at the wells. However new methods of transporting natural gas and converting it into othe products are being explored. At −162°C (−126°F), natural gas be comes a liquid and has only 1/600 of the volume of its gaseou form. Tankers have been designed to transport **liquefied natura gas** from the area of production to an area of demand. In 2007, ove 211 billion cubic meters (about 7500 billion cubic feet) of natura gas were shipped between countries as liquefied natural gas. This i over 7.5 percent of the natural gas consumed in the world. Of tha amount, Japan alone imported 80 billion cubic meters (2800 billior cubic feet). As the demand for natural gas increases, the amount o it wasted will decrease and new methods of transportation will be employed. Higher prices will make it profitable to transport natura gas greater distances between the wells and the consumers.

A major public concern about liquefied natural gas is the safety at loading and unloading facilities. When new ports are suggested, there is concern about explosions that could result from accidents or the actions of terrorists. Because of these concerns, the loading and unloading facilities are often located several kilometers off-shore.

Environmental Issues

Of the three fossil fuels, natural gas is the least disruptive to the environment. A natural gas well does not produce any unsightly waste, although there may be local odor problems. Except for the

CASE STUDY 9.1

The Arctic National Wildlife Refuge

The Arctic National Wildlife Refuge (ANWR) has been a source of controversy for many years. The major players are environmentalists who seek to preserve this region as wilderness; the state of Alaska, which funds a major portion of its activities with dividends from oil production; Alaska residents, who receive a dividend payment from oil revenues; oil companies that want to drill in the refuge; and members of Congress who see the oil reserves in the region as important economic and political issues.

In 1960, 3.6 million hectares (8.9 million acres) were set aside as the Arctic National Wildlife Range. Passage of the Alaskan National Interest Lands Conservation Act in 1980 expanded the range to 8 million hectares (19.8 million acres) and established 3.5 million hectares (8.6 million acres) as wilderness. The act also renamed the area the Arctic National Wildlife Refuge. There are international implications to this act. The refuge borders Canada's Northern Yukon National Park. Many animals, particularly members of the Porcupine caribou herd, travel across the border on a regular yearly migration. The United States is obligated by treaty to protect these migration routes.

Alaska relies on oil for about 80 percent of its revenue and has no sales or income tax. Furthermore, each Alaskan citizen receives a yearly dividend check from a state fund established with proceeds from oil companies. Even so, some Alaskan citizens support drilling; others oppose it. The Inupiat Eskimos who live along the north Alaskan coast mostly are in favor of drilling in ANWR. The Inupiat believe oil revenues and land-rental fees from oil companies will raise their living standards. The other Native American tribe in the region, the Gwich'in, who live on the southern fringe of the refuge, oppose drilling. They argue that the drilling will impact the caribou migration through the area every fall and thus affect their ability to provide food for their families.

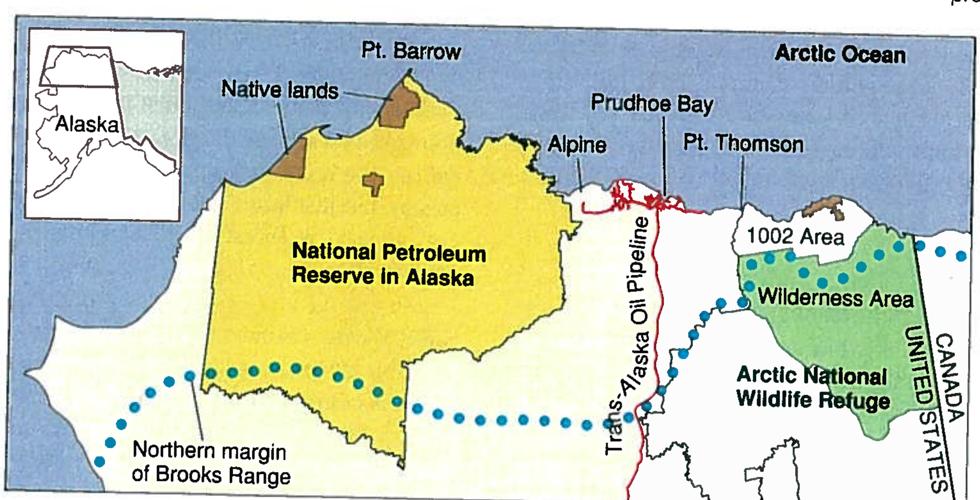
In 2000, the Energy Information Administration (EIA) released a report on the potential oil production from the coastal plain of ANWR. The report stated that the coastal plain region of ANWR is the largest unexplored, potentially productive geologic onshore basin in the United States.

Oil companies have repeatedly stated that the oil can be recovered without endangering wildlife or the fragile Arctic ecosystem. Conservationists have argued that none of the reserve should be developed when improvements in energy conservation could reduce the demand for oil. They argue that drilling in the reserve will harm the habitat of millions of migratory birds, caribou, and polar bears.

In 2002, President George W. Bush reconfirmed his support for drilling. A decision on permitting the exploration and development is up to the U.S. Congress. The act that established ANWR requires specific authorization from Congress before oil drilling or other development activities can take place on the coastal plain in the refuge. The coastal plain has the greatest concentration of wildlife, is the calving ground for the Porcupine caribou, and has the greatest potential for oil production.

