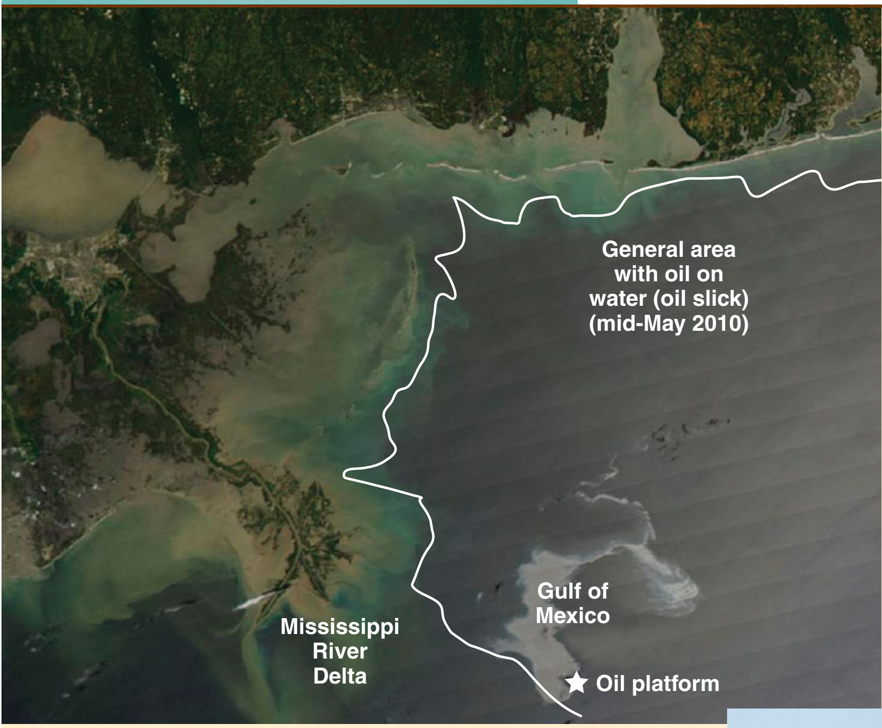
CHAPTER 15

Fossil Fuels and the Environment



LEARNING OBJECTIVES

We rely almost completely on fossil fuels—oil, natural gas, and coal—for our energy needs. However, these are nonrenewable resources, and their production and use have a variety of serious environmental impacts. After reading this chapter, you should understand . . .

- Why we may have serious, unprecedented supply problems with oil and gasoline within the next 20 to 50 years;
- How oil, natural gas, and coal form;
- What the environmental effects are of producing and using oil, natural gas, and coal.

Oil is the most important fossil fuel today, but working in oil fields has never been easy. Drilling for oil is difficult, dangerous and potentially damaging to the environment. On April 20, 2010 a blowout on the platform Deepwater Horizon in the Gulf of Mexico while drilling in water about 1.6 km (1 mile) deep occurred. Explosive gas rose up the well and exploded. Eleven men were killed, the platform destroyed, and oil leaked for 3 months at a rate of 36,000 to 60,000 barrels of oil per day (1 barrel is 42 gallons).By mid-July about 5 million barrels of oil were in the water column or on the surface and moving with the currents. The high altitude image shows the extent of the spill, off the coast of Louisiana, The smaller photo is of a wetland contaminated with oil. The oil by mid-July had washed up in variable amounts as thick oil or tar balls on beaches and coastal wetlands from Texas to Florida.The spill is the largest in U.S. history, far exceeding the Exxon Valdez in Alaska (1989). A temporary cap on the well first stopped the leak on July 17. Relief wells drilled "killed" the well.

CASE STUDY

Peak Oil: Are We Ready for It?

People in the wealthier countries have grown prosperous and lived longer during the past century as a result of abundant low-cost energy in the form of crude oil. The benefits of oil are undeniable, but so are the potential problems they create, from air and water pollution to climate change. In any case, we are about to learn what life will be like with less, more expensive oil. The question is no longer whether the peak in production will come, but when it will come and what the consequences to a society's economics and politics will be.[1] The peak, or **peak oil**, is the time when one-half of Earth's oil has been exploited.

The global history of oil in terms of rate of discovery and consumption is shown in Figure 15.1. Notice that in 1940 five times as much oil was discovered as was consumed; by 1980 the amount discovered equaled the amount consumed; and in the year 2000 the consumption of oil was three times the amount discovered. Obviously, the trend is not sustainable.

The concept of peak oil production is shown in Figure 15.2. We aren't sure what the peak production will be, but let's assume it will be about 40–50 billion barrels (bbl) per year and that the peak will arrive sometime between 2020 and 2050. In 2004 the growth rate for oil production was 3.4%. Moving from the present production rate of about 31 billion barrels per year (85 million bbl per day) to 50 billion barrels in a few decades is an optimistic estimate that may not be realized. Several oil company executives believe that even 40 billion barrels per year will be difficult. For the past several years, production has been flat, at about 30 billion barrels per year, leading some to believe that the peak is close.[2, 3]

When production peaks, and if demand increases, a gap between production and demand will result. If demand exceeds supply, the cost will rise, as it did in 2008. The price of a barrel of oil doubled from 2007 to mid-2008, and a gallon of gasoline in the United States approached $5 (Figure 15.3), causing a lot of anxiety for consumers. However, the latter part of 2008 saw the cost of oil drop more than 50% from its earlier high, and gasoline prices fell below $2 a gallon. The price was about $40/barrel by April 2009, but rose again, to about $65/barrel, by July. The instability in the cost of oil and gasoline in the first years of the 21st century reflects uncertainty about supplies because of wars and the delivery/refining processes.

We have time now to prepare for the eventual peak and to use the fossil fuels we have more carefully during the time of transition to other energy sources. If we have not prepared for the peak, then disruption to society is likely. In the best scenario, the transition from oil will not occur until we have cost-competitive alternatives in place.[2,4] Alternatives for liquid fuels include conservation (using less); producing massive amounts of biofuel from corn, sugarcane, and other plants; turning our vast coal reserves into liquid fuel; and developing other conventional sources of oil, including tar sands and oil shale. With the exception of conservation, all these have potentially significant environmental consequences. We will return to the concept of peak oil in the Critical Thinking exercise at the end of the chapter.

The approaching peak in oil production is a wake-up call, reminding us that although we will not run out of oil,

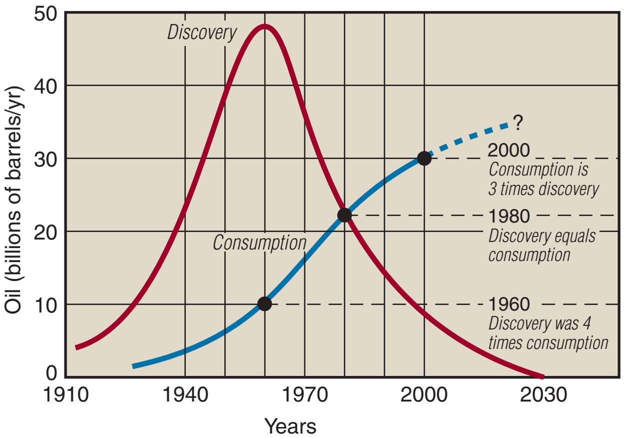


FIGURE 15.1 Discovery of oil peaked around 1960, and consumption exceeded discovery by 1980. *Source:* Modified after K. Alekett, "Oil: A Bumpy Road Ahead," *World Watch 19*, no. 1(2006):10–12.)

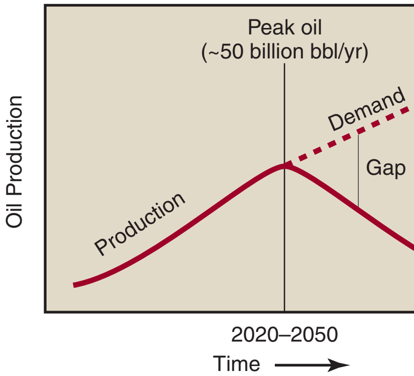


FIGURE 15.2 Idealized diagram of world oil production and peak between 2020 and 2050. When production cannot meet demand, a gap (shortage) develops.

FIGURE 15.3 A California gas station in 2008, at the height of gas pricing.

it will become much more expensive, and that there will be supply problems as demand increases by about 50% in the next 30 years. The peak in world oil production, when it arrives, will be unlike any problem we have faced in the past. The human population will increase by several billion in the coming decades, and countries with growing economies, such as China and India, will consume more oil. China, in fact, expects to double its import of oil in the next five years! Clearly, the social, economic, and political ramifications of peak oil will be enormous. Planning now for ways to conserve oil and transition to alternative energy sources will be critical in the coming decades.[4] We cannot afford to leave the age of oil until alternatives are firmly in place. The remainder of this chapter will discuss the various fossil fuels and their uses.

15.1 Fossil Fuels

Fossil fuels are forms of stored solar energy. Plants are solar energy collectors because they can convert solar energy to chemical energy through photosynthesis (see Chapter 6). The main fossil fuels used today were created from incomplete biological decomposition of dead organic matter (mostly land and marine plants). Buried organic matter that was not completely oxidized was converted by chemical reactions over hundreds of millions of years to oil, natural gas, and coal. Biological and geologic processes in various parts of the geologic cycle produce the sedimentary rocks in which we find these fossil fuels.[5, 6]

The major fossil fuels—crude oil, natural gas, and coal—are our primary energy sources; they provide approximately 90% of the energy consumed worldwide (Figure 15.4). World energy consumption grew about 1.4% in 2008. The largest increase, 7.2%, was in China. In the United States, consumption dropped about 2.8%. Most of the global increase (75%) was due to burning coal in China.[7] Globally, oil and natural gas provide 70 to 80% of the primary energy. Two exceptions are Asia, which uses a lot of coal, and the Middle East, where oil and gas provide nearly all of the energy. In this chapter, we focus primarily on these major fossil fuels. We also briefly discuss two other fossil fuels, oil shale and tar

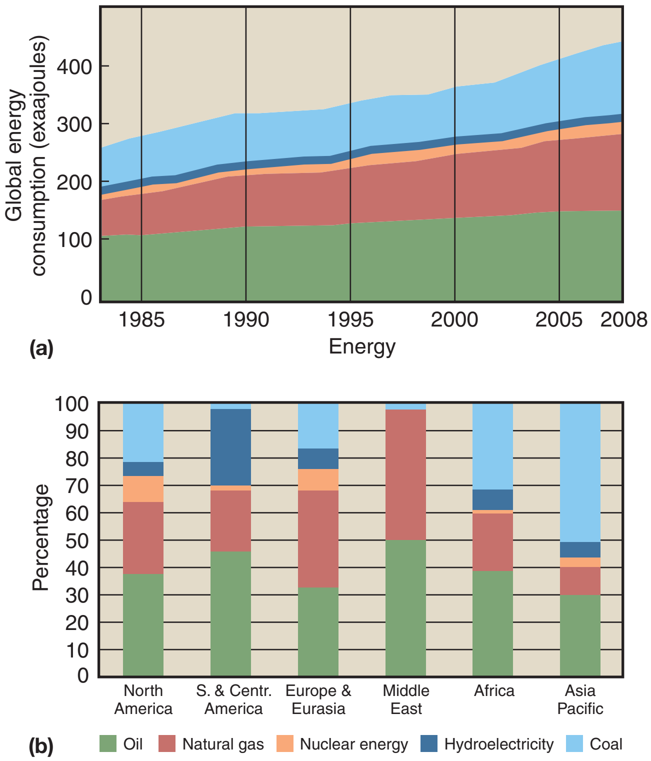


FIGURE 15.4 **(a)** World energy consumption (in exajoules) by primary source from 1983 to 2008; **(b)** world energy consumption by primary sources in 2008. (*Source*: *BP Statistical Review of World Energy 2010.* BP p.l.c.)

sands, that may become increasingly important as oil, gas, and coal reserves are depleted.

15.2 Crude Oil and Natural Gas

Most geologists accept the hypothesis that **crude oil** (petroleum) and **natural gas** are derived from organic materials (mostly plants) that were buried with marine or lake sediments in what are known as *depositional basins*. Oil and gas are found primarily along geologically young tectonic belts at plate boundaries, where large depositional basins are more likely to occur (see Chapter 6). However, there are exceptions, such as in Texas, the Gulf of Mexico, and the North Sea, where oil has been discovered in depositional basins far from active plate boundaries.

The source material, or *source rock*, for oil and gas is fine-grained (less than 1/16 mm, or 0.0025 in., in diameter), organic-rich sediment buried to a depth of at least 500 m (1,640 ft), where it is subjected to increased heat and pressure. The elevated temperature and pressure initiate the chemical transformation of the sediment's organic material into oil and gas. The pressure compresses the sediment; this, along with the elevated temperature in the source rock, initiates the upward migration of the oil and gas, which are relatively light, to a lower-pressure environment (known as the *reservoir rock*). The reservoir rock is coarser-grained and relatively porous (it has more and larger spaces between the grains). Sandstone and porous limestone, which have a relatively high proportion (about 30%) of empty space in which to store oil and gas, are common reservoir rocks.

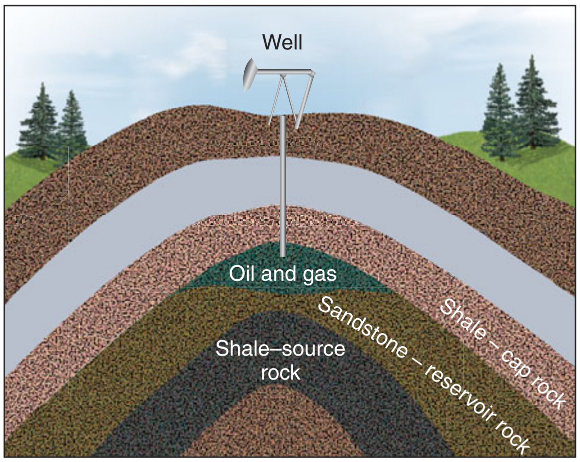
As mentioned, oil and gas are light; if their upward mobility is not blocked, they will escape to the atmosphere. This explains why oil and gas are not generally found in geologically old rocks. Oil and gas in rocks older than about 0.5 billion years have had ample time to migrate to the surface, where they have either vaporized or eroded away.[6]

The oil and gas fields from which we extract resources are places where the natural upward migration of the oil and gas to the surface is interrupted or blocked by what is known as a *trap* (Figure 15.5). The rock that helps form the trap, known as the *cap rock*, is usually a very fine-grained sedimentary rock, such as shale, composed of silt and clay-sized particles. A favorable rock structure, such as an anticline (arch-shaped fold) or a fault (fracture in the rock along which displacement has occurred), is necessary to form traps, as shown in Figure 15.5. The important concept is that the combination of favorable rock structure and the presence of a cap rock allow deposits of oil and gas to accumulate in the geologic environment, where they are then discovered and extracted.[6]

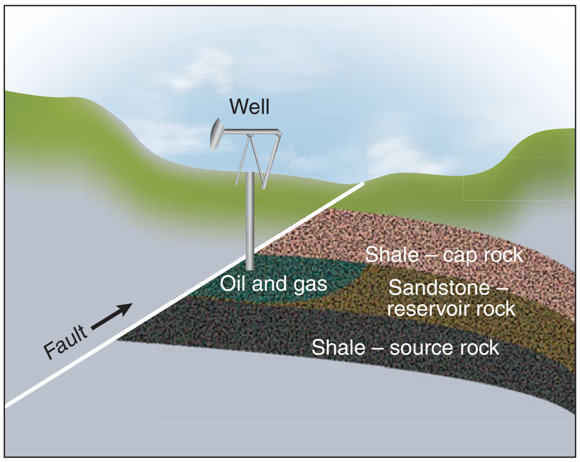
Petroleum Production

Production wells in an oil field recover oil through both primary and enhanced methods. *Primary production* involves simply pumping the oil from wells, but this method can recover only about 25% of the petroleum in the reservoir. To increase the amount of oil recovered to about 60%, enhanced methods are used. In *enhanced* recovery, steam, water, or chemicals, such as carbon dioxide or nitrogen gas, are injected into the oil reservoir to push the oil toward the wells, where it can be more easily recovered by pumping.

Next to water, oil is the most abundant fluid in the upper part of the Earth's crust. Most of the known, proven oil reserves, however, are in a few fields. *Proven* oil reserves are



(a)



(b)

FIGURE 15.5 Two types of oil and gas traps: **(a)** anticline and **(b)** fault.

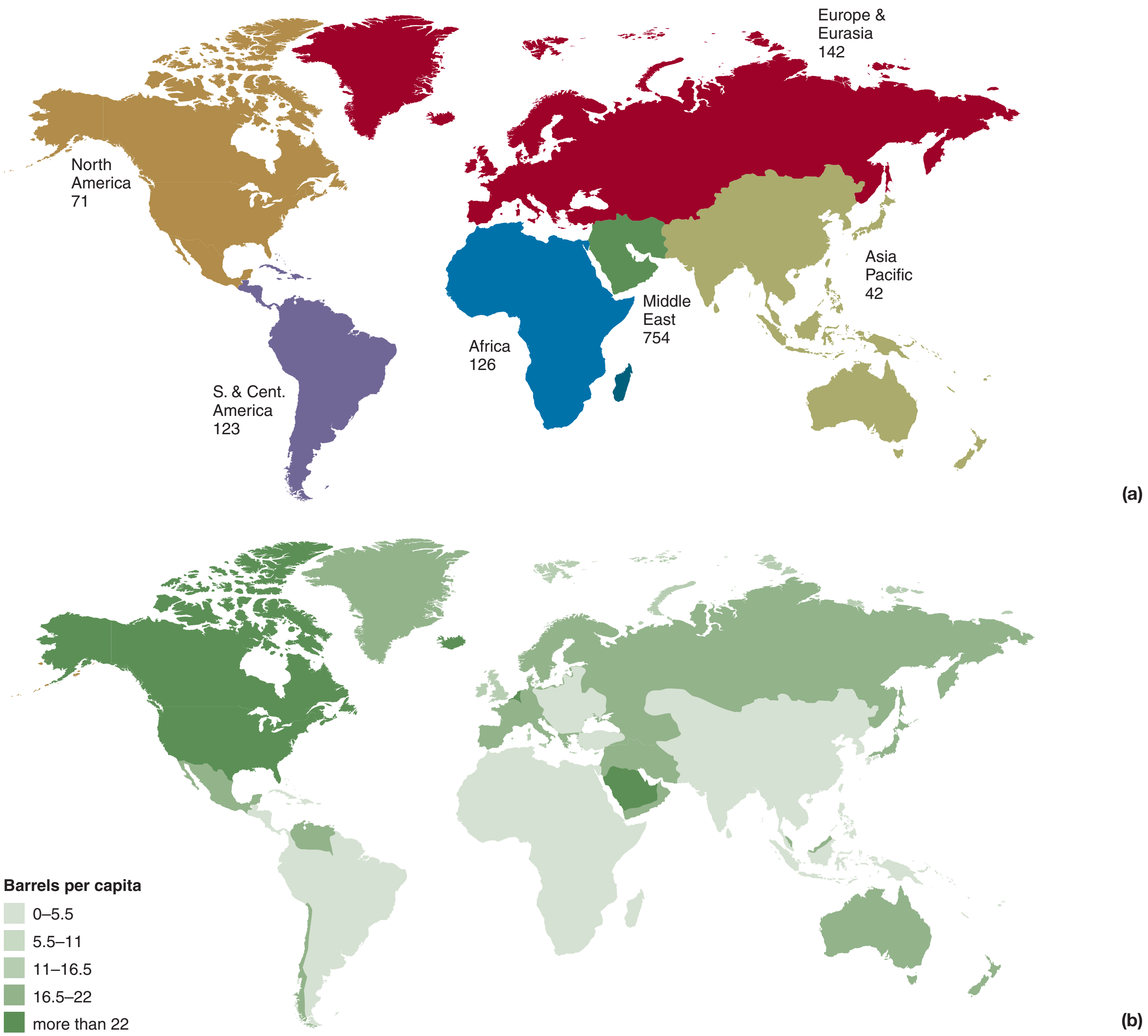


FIGURE 15.6 **(a)** Proven world oil reserves (billions of barrels) in 2008. The Middle East dominates, with 60% of total reserves. **(b)** Consumption of oil per person in 2008. Units are barrels (1 barrel is 42 gallons). (*Source*: *BP Statistical Review of World Energy 2010.* BP p.l.c.)

the part of the total resource that has been identified and can be extracted now at a profit. Of the total reserves, 62% are in 1% of the fields, the largest of which (60% of total known reserves) are in the Middle East (Figure 15.6a). The consumption of oil per person is shown in Figure 15.6b. Notice the domination of energy use in North America. Although new oil and gas fields have recently been and continue to be discovered in Alaska, Mexico, South America, and other areas of the world, the present known world reserves may be depleted in the next few decades.