Members of Congress are split on this issue. Debate is heated. In 2007, an attempt was made by an Alaskan senator to allow drilling by attaching an amendment to an appropriations bill. This attempt failed, but the issue will continue to come up as the United States continues to explore ways to meet its energy needs.

Migrating Caribou in ANWR



Source: Data from USGS Fact Sheet 0028-01: online report.

danger of an explosion or fire, natural gas poses no harm to the environment during transport. Since it is clean burning, it causes almost no air pollution. The products of its combustion are carbon dioxide and water. Although the burning of natural gas produces carbon dioxide, which contributes to global warming, it produces less carbon dioxide than does coal or oil. Global warming is discussed in chapter 16.

Although natural gas is used primarily for heat energy, it does have other uses, such as the manufacture of petrochemicals and fertilizer. Methane contains hydrogen atoms that are combined with nitrogen from the air to form ammonia, which can be used as fertilizer.

RENEWABLE SOURCES OF ENERGY

The burning of fossil fuels (oil, natural gas, and coal) provides over 80 percent of the energy used in the world. Nuclear energy provides an additional 6.3 percent. The burning of fossil fuels is also responsible for the most of the human-caused carbon dioxide emissions. Energy consumption has been growing at a rate of over 2 percent per year and has nearly doubled in the past 20 years. If growth continues at this rate, we can expect a further doubling of energy consumption in the next 20 years. Since fossil fuels are nonrenewable, they will eventually become scarce and the price will rise. This has led to increased investment in renewable sources of energy.

Currently, alternative energy sources—biomass, hydroelectricity, wind turbines, solar energy, geothermal energy, and tidal energy—supply about 12.7 percent of the world's total energy. Biomass accounts for about 10 percent of the energy used in the world, since firewood and other plant materials are the primary source of energy in much of the developing world.

Hydroelectric power accounts for over 2 percent and the remaining renewable technologies account for about 0.5 percent. (See figure 9.17.) Some optimistic studies suggest that these sources could provide half of the world's energy needs by 2050. It is unlikely that that will occur, but renewable sources certainly will become much more important as fossil fuel supplies become more expensive.

Biomass Conversion

Biomass fulfilled almost all of humankind's energy needs prior to the Industrial Revolution. All biomass is traceable back to green plants that convert sunlight into plant material through photosynthesis. As recently as 1850, 91 percent of total U.S. energy consumption was biomass in the form of wood. Since the Industrial Revolution, the majority of the developed world's energy requirements have been met by the combustion of fossil fuels such as coal, oil, and natural gas. Biomass, however, is still the predominant form of energy used by people in the less-developed countries, accounting for 10 percent of world energy use.

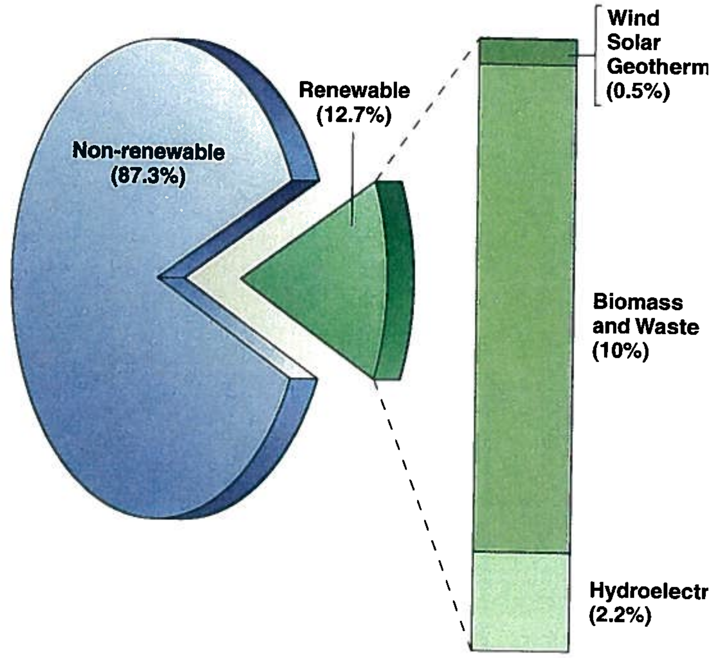


FIGURE 9.17 Renewable Energy as a Share of Total Energy Consumption (World 2006) Of the energy consumed in the world, over 87 percent is from nonrenewable fossil fuels and nuclear power. Renewable energy sources provide 12.7 percent, and of that about 80 percent is from the burning of biomass.

Source: International Energy Agency.

Major Types of Biomass

There are several distinct sources of biomass energy: fuelwood, municipal and industrial wastes, agricultural crop residues and animal waste, and energy plantations.

Fuelwood In less-developed countries, wood has been the major source of fuel for centuries. In fact, wood is still the primary source of energy for nearly half of the world's population. In these regions, the primary use of wood is for cooking.