The total resource always exceeds known reserves; it includes petroleum that cannot be extracted at a profit and petroleum that is suspected but not proved to be present. Several decades ago, the amount of oil that ultimately could be recovered (the total resource) was estimated to be about 1.6 trillion barrels. Today, that estimate is just over 2 trillion barrels.[8] The increases in proven reserves of oil in the last few decades have primarily been due to discoveries in the Middle East, Venezuela, Kazakhstan, and other areas.

Table 15.1 IMPORTS AND EXPORTS OF OIL, 2010

	THOUSAND BARRELS DAILY			
	CRUDE IMPORT	PRODUCTS IMPORT	CRUDE EXPORT	PRODUCTS EXPORT
US	8893	2550	44	1871
Canada	785	320	1938	538
Mexico	9	439	1282	168
S. & Cent. America	504	863	2588	1137
Europe	10308	3177	464	1523
Former Soviet Union	18	67	6868	2197
Middle East	140	219	16510	1916
North Africa	369	209	2232	528
West Africa	1	254	4263	110
East & Southern Africa	439	119	297	6
Australasia	458	358	258	42
China	4086	1041	94	614
India	2928	217	1.9	740
Japan	3545	738	–	345
Singapore	930	1668	47	1505
Other Asia Pacific	4590	2667	807	1252
Unidentified*	–	18	311	430
Total World	38005	14925	38005	14925

Source: *BP Statistical Review of World Energy* (2010.B.P. p.l.c.)

Because so much of the world's oil is in the Middle East, oil revenues have flowed into that area, resulting in huge trade imbalances. Table 15.1 shows the major trade for oil. The United States imports oil from Venezuela, the Middle East, Africa, Mexico, Canada, and Europe. Japan is dependent on oil from the Middle East and Africa.

Oil in the 21st Century

Recent estimates of proven oil reserves suggest that, at present production rates, oil and natural gas will last only a few decades.[7, 9] The important question, however, is not how long oil is likely to last at present and future production rates, but when we will reach peak production. This is important because, following peak production, less oil will be available, leading to shortages and price shocks. World oil production, as mentioned in the opening case study, is likely to peak between the years 2020 and 2050, within the lifetime of many people living today.[10] Even those who think peak oil production in the near future is a myth acknowledge that the peak is coming and that we need to be prepared.[2] Whichever projections are correct, there is a finite amount of time (a few decades or perhaps a bit longer) left in which to adjust to potential changes in lifestyle and economies in a post-petroleum era.[10] We will never entirely run out of crude oil, but people of the world depend on oil for nearly 40% of their energy, and significant shortages will cause major problems.[11]

Consider the following argument that we are heading toward a potential crisis in availability of crude oil:

- We are approaching the time when approximately 50% of the total crude oil available from traditional oil fields will have been consumed.[10] Recent studies suggest that about 20% more oil awaits discovery than predicted a few years ago, and that there is more oil in known fields than earlier thought. However, the volumes of new oil discovered and recovered in known fields will not significantly change the date when world production will peak and a decline in production will begin.[9] This point is controversial. Some experts believe that modern technology for exploration, drilling, and recovery of oil will ensure an adequate supply of oil for the distant future.[8]
- Proven reserves are about 1.3 trillion barrels.[7] It is estimated that approximately 2 trillion barrels of crude oil may ultimately be recovered from remaining oil resources. World production today is about 31 billion barrels per year (85 million barrels per day), and we are using what is left very rapidly.[2]

- Today, for every three barrels of oil we consume, we are finding only one barrel.[11] In other words, output is three times higher than input. However, this could improve in the future.[8]
- Forecasts that predict a decline in oil production are based on the estimated amount of oil that may ultimately be recoverable (2 trillion barrels, nearly two times today's proven reserves), along with projections of new discoveries and rates of future consumption. As already mentioned, it has been estimated that the peak in world crude oil production, about 40 billion bbl/yr, will occur between the years 2020 and 2050.[1,2,9,11] The production of 40 billion bbl/yr is about a 30% increase over 2007. Whether you think this increase is optimistic or pessimistic depends on your view of past oil history, in which oil has survived several predicted shortages, or beliefs that the peak is inevitable sooner than later.[1, 2] Most oil experts believe peak oil is only a few decades away.
- It is expected that U.S. production of oil as we know it now will end by about 2090 and that world production of oil will be nearly exhausted by 2100.[11]

Table 15.1 suggests that world exports of oil are about one-half of world production. We conclude that the other half is often used in the country that produced it. A prospect perhaps as significant as peak oil may be the time when exporting nations no longer have significant oil to export. This will occur in different exporting countries at different times and is sure to cause problems with global supply and demand.

What is an appropriate response to the likelihood that oil production will likely decline in the mid-21st century? First, we need an improved educational program to inform or remind people and governments of the potential depletion of crude oil and the consequences of shortages. Presently, many people seem to be in denial. Planning and appropriate action are necessary to avoid military confrontation (we have already had one oil war), food shortages (oil is used to make the fertilizers modern agriculture depends on), and social disruption. Before significant oil shortages occur, we need to develop alternative energy sources, such as solar energy and wind power, and perhaps rely more on nuclear energy. This is a proactive response to a potentially serious situation.

Natural Gas

We have only begun to seriously search for natural gas and to utilize this resource to its full potential. One reason for the slow start is that natural gas is transported primarily by pipelines, and only in the last few decades have these pipelines been constructed in large numbers. In fact, until recently, natural gas found with petroleum was often simply burned off as waste; in some cases this practice continues.[12]

The worldwide estimate of recoverable natural gas is about 185 trillion cubic meters (m^3), which, at the current rate of world consumption, will last approximately 60 years.[7] Considerable natural gas was recently discovered in the United States, and at present U.S. consumption levels (0.7 trillion m^3 in 2008) this resource is expected to last at least 30 years. Furthermore, new supplies are being found in surprisingly large amounts, particularly at greater depths than those at which oil is found. Optimistic estimates of the total resource suggest that, at current rates of consumption, the supply may last approximately 100 years.[5]

This possibility has important implications. Natural gas is considered a clean fuel; burning it produces fewer pollutants than does burning oil or coal, so it causes fewer environmental problems than do the other fossil fuels. As a result, it is being considered as a possible transition fuel from other fossil fuels (oil and coal) to alternative energy sources, such as solar power, wind power, and hydropower.

Despite the new discoveries and the construction of pipelines, long-term projections for a steady supply of natural gas are uncertain. The supply is finite, and at present rates of consumption it is only a matter of time before the resources are depleted.

Coal-Bed Methane

The processes responsible for the formation of coal include partial decomposition of plants buried by sediments that slowly convert the organic material to coal. This process also releases a lot of methane (natural gas) that is stored within the coal. The methane is actually stored on the surfaces of the organic matter in the coal, and because coal has many large internal surfaces, the amount of methane for a given volume of rock is something like seven times more than could be stored in gas reservoirs associated with petroleum. The estimated amount of coal-bed methane in the United States is more than 20 trillion cubic meters, of which about 3 trillion cubic meters could be recovered economically today with existing technology. At current rates of consumption in the United States, this represents about a five-year supply of methane.[13]

Two areas within the nation's coalfields that are producing methane are the Wasatch Plateau in Utah and the Powder River Basin in Wyoming. The Powder River Basin is one of the world's largest coal basins, and presently an energy boom is occurring in Wyoming, producing an "energy rush." The technology to recover coal-bed methane is a young one, but it is developing quickly. As of early 2003, approximately 10,000 shallow wells were producing methane in the Powder River Basin, and some say there will eventually be about 100,000 wells. The big advantage of the coal-bed methane wells is that they only need to be drilled to shallow depths (about 100 m, or a few hundred feet). Drilling can be done with conventional water-well technology, and the cost is about $100,000 per well, compared to several million dollars for an oil well.[14]

Coal-bed methane is a promising energy source that comes at a time when the United States is importing vast amounts of energy and attempting to evaluate a transition from fossil fuels to alternative fuels. However, coal-bed methane presents several environmental concerns, including (1) disposal of large volumes of water produced when the methane is recovered and (2) migration of methane, which may contaminate groundwater or migrate into residential areas.

A major environmental benefit of burning coal-bed methane, as well as methane from other sources, is that its combustion produces a lot less carbon dioxide than does the burning of coal or petroleum. Furthermore, production of methane gas prior to mining coal reduces the amount of methane that would be released into the atmosphere. Both methane and carbon dioxide are strong greenhouse gases that contribute to global warming. However, because methane produces a lot less carbon dioxide, it is considered one of the main transitional fuels from fossil fuels to alternative energy sources.

Of particular environmental concern in Wyoming is the safe disposal of salty water that is produced with the methane (the wells bring up a mixture of methane and water that contains dissolved salts from contact with subsurface rocks). Often, the water is reinjected into the subsurface, but in some instances the water flows into surface drainages or is placed in evaporation ponds.[13]

Some of the environmental conflicts that have arisen are between those producing methane from wells and ranchers trying to raise cattle on the same land. Frequently, the ranchers do not own the mineral rights; and although energy companies may pay fees for the well, the funds are not sufficient to cover damage resulting from producing the gas. The problem results when the salty water produced is disposed of in nearby streams. When ranchers use the surface water to irrigate crops for cattle, the salt damages the soils, reducing crop productivity. Although it has been argued that ranching is often a precarious economic venture, and that ranchers have in fact been saved by the new money from coal-bed methane, many ranchers oppose coal-bed methane production without an assurance that salty waters will be safely disposed of.

People are also concerned about the sustainability of water resources as vast amounts of water are removed from the groundwater aquifers. In some instances, springs have been reported to have dried up after coal-bed methane extraction in the area.[14] In other words, the "mining" of groundwater for coal-bed methane extraction will remove water that has perhaps taken hundreds of years to accumulate in the subsurface environment.

Another concern is the migration of methane away from the well sites, possibly to nearby urban areas. The problem is that unlike the foul-smelling variety in homes, methane in its natural state is odorless as well as explosive. For example, in the 1970s an urban area near Gallette, Wyoming, had to be evacuated because methane was migrating into homes from nearby coal mines.

Finally, coal-bed methane wells, with their compressors and other equipment, have caused people living a few hundred meters away to report serious and distressing noise pollution.[14]

In sum, coal-bed methane is a tremendous source of energy and relatively clean-burning, but its extraction must be closely evaluated and studied to minimize environmental degradation.

Black Shale (tight) Natural Gas

According to the U.S. Geological Survey, Black Devonian shale over 350 million years old buried a kilometer or so beneath northern Appalachia, contains about 500 trillion cubic feet of natural gas (mostly methane) of which10% or more may be ultimately recovered. The methane is distributed throughout the black shale as an unconventional gas resource compared to gas fields where the methane is in rock pockets often associated with oil. A very large area including parts of Ohio, New York, Pennsylvania, Virginia and Kentucky. Recovery of the methane is costly, because deep wells that turn at depth to a horizontal position are necessary to extract the gas. Water and other chemicals are used to fracture the rocks (hydrofracturing) to recover the gas. An energy rush is now occurring to develop the recovery of tight natural gas. Hundreds of gas wells have already been permitted in Pennsylvania alone. There is concern that drilling and hydrofracturing could result in water pollution, because the fluids used to fracture the rock must be recovered from wells and disposed of before gas production starts. There is also concern that contaminate water could migrate upward and leak from wells to pollute water supplies. The city of New York is very concerned that drilling may contaminated their water supply in upstate New York.[15]

Methane Hydrates

Beneath the seafloor, at depths of about 1,000 meters, there exist deposits of **methane hydrate**, a white, ice-like compound made up of molecules of methane gas (CH_4), molecular "cages" of frozen water. The methane has formed as a result of microbial digestion of organic matter in the sediments of the seafloor and has become trapped in these ice cages. Methane hydrates in the oceans were discovered over 30 years ago and are widespread in both the Pacific and Atlantic oceans. Methane hydrates are also found on land; the first ones discovered were in permafrost areas of Siberia and North America, where they are known as marsh gas.[16]

Methane hydrates in the ocean occur where deep, cold seawater provides high pressure and low temperatures. They are not stable at lower pressure and warmer temperatures. At a water depth of less than about 500 m, methane hydrates decompose rapidly, freeing methane gas from the ice cages to move up as a flow of methane bubbles (like rising helium balloons) to the surface and the atmosphere.

In 1998 researchers from Russia discovered the release of methane hydrates off the coast of Norway. During the release, scientists documented plumes of methane gas as tall as 500 m being emitted from methane hydrate deposits on the seafloor. It appears that there have been large emissions of methane from the sea. The physical evidence includes fields of depressions, looking something like bomb craters, that pockmark the seafloor near methane hydrate deposits. Some of the craters are as large as 30 m deep and 700 m in diameter, suggesting that they were produced by rapid, if not explosive, eruptions of methane.

Methane hydrates in the marine environment are a potential energy resource with approximately twice as much energy as all the known natural gas, oil, and coal deposits on Earth.[16] Methane hydrates are particularly attractive to countries such as Japan that rely exclusively on foreign oil and coal for their fossil fuel needs. Unfortunately, mining methane hydrates will be a difficult task, at least for the near future. The hydrates tend to be found along the lower parts of the continental slopes, where water is often deeper than 1 km. The deposits themselves extend into the seafloor sediments another few hundred meters. Drilling rigs have more problems operating safely at these depths, and developing a way to produce the gas and transport it to land will be challenging.

(a) (b)

FIGURE 15.7 Drilling for oil in **(a)** the Sahara Desert of Algeria; **(b)** the Cook Inlet of southern Alaska.

The Environmental Effects of Oil and Natural Gas

Recovering, refining, and using oil—and to a lesser extent natural gas—cause well-known, documented environmental problems, such as air and water pollution, acid rain, and global warming. People have benefited in many ways from abundant, inexpensive energy, but at a price to the global environment and human health.

Recovery

Development of oil and gas fields involves drilling wells on land or beneath the seafloor (Figure 15.7).

Possible environmental impacts on land include the following:

- Use of land to construct pads for wells, pipelines, and storage tanks and to build a network of roads and other production facilities.
- Pollution of surface waters and groundwater from (1) leaks from broken pipes or tanks containing oil or other oil-field chemicals and (2) salty water (brine) brought to the surface in large volumes with the oil. The brine is toxic and may be disposed of by evaporation in lined pits, which may leak. Alternatively, it may be disposed of by pumping it into the ground, using deep disposal wells outside the oil fields. However, disposal wells may pollute groundwater.
- Accidental release of air pollutants, such as hydrocarbons and hydrogen sulfide (a toxic gas).
- Land subsidence (sinking) as oil and gas are withdrawn.
- Loss or disruption of and damage to fragile ecosystems, such as wetlands or other unique landscapes. This is the center of the controversy over the development of petroleum resources in pristine environments such as the Arctic National Wildlife Refuge in Alaska (see A Closer Look 15.1).

Environmental impacts associated with oil production in the marine environment include the following:

- Oil seepage into the sea from normal operations or large spills from accidents, such as blowouts or pipe ruptures (see photograph opening this chapter). The very serious oil spill in the Gulf of Mexico (April 20, 2010) began from a blowout when equipment designed to prevent a blowout for this well drilled in very deep water (over 1.5 km,1 mile) failed to operate properly. The platform was destroyed by a large explosion and 11 oil workers were killed. By the middle of May oil started to make landfall in Louisiana and other areas, and fishing was shut down over a large area. The oil spread despite the many and continuing efforts (chemical dispersants, skimming and burning among others) to deter the oil from spreading. The spill was the largest and potentially most damaging in U.S. history (see Chapter 19 for a discussion of other oil spills and Chapter 24 for a more detailed case study of the 2010 Gulf spill).
- Release of drilling muds (heavy liquids injected into the borehole during drilling to keep the hole open). These contain heavy metals, such as barium, which may be toxic to marine life.
- Aesthetic degradation from the presence of offshore oil-drilling platforms, which some people consider unsightly.

Refining

Refining crude oil and converting it to products also has environmental impacts. At refineries, crude oil is heated so that its components can be separated and collected (this process is called *fractional distillation*). Other industrial processes then make products such as gasoline and heating oil.

Refineries may have accidental spills and slow leaks of gasoline and other products from storage tanks and pipes. Over years of operation, large amounts of liquid hydrocarbons may be released, polluting soil and groundwater below the site. Massive groundwater-cleaning projects have been required at several West Coast refineries.

Crude oil and its distilled products are used to make fine oil, a wide variety of plastics, and organic chemicals used by society in huge amounts. The industrial processes involved in producing these chemicals have the potential to release a variety of pollutants into the environment.

Delivery and Use

Some of the most extensive and significant environmental problems associated with oil and gas occur when the fuel is delivered and consumed. Crude oil is mostly transported on land in pipelines or across the ocean by tankers; both methods present the danger of oil spills. For example, a bullet from a high-powered rifle punctured the Trans-Alaska Pipeline in 2001, causing a small but damaging oil spill. Strong earthquakes may pose a problem for pipelines in the future, but proper engineering can minimize earthquake hazard. The large 2002 Alaskan earthquake ruptured the ground by several meters where it crossed the Trans-Alaska Pipeline. The pipeline's design prevented damage to the pipeline and to the environment. Although most effects of oil spills are relatively short-lived (days to years), marine spills have killed thousands of seabirds, spoiled beaches for decades (especially beneath the surface of gravel beaches), and caused loss of tourist and fishing revenues (see Chapter 19).

A CLOSER LOOK 15.1

The Arctic National Wildlife Refuge: To Drill or Not to Drill

The Arctic National Wildlife Refuge (ANWR) on the North Slope of Alaska is one of the few pristine wilderness areas remaining in the world (Figure 15.8). The U.S. Geological Survey estimates that the refuge contains about 3 billion barrels

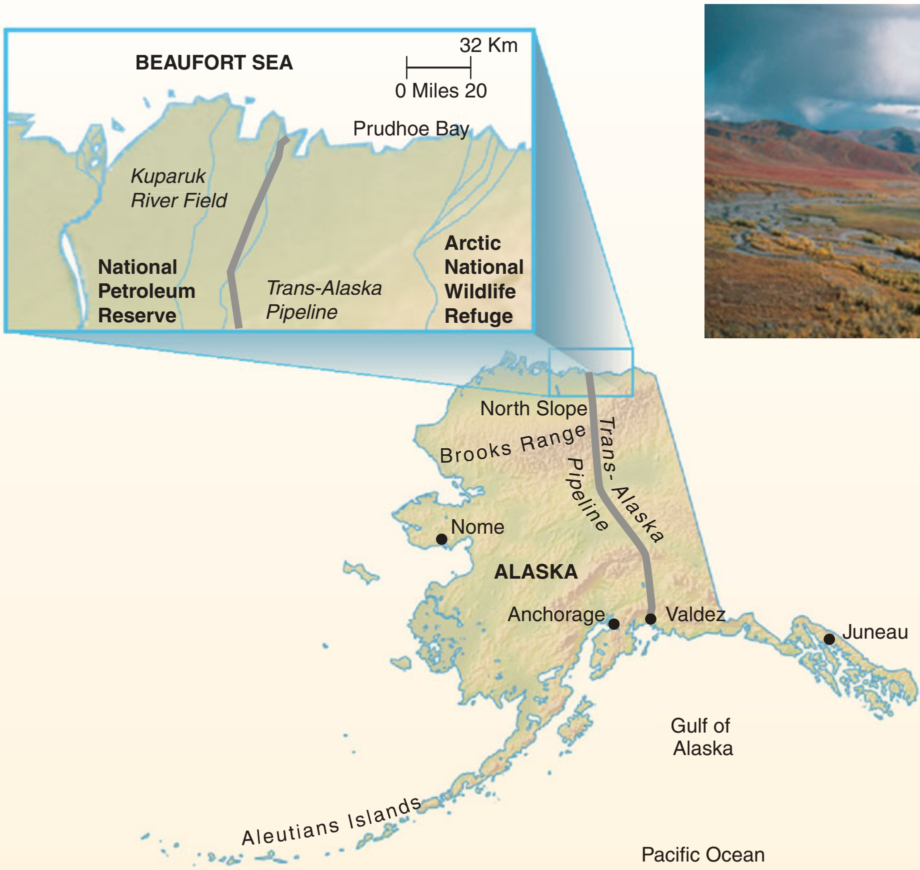


FIGURE 15.8 The Arctic National Wildlife Refuge, on Alaska's North Slope, is valued for its scenery, wildlife, and oil.

of recoverable oil. The United States presently consumes about 20 million barrels of oil per day, so ANWR could provide about a six-month supply if that were the only oil we used. Spread out to supply 1 million barrels per day, the supply at ANWR would last about eight years. According to the oil industry, several times more oil than that can be recovered. The oil industry has long argued in favor of drilling for oil in the ANWR, but the idea has been unpopular for decades among many members of the public and the U.S. government, and no drilling has been permitted. Former president George W. Bush favored drilling in the ANWR, which renewed the controversy over this issue. President Barack Obama is opposed to such drilling.