Because of its bulk and low level of energy compared to equal amounts of coal or oil, wood is not practical to transport over a long distance, so most of it is used locally. In the United States, Norway, and Sweden, wood furnishes 10 percent of the energy for home heating. Canada obtains 3 percent of its total energy, not just home heating energy, from wood. Most of this energy is used in forest product industries, such as lumbering and paper mills.

Solid Waste Solid waste is a major source of biomass and other burnable materials produced by society. About 80 percent of this waste is combustible and, therefore, represents a potential energy source. (See figure 9.18.) However, to use waste to produce energy requires that the waste be sorted to separate the burnable organic material from the inorganic material. The sorting is done most economically by those who produce the waste, which means that residents and businesses must separate their trash into garbage, burnable materials, glass, and metals. The trash must be gathered by compartmentalized collection trucks.

FIGURE 9.18 **Waste to Energy** Municipal trash can be burned to produce heat and electricity. This refuse pit is used to feed hoppers of high-temperature furnaces.

The burning of solid waste to produce energy only makes economic sense when the cost of waste disposal is taken into account. In other words, although energy from solid waste is expensive, one can deduct the avoided landfill costs from the cost of producing energy from waste. Where landfill costs are high, waste-to-energy plants make economic sense. In the United States, about 15 percent of solid waste is burned in about 90 plants resulting in about 2500 megawatts of electricity. Europe and Japan have much less available land and have placed restrictions on landfills. Thus, these countries have a much higher rate of burning of solid waste. Countries in Western Europe have over 400 waste-to-energy plants. Japan burns about 80 percent of its waste and Germany burns nearly all of its waste that is not recyclable.

Crop Residues and Animal Wastes The materials that are left following the harvest of a crop can be used as a biomass fuel. In many parts of the world the straw and stalks left on the field are collected and used to provide fuel for heat and cooking. Animal wastes are also used for energy. Animal dung is dried and burned or processed in anaerobic digesters to provide a burnable gas.

Energy Plantations Many crops can be grown for the express purpose of energy production. Crops that have been used for energy include forest plantations, sugarcane, corn, sugar beets, grains, kelp, palm oil, and many others. Two main factors determine whether a crop is suitable for energy use. Good energy crops have a very high yield of dry material per unit of land (dry metric tons per hectare). A high yield reduces land requirements and lowers the cost of producing energy from biomass. Similarly, the amount of energy that can be produced from a biomass crop must be more than the amount of energy required to grow the crop. In some circumstances such as the heavily mechanized corn farms of the U.S. Midwest, the amount of energy in ethanol produced from corn is not much greater than the energy used for tractors, to manufacture fertilizer, and to process the grain into ethanol.

Biomass Conversion Technologies

There are several technologies capable of converting biomass into energy. These include direct combustion and cogeneration, ethanol production, anaerobic digestion, and pyrolysis.

Direct Combustion The most common way that biomass and waste are used for energy production is by burning them. In much of the developing world the primary use of energy derived from biomass is as fires to provide heat for cooking and heating homes.

Large-scale operations are used to power industrial processes or to generate electricity. Large biomass power-generation systems can have efficiencies that are comparable to those of fossil-fuel systems, but this comes at a higher cost due to the design of the burner to handle the higher moisture content of biomass. However, using the biomass in a combined heat- and electricity-production system (or cogeneration system) significantly improves the economics.

Worldwide, about 1 percent of electricity is generated from biomass. This compares to about 16 percent for hydroelectricity. Although the United States produces more total electrical energy from biomass than any other country, its production is only about 1.3 percent of total electrical generation. Finland, which has abundant forest resources, produces nearly 11 percent of its electricity from biomass, although its total production is less than that of the United States.

Biofuels Production Ethanol can be produced from certain biomass materials that contain sugars, starch, or cellulose. The best-known feedstock for ethanol production is sugarcane, but other materials can be used, including wheat, corn, other cereals, and sugar beets.

Ethanol is produced by a process known as fermentation. Typically, sugar or starch is extracted from the biomass crop by crushing and mixing with water and yeast and then keeping the mixture warm in large tanks called fermenters. The yeast breaks down the sugar and converts it to ethanol and carbon dioxide. A distillation process is required to remove the water and other impurities from the dilute alcohol product. The low price of sugar coupled with the high price of oil has prompted Brazil to use its large crop of sugarcane to produce ethanol. Ethanol is sold in a variety of mixtures for automobile fuel, from 100 percent ethanol to 20 percent ethanol and 80 percent gasoline. In total, ethanol provides 40 percent of Brazil's automobile fuel.

In the United States, corn is used for ethanol production and then blended with gasoline to produce E85, a fuel that is 85 percent ethanol and 15 percent gasoline. (See figure 9.19.)

Biodiesel can be produced from the oils in a variety of crops, including soybeans, rapeseed, and palm oil as well as animal fats. These raw materials need to be modified chemically before they can be used as fuel. Currently, about 2 percent of the diesel fuel consumed in the world is biodiesel. Germany leads the world in production of biodiesel fuel with about 36 percent of the total world production.

Anaerobic Digestion Anaerobic digestion involves the decomposition of wet and green biomass or animal waste through bacterial action in the absence of oxygen. This process produces a