Arguments in Favor of Drilling in the ANWR

- The United States needs the oil, and it will help us to be more independent of imported oil.
- The unprecedented price increase in oil in 2008 has provided a big economic incentive to develop our domestic oil reserves.
- New oil facilities will bring jobs and dollars to Alaska.
- New exploration tools to evaluate the subsurface for oil pools require far fewer exploratory wells.
- New drilling practices have much less impact on the environment (Figure 15.9a and b). These include (1) constructing roads of ice in the winter that melt in the summer instead of constructing permanent roads; (2) elevating pipelines to allow for animal migration (Figure 15.9c); (3) drilling in various directions from a central location, thus minimizing land needed for wells; and (4) disposing of fluid oil-field wastes by putting them back into the ground to minimize surface pollution.
- The land area affected will be small relative to the total area.

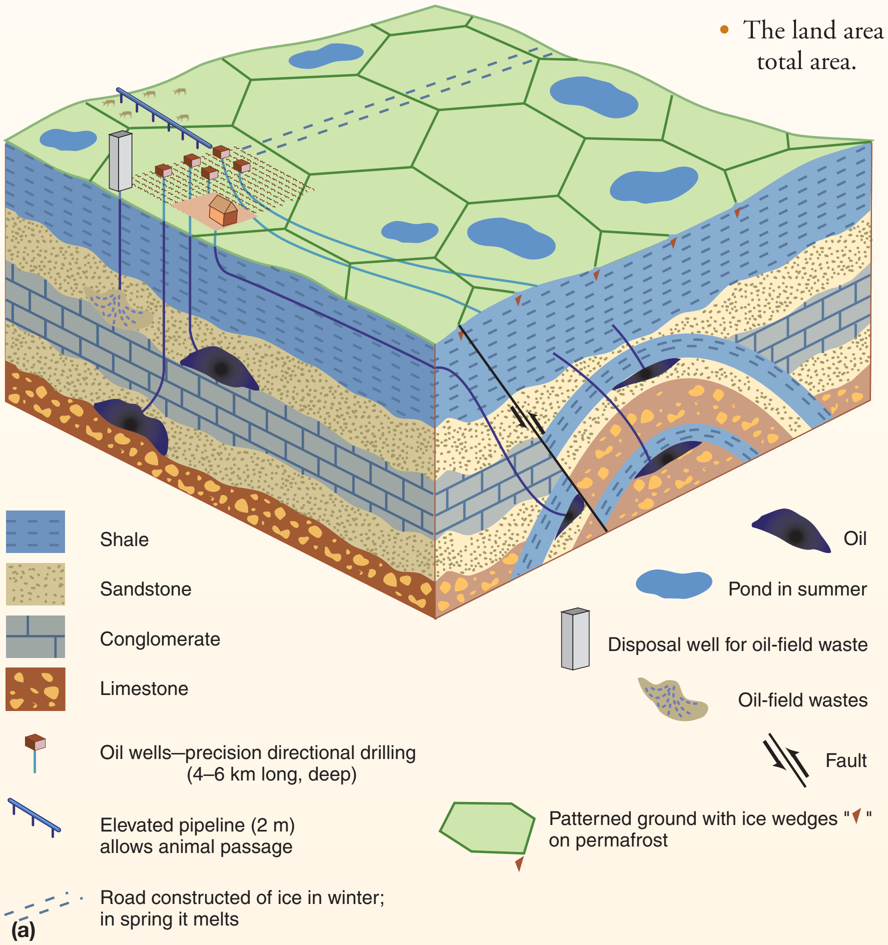


FIGURE 15.9 **(a)** Those in favor of ANWR drilling argue that new technology can reduce the impact of developing oil fields in the Arctic: Wells are located in a central area and use directional drilling; roads are constructed of ice in the winter, melting to become invisible in summer; pipelines are elevated to allow animals, in this case caribou, to pass through the area; and oil-field and drilling wastes are injected deep underground. (See text for arguments against drilling.) **(b)** Oil wells being drilled on frozen ground (tundra), North Slope of Alaska. **(c)** Caribou passing under a pipeline near the Arctic National Wildlife Refuge in Alaska.

- Many Alaskans want the drilling to proceed and point out that oil drilling for 30 years on the North Slope of Alaska (Prudhoe Bay) has not harmed animals or the environment.

Arguments against Drilling in the ANWR

- Advances in technology are irrelevant to the question of whether or not the ANWR should be drilled. Some wilderness should remain wilderness! Drilling will forever change the pristine environment of the North Slope.
- Even with the best technology, oil exploration and development will impact the ANWR. Intensive activity, even in winter on roads constructed of ice, will probably disrupt wildlife.
- Ice roads are constructed from water from the tundra ponds. To build a road 1 km (0.63 mi) long requires about 3,640 m^3 (1 million gallons) of water.
- Heavy vehicles used in exploration permanently scar the ground—even if the ground is frozen hard when the vehicles travel across the open tundra.
- Accidents may occur in even the best facilities.
- Oil development is inherently damaging because it involves a massive industrial complex of people, vehicles, equipment, pipelines, and support facilities.

Our decision about drilling in the Alaska National Wildlife Refuge will reflect both science and values at a basic level. New technology will lessen the environmental impact of oil drilling. How we value the need for energy from oil compared with how we value preservation of a pristine wilderness area will determine our action: to drill or not to drill. The debate is not over yet. The oil crisis of 2008 that drove the price of gasoline to nearly $5 per gallon placed ANWR oil development in the spotlight again.

Air pollution is perhaps the most familiar and serious environmental impact of burning oil. Combustion of gasoline in automobiles produces pollutants that contribute to urban smog. (The adverse effects of smog on vegetation and human health are well documented and are discussed in detail in Chapter 21.)

15.3 Coal

Partially decomposed vegetation, when buried in a sedimentary environment, may be slowly transformed into the solid, brittle, carbonaceous rock we call **coal**. This process is shown in Figure 15.10. Coal is by far the world's most abundant fossil fuel, with a total recoverable resource of about 825 billion metric tons (Figure 15.11). The annual world consumption of coal is about 7 billion metric tons, sufficient for about 120 years at the current rate of use.[7] There are about 18,500 coal mines in the United States with combined reserves of 262 billion tons and 2008 production of 1.2 billion tons. At present rates of mining, U.S. reserves will last nearly 250 years.[7, 17] If, however, consumption of coal increases in the coming decades, the resource will not last nearly as long.[18]

Coal is classified, depending on its energy and sulfur content, as anthracite, bituminous, subbituminous, or lignite (see Table 15.2). The energy content is greatest in anthracite coal and lowest in lignite coal. The distribution of coal in the contiguous United States is shown in Figure 15.12.

The sulfur content of coal is important because low-sulfur coal emits less sulfur dioxide (SO_2) and is therefore more desirable as a fuel for power plants. Most low-sulfur coal in the United States is the relatively low-grade, low-energy lignite and subbituminous coal found west of the Mississippi River. Power plants on the East

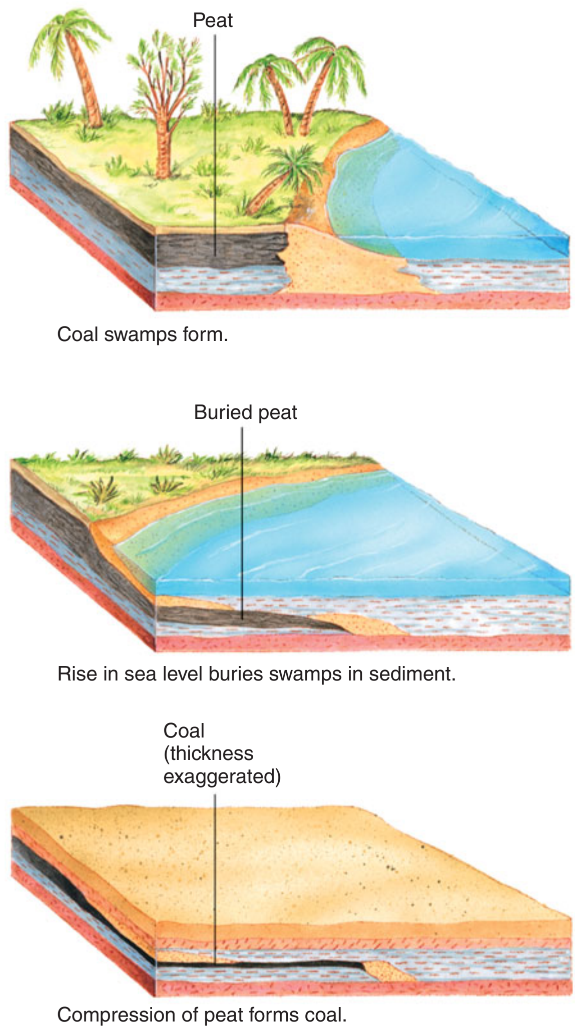


FIGURE 15.10 Processes by which buried plant debris (peat) is transformed into coal.

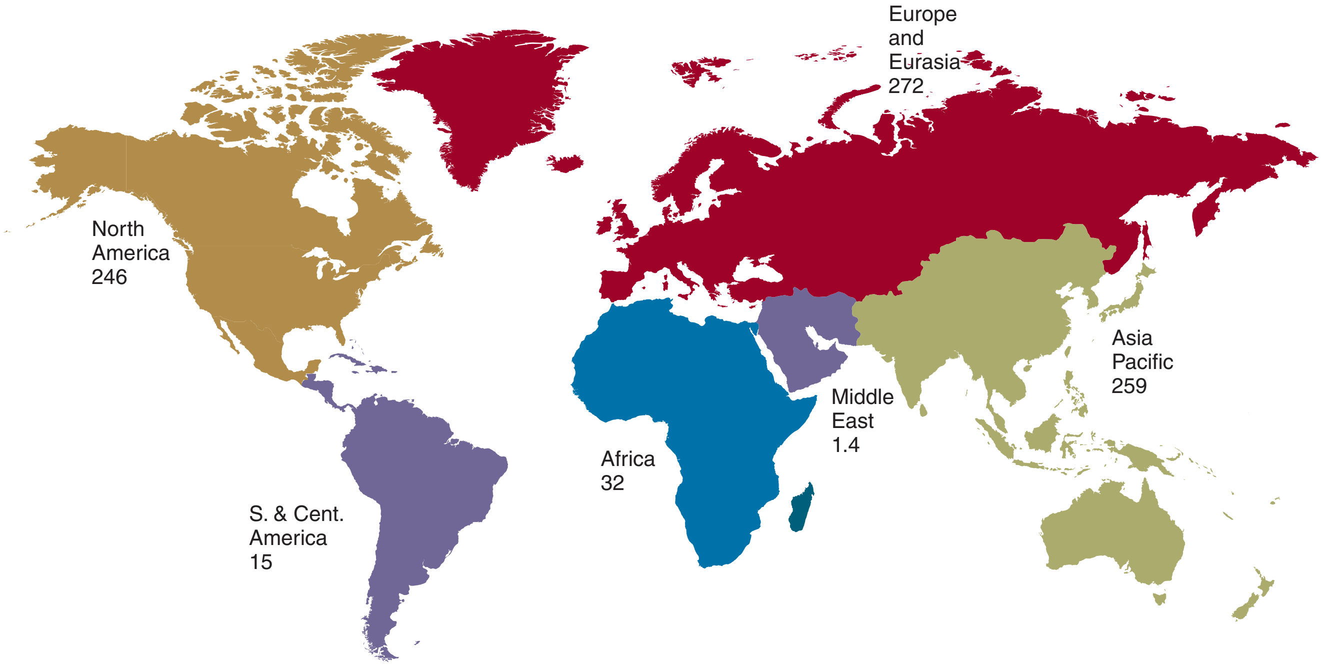


FIGURE 15.11 World coal reserves (billions of tons) in 2008. (*Source*: *BP Statistical Review of World Energy* 2009.B.P. p.l.c.).

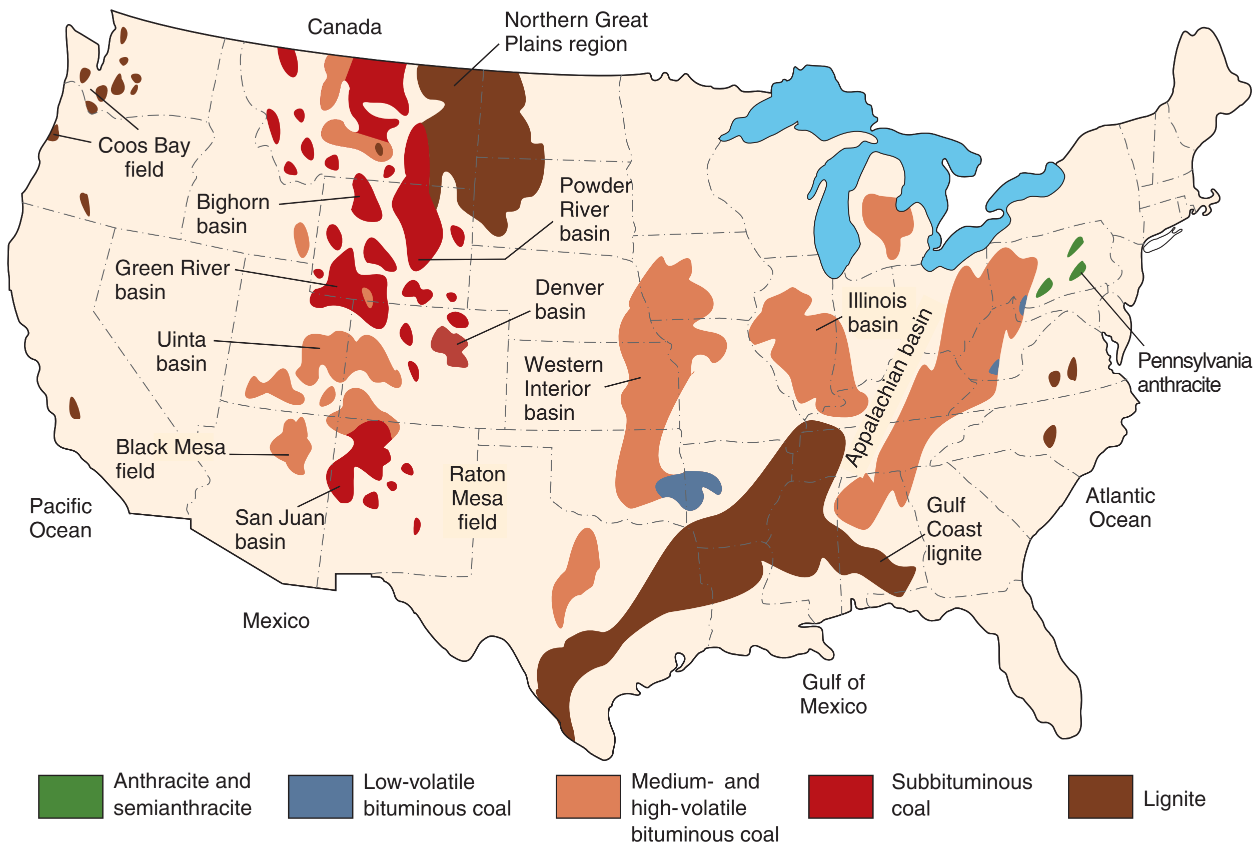


FIGURE 15.12 Coal areas of the contiguous United States. This is a highly generalized map, and numerous relatively small occurrences of coal are not shown. (*Source*: S. Garbini and S.P. Schweinfurth, *U.S. Geological Survey Circular 979, 1986.)*

Coast treat the high-sulfur coal mined in their own region to lower its sulfur content before, during, or after combustion and, thus, avoid excessive air pollution. Although it is expensive, treating coal to reduce pollution may be more economical than transporting low-sulfur coal from the western states.

Table 15.2 U.S. COAL RESOURCES

TYPE OF COAL	RELATIVE RANK	ENERGY OF CONTENT (MILLIONS OF JOULES/KG)	SULFUR CONTENT (%)		
			LOW (0–1)	MEDIUM (1.1–3.0)	HIGH (3 +)
Anthracite	1	30–34	97.1	2.9	–
Bituminous Coal	2	23–34	29.8	26.8	43.4
Subbituminous Coal	3	16–23	99.6	0.4	–
Lignite	4	13–16	90.7	9.3	–

Sources: U.S. Bureau of Mines Circular 8312, 1966: P. Averitt, "Coal" in D.A. Brobst and W.P Pratt, eds., United States Mineral Resources, *U.S. Geological Survey, Professional Paper* 820, pp 133–142.

Coal Mining and the Environment

In the United States, thousands of square kilometers of land have been disturbed by coal mining, and only about half this land has been reclaimed. Reclamation is the process of restoring and improving disturbed land, often by re-forming the surface and replanting vegetation (see Chapter 9). Unreclaimed coal dumps from open-pit mines are numerous and continue to cause environmental problems. Because little reclamation occurred before about 1960, and mining started much earlier, abandoned mines are common in the United States. One surface mine in Wyoming, abandoned more than 40 years ago, caused a disturbance so intense that vegetation has still not been reestablished on the waste dumps. Such barren, ruined landscapes emphasize the need for reclamation.[18]

Strip Mining

Over half of the coal mining in the United States is done by *strip mining*, a surface mining process in which the overlying layer of soil and rock is stripped off to reach the coal. The practice of strip mining started in the late 19th century and has steadily increased because it tends to be cheaper and easier than underground mining. More than 40 billion metric tons of coal reserves are now accessible to surface mining techniques. In addition, approximately 90 billion metric tons of coal within 50 m (165 ft) of the surface are potentially available for strip mining. More and larger strip mines will likely be developed as the demand for coal increases.

The impact of large strip mines varies from region to region, depending on topography, climate, and reclamation practices. One serious problem in the eastern United States that get abundant rainfall is *acid mine drainage*—the drainage of acidic water from mine sites (see Chapter 19). Acid mine drainage occurs when surface water (H_2O) infiltrates the spoil banks (rock debris left after the coal is removed). The water reacts chemically with sulfide minerals, such as pyrite (FeS_2), a natural component of some sedimentary rocks containing coal, to produce sulfuric acid (H_2SO_4). The acid then pollutes streams and groundwater (Figure15.13). Acid water also drains from underground mines and from roads cut in areas where coal and pyrite are abundant, but the problem of acid mine drainage is magnified when large areas of disturbed material remain exposed to surface waters.

FIGURE 15.13 Tar Creek near Miami, Oklahoma, runs orange in 2003 due to contamination by heavy metals from acid mine drainage.

FIGURE 15.14 Strip coal mine in Wyoming. The land in the foreground is being mined, and the green land in the background has been reclaimed after mining.

Acid mine drainage from active mines can be minimized by channeling surface runoff or groundwater before it enters a mined area and diverting it around the potentially polluting materials. However, diversion is not feasible in heavily mined regions where spoil banks from unreclaimed mines may cover hundreds of square kilometers. In these areas, acid mine drainage will remain a long-term problem.

Water problems associated with mining are not as pronounced in arid and semiarid regions as they are in wetter regions, but the land may be more sensitive to activities related to mining, such as exploration and road building. In some arid areas of the western and southwestern United States, the land is so sensitive that tire tracks can remain for years. (Indeed, wagon tracks from the early days of the westward migration reportedly have survived in some locations.) To complicate matters, soils are often thin, water is scarce, and reclamation work is difficult.

Strip mining has the potential to pollute or damage water, land, and biological resources. However, good reclamation practices can minimize the damage (Figure 15.14). Reclamation practices required by law necessarily vary by site. Some of the principles of reclamation are illustrated in the case history of a modern coal mine in Colorado (see A Closer Look 15.2).

Large surface coal mining is almost always controversial. One of the most controversial has been the Black Mesa Mine in Arizona. The mine is in the Black Mesa area of the Hopi Reservation and was the only supplier of coal to the very large 1.5-MW Mohave Generating Station, a power plant at Laughlin, Nevada (144 km, or 90 mi, southeast of Las Vegas). The coal was delivered to the plant by a 440-km (275-mi) pipeline that transported slurry (crushed coal and water). The pipeline used over 1 billion gallons of water pumped from the ground per year—water that nourishes sacred springs and water for irrigation. Both the mine and the power plant suspended operation on December 31, 2005.

Mountaintop Removal

Coal mining in the Appalachian Mountains of West Virginia is a major component of the state's economy. However, there is growing environmental concern about a strip-mining technique known as "mountaintop removal" (Figure 15.16). This technique is very effective in obtaining coal as it levels the tops of mountains. But as mountaintops are destroyed, valleys are filled with waste rock and other mine waste, and the flood hazard increases as toxic wastewater is stored behind coal-waste sludge dams. Several hundred mountains have been destroyed, and by 2103 over 3,840 km (2,400 mi) of stream channels will likely have been damaged or destroyed.[19]

In October 2000, one of the worst environmental disasters in the history of mining in the Appalachian Mountains occurred in southeastern Kentucky. About 1 million cubic meters (250 million gallons) of toxic, thick black coal sludge, produced when coal is processed, was released into the environment. Part of the bottom of the impoundment (reservoir) where the sludge was being stored collapsed, allowing the sludge to enter an abandoned mine beneath the impoundment. The abandoned mine had openings to the surface, and sludge emerging from the mine flowed across people's yards and roads into a stream of the Big Sandy River drainage. About 100 km (65 mi) of stream was severely contaminated, killing several hundred thousand fish and other life in the stream.

Mountaintop removal also produces voluminous amounts of coal dust that settles on towns and fields, polluting the land and causing or exacerbating lung diseases, including asthma. Protests and complaints by communities in the path of mining were formerly ignored but are now getting more attention from state mining boards. As people become better educated about mining laws, they are more effective in confronting mining companies to get them to reduce potential adverse consequences of mining. However, much more needs to be done.

Those in favor of mountaintop mining emphasize its value to the local and regional economy. They further argue that only the mountaintops are removed, leaving most of the mountain, with only the small headwater streams filled with mining debris. They go on to say that

A CLOSER LOOK 15.2

The Trapper Mine

The Trapper Mine on the western slope of the Rocky Mountains in northern Colorado is a good example of a new generation of large coal strip mines. The operation, in compliance with mining laws, is designed to minimize environmental degradation, including damage to land farming and to grazing of livestock and big game. A landslide in 2006 impacted 102 hectares (200 acres) of the mine and caused a rethinking of the landslide hazard at the mine.

Over a 35-year period, the mine will produce 68 million metric tons of coal from the 20–24 km (50–60 mi^2) site, to be delivered to a 1,300-MW power plant adjacent to the mine. Today the mine produces about 2 million tons of coal per year, enough power for about half a million homes. Four coal seams, varying in thickness from about 1 to 4 m (3.3–13.1 ft), will be mined. The seams are separated by layers of rock, called overburden (rocks without coal), and there is additional overburden above the top seam of coal. The depth of the overburden varies from 0 to about 50 m (165 ft).

A number of steps are involved in the actual mining. First, bulldozers and scrapers remove the vegetation and topsoil from an area up to 1.6 km long and 53 m wide (1 mi by 175 ft), and the soil is stockpiled for reuse. Then the overburden is removed with a 23-m^3 (800-ft) dragline bucket. Next, the exposed coal beds are drilled and blasted to fracture the coal, which is removed with a backhoe and loaded onto trucks (Figure 15.15). Finally, the cut is filled, the topsoil replaced, and the land either planted with a crop or returned to rangeland.

(a)

(b)

FIGURE 15.15 **(a)** Mining an exposed coal bed at the Trapper Mine, in Colorado; and **(b)** the land during restoration following mining. Topsoil (lower right) is spread prior to planting of vegetation.

At the Trapper Mine, the land is reclaimed without artificially applying water. Precipitation (mostly snow) is about 35 cm/year (about 14 in./year), which is sufficient to reestablish vegetation if there is adequate topsoil. That reclamation is possible at this site emphasizes an important point about reclamation: It is site-specific—what works at one location may not be applicable to other areas. Drainage of reclaimed land has been improved.

Water and air quality are closely monitored at the Trapper Mine. Surface water is diverted around mine pits, and groundwater is intercepted while pits are open. “Settling basins,” constructed downslope from the pit, allow suspended solids in the water to settle out before the water is discharged into local streams. Although air quality at the mine can be degraded by dust from the blasting, hauling, and grading of the coal, the dust is minimized by regular sprinkling of water on the dirt roads. Recently, drainage from reclaimed lands has been redesigned to use a sinuous channel rather than a straighter one to slow down sediment deposition, reduce erosion, and minimize maintenance of the channels.

Reclamation at the Trapper Mine has been successful during the first years of operation. In fact, the U.S. Department of the Interior named it one of the best examples of mine reclamation. Although reclamation increases the cost of the coal as much as 50%, it will pay off in the long-range productivity of the land as it is returned to farming and grazing. Wildlife also thrives; the local elk population has significantly increased, and the reclaimed land is home to sharp-tailed grouse, a threatened species.

On the one hand, it might be argued that the Trapper Mine is unique in its combination of geology, hydrology, and topography, which has allowed for successful reclamation. To some extent this is true, and perhaps the Trapper Mine presents an overly optimistic perspective on mine reclamation compared with sites that have less favorable conditions. On the other hand, the success of the mine operation demonstrates that with careful site selection and planning, the development of energy resources can be compatible with other land uses.

FIGURE 15.16 Mountaintop mining in West Virginia has been criticized as damaging to the environment as vegetation is removed, stream channels are filled with rock and sediment, and the land is changed forever.

the mining, following reclamation, produces flat land for a variety of uses, such as urban development, in a region where flat land is mostly on floodplains with fewer potential uses.

Since the adoption of the Surface Mining Control and Reclamation Act of 1977, the U.S. government has required that mined land be restored to support its premining use. The regulations also prohibit mining on prime agricultural land and give farmers and ranchers the opportunity to restrict or prohibit mining on their land, even if they do not own the mineral rights. Reclamation includes disposing of wastes, contouring the land, and replanting vegetation.

Reclamation is often difficult and unlikely to be completely successful. In fact, some environmentalists argue that reclamation success stories are the exception and that strip mining should not be allowed in the semiarid southwestern states because reclamation is uncertain in that fragile environment.

Underground Mining

Underground mining accounts for approximately 40% of the coal mined in the United States and poses special risks both for miners and for the environment. The dangers to miners have been well documented over the years in news stories, books, and films. Hazards include mine shaft collapses (cave-ins), explosions, fires, and respiratory illnesses, especially the well-known black lung disease, which is related to exposure to coal dust, which has killed or disabled many miners over the years.

Some of the environmental problems associated with underground mining include the following:

- Acid mine drainage and waste piles have polluted thousands of kilometers of streams (see Chapter 19).
- Land subsidence can occur over mines. Vertical subsidence occurs when the ground above coal mine tunnels collapses, often leaving a crater-shaped pit at the surface (Figure 15.17). Coal-mining areas in Pennsylvania and West Virginia, for example, are well known for serious subsidence problems. In recent years, a parking lot and crane collapsed into a hole over a coal mine in Scranton, Pennsylvania; and damage from subsidence caused condemnation of many buildings in Fairmont, West Virginia.
- Coal fires in underground mines, either naturally caused or deliberately set, may belch smoke and hazardous fumes, causing people in the vicinity to suffer from a variety of respiratory diseases. For example, in Centralia, Pennsylvania, a trash fire set in 1961 lit nearby underground coal seams on fire. They are still burning today and have turned Centralia into a ghost town.

Transporting Coal

Transporting coal from mining areas to large population centers where energy is needed is a significant environmental issue. Although coal can be converted at the

FIGURE 15.17 Subsidence below coal mines in the Appalachian coal belt.

production site to electricity, synthetic oil, or synthetic gas, these alternatives have their own problems. Power plants for converting coal to electricity require water for cooling, and in semiarid coal regions of the western United States there may not be sufficient water. Furthermore, transmitting electricity over long distances is inefficient and expensive (see Chapter 14). Converting coal to synthetic oil or gas also requires a huge amount of water, and the process is expensive.[20, 21]

Freight trains and coal-slurry pipelines (designed to transport pulverized coal mixed with water) are options to transport the coal itself over long distances. Trains are typically used, and will continue to be used, because they provide relatively low-cost transportation compared with the cost of constructing pipelines. The economic advantages of slurry pipelines are tenuous, especially in the western United States, where large volumes of water to transport the slurry are not easily available.

The Future of Coal

The burning of coal produces nearly 50% of the electricity used and about 25% of the total energy consumed in the United States today. Coal accounts for nearly 90% of the fossil fuel reserves in the United States, and we have enough coal to last at least several hundred years. However, there is serious concern about burning that coal. Giant power plants that burn coal as a fuel to produce electricity in the United States are responsible for about 70% of the total emissions of sulfur dioxide, 30% of the nitrogen oxides, and 35% of the carbon dioxide. (The effects of these pollutants are discussed in Chapter 21.)

Legislation as part of the Clean Air Amendments of 1990 mandated that sulfur dioxide emissions from coal-burning power plants be eventually cut by 70–90%, depending on the sulfur content of the coal, and that nitrogen oxide emissions be reduced by about 2 million metric tons per year. As a result of this legislation, utility companies are struggling with various new technologies designed to reduce emissions of sulfur dioxide and nitrogen oxides from burning coal. Options being used or developed include the following:[21, 22]

- Chemical and/or physical cleaning of coal prior to combustion.
- Producing new boiler designs that permit a lower temperature of combustion, reducing emissions of nitrogen oxides.
- Injecting material rich in calcium carbonate (such as pulverized limestone or lime) into the gases produced by the burning of coal. This practice, known as **scrubbing**, removes sulfur dioxides. In the scrubber—a large, expensive component of a power plant—the carbonate reacts with sulfur dioxide, producing hydrated calcium sulfite as sludge. The sludge has to be collected and disposed of, which is a major problem.
- Converting coal at power plants into a gas (syngas, a methane-like gas) before burning. This technology is being tested and may become commercial by 2013 at the Polk Power Station in Florida. The syngas, though cleaner-burning than coal, is still more polluting than natural gas.
- Converting coal to oil: We have known how to make oil (gasoline) from coal for decades. Until now, it has been thought too expensive. South Africa is doing this now, producing over 150,000 barrels of oil per day from coal, and China in 2009 finished construction of a plant in Mongolia. In the United States, we could produce 2.5 million barrels per day, which would require about 500 million tons of coal per year by 2020. There are environmental consequences, however, as superheating coal to produce oil generates a lot of carbon dioxide (CO_2), the major greenhouse gas.
- Educating consumers about energy conservation and efficiency to reduce the demand for energy and, thus, the amount of coal burned and emissions released.
- Developing zero-emission coal-burning electric power plants. Emissions of particulates, mercury, sulfur dioxides, and other pollutants would be eliminated by physical and chemical processes. Carbon dioxide would be eliminated by injecting it deep into the earth or using a chemical process to sequester it (tie it up) with calcium or magnesium as a solid. The concept of zero emission is in the experimental stages of development.

The bottom line is that as oil prices rise, coal is getting a lot of attention in the attempt to find ways to lessen the economic shock . The real shortages of oil and gas may still be a few years away, but when they come, they will put pressure on the coal industry to open more and larger mines in both the eastern and western coal beds of the United States. Increased use of coal will have significant environmental impacts for several reasons.

First, more and more land will be strip-mined and will therefore require careful and expensive restoration.

Second, unlike oil and gas, burning coal, as already mentioned, produces large amounts of air pollutants. It also creates ash, which can be as much as 20% of the coal burned; boiler slag, a rocklike cinder produced in the furnace; and calcium sulfite sludge, produced from removing sulfur through scrubbing. Coal-burning power plants in the United States today produce about 90 million tons of these materials per year. Calcium sulfite from scrubbing can be used to make wallboard (by converting calcium sulfite to calcium sulfate, which is gypsum) and other products. Gypsum is being produced for wallboard this way in Japan and Germany, but the United States can make wallboard less expensively from abundant natural gypsum deposits. Another waste product, boiler slag, can be used for fill along railroad tracks and at construction projects. Nevertheless, about 75% of the combustion products of burning coal in the United States today end up in waste piles or landfills.

Third, handling large quantities of coal through all stages (mining, processing, shipping, combustion, and final disposal of ash) could have adverse environmental effects. These include aesthetic degradation, noise, dust, and—most significant from a health standpoint—release of toxic or otherwise harmful trace elements into the water, soil, and air. For example, in late December 2008, the retaining structure of an ash pond at the Kingston Fossil Plant in Tennessee failed, releasing a flood of ash and water that destroyed several homes, ruptured a gas line, and polluted a river.[23]

All of these negative effects notwithstanding, it seems unlikely that the United States will abandon coal in the near future because we have so much of it and have spent so much time and money developing coal resources. Some suggest that we should now promote the use of natural gas in preference to coal because it burns so much cleaner, but that raises the valid concern that we might then become dependent on imports of natural gas. Regardless, it remains a fact that coal is the most polluting of all the fossil fuels.

Allowance Trading

An innovative approach to managing U.S. coal resources and reducing pollution is **allowance trading**, through which the Environmental Protection Agency grants utility companies tradable allowances for polluting: One allowance is good for one ton of sulfur dioxide emissions per year. In theory, some companies wouldn't need all their allowances because they use low-sulfur coal or new equipment and methods that have reduced their emissions. Their extra allowances could then be traded and sold by brokers to utility companies that are unable to stay within their allocated emission levels. The idea is to encourage competition in the utility industry and reduce overall pollution through economic market forces.[22]

Some environmentalists are not comfortable with the concept of allowance trading. They argue that although buying and selling may be profitable to both parties in the transaction, it is less acceptable from an environmental viewpoint. They believe that companies should not be able to buy their way out of taking responsibility for pollution problems.

15.4 Oil Shale and Tar Sands

Oil shale and tar sands play a minor role in today's mix of available fossil fuels, but they may be more significant in the future, when traditional oil from wells becomes scarce.

Oil Shale

Oil shale is a fine-grained sedimentary rock containing organic matter (kerogen). When heated to 500°C (900°F) in a process known as *destructive distillation*, oil shale yields up to nearly 60 liters (14 gallons) of oil per ton of shale. If not for the heating process, the oil would remain in the rock. The oil from shale is one of the so-called **synfuels** (from the words *synthetic* and *fuel*), which are liquid or gaseous fuels derived from solid fossil fuels. The best-known sources of oil shale in the United States are found in the Green River formation, which underlies approximately 44,000 km^2 (17,000 mi^2) of Colorado, Utah, and Wyoming.

Total identified world oil shale resources are estimated to be equivalent to about 3 trillion barrels of oil. However, evaluation of the oil grade and the feasibility of economic recovery with today's technology is not complete. Oil shale resources in the United States amount to about 2 trillion bbl of oil, or two-thirds of the world total. Of this, 90%, or 1.8 trillion bbl, is located in the Green River oil shales. The total oil that could be removed from U.S. oil shale deposits is about 100 billion barrels. This exceeds the oil reserves of the Middle East! But extraction is not easy, and environmental impacts would be serious.[24, 25]

The environmental impact of developing oil shale varies with the recovery technique used. Both surface and subsurface mining techniques have been considered. Surface mining is attractive to developers because nearly 90% of the shale oil can be recovered, compared with less than 60% by underground mining. However, waste disposal is a major problem with either surface or subsurface mining. Both require that oil shale be processed, or *retorted* (crushed and heated), at the surface. The volume of waste will exceed the original volume of shale mined by 20–30% because crushed rock has pore spaces and thus more volume than the solid rock had. (If you doubt this, pour some concrete into a milk carton, remove it when it hardens, and break it into small pieces with a hammer. Then try to put the pieces back into the carton.) Thus, the mines from which the shale is removed will not be able to accommodate all the waste, and its disposal will become a problem.[12]

Although it is much more expensive to extract a barrel of oil from shale than to pump it from a well, interest in oil shale was heightened by an oil embargo in 1973 and by fear of continued shortages of crude oil. In the 1980s through the mid-1990s, however, plenty of cheap oil was available, so oil-shale development was put on the back burner. Today, when it is clear that we will face oil shortages in the future, we are seeing renewed interest in oil shale,[25] and it is clear that any steep increases in oil prices will likely heighten this interest. This would result in significant environmental, social, and economic impacts in the oil shale areas, including rapid urbanization to house a large workforce, construction of industrial facilities, and increased demand on water resources.

Tar Sands

Tar sands are sedimentary rocks or sands impregnated with tar oil, asphalt, or bitumen. Petroleum cannot be recovered from tar sands by pumping wells or other usual commercial methods because the oil is too viscous (thick) to flow easily. Oil in tar sands is recovered by first mining the sands—which are very difficult to remove—and then washing the oil out with hot water. It takes about two tons of tar sand to produce one barrel of oil.

About 19% of U.S. oil imports come from Canada, and about one-half of this is from tar sands.[26] Some 75% of the world's known tar sand deposits are in the Athabasca Tar Sands near Alberta, Canada. The total Canadian resource that lies beneath approximately 78,000 km^2 (30,116 mi^2) of land is about 300 billion barrels that might be recovered. About half of this (173 billion barrels) can be economically recovered today.[26] Production of the Athabasca Tar Sands is currently about 1.2 million barrels of synthetic crude oil per day. Production will likely increase to about 3 million barrels per day in the next decade or so.

In Alberta, tar sand is mined in a large open-pit mine (Figure 15.18). The mining process is complicated by the fragile native vegetation, a water-saturated mat known as a muskeg swamp—a kind of wetland that is difficult to remove except when frozen. The mining of the tar sands does have environmental consequences, ranging from a rapid increase in the human population in mining areas to the need to reclaim the land disturbed by the mining. Restoration of this fragile, naturally frozen (permafrost) environment is difficult. There is also a waste-disposal problem because the mined sand material, like the mined oil shale just discussed, has a greater volume than the unmined material. The land surface can be up to 20 m (66 ft) higher after mining than it was originally. The Canadian approach is to require that the land be returned not to its original use but to some equivalent use, such as turning what was forestland into grazing land.[27]

FIGURE 15.18 Mining tar sands north of Fort McMurray in Alberta, Canada. The large shovel-bucket holds about 100 tons of tar sand. It takes about two tons of tar sand to produce one barrel of oil.

CRITICAL THINKING ISSUE

What Will Be the Consequences of Peak Oil?

The summer of 2008 brought record oil prices. By late May the price had risen to $133 per barrel. Each barrel has 42 gallons. That is $3.17 per gallon of oil, before being shipped, refined, and taxed! Consider the following:[28]

1. Oil doubled in price from 2007 to 2008, then dropped to about $70 per barrel as demand declined. The price remains very uncertain.
2. Grain production increased from about 1.8 billion tons to 2.15 billion tons per year from 2002 to 2008.
3. The global food price index rose about 30% from 2007 to 2008. Sugar prices rose about 40% and grain prices about 90%. Wheat that cost about $375 per ton in 2006 soared to more than $900 in 2008. Large discount stores in the United States in 2008 set limits on the amount of rice that a person could purchase.
4. World biofuel (biodiesel and bioethanol) production increased from about 6.4 billion gallons per year in 2000 to just over 20 billion gallons in 2008, and probably will continue to rise rapidly. In the late 1990s the United States used about 5% of corn production for biofuel (ethanol); in 2009 it used 25% for this purpose.
5. Our worldwide safety net of grain stocks on hand declined from about 525 million tons in 2000 to about 300 million tons in 2008.

Critical Thinking Questions

Assume oil prices will remain unstable:

1. Examine Figure 15.19. What are the main points you can conclude from reading the graph? (*Hint:* Look closely at the shape of the curves and the labeling.) Summarize your thoughts.
2. How is the above information linked? (*Hint:* Make linkages between Figure 15.19 and points 1–5 above.) Summarize your thoughts.
3. What will be the differences in the potential economic and environmental impacts on countries ranging from poor to rich?
4. Should the United States stop producing corn for biofuel?
5. Will famine in the future be due to rising food prices? Why? Why not?
6. Do you think food riots may lead to civil wars in some countries?
7. What solutions can you offer to minimize the impacts of increasing energy costs tied to food production and cost?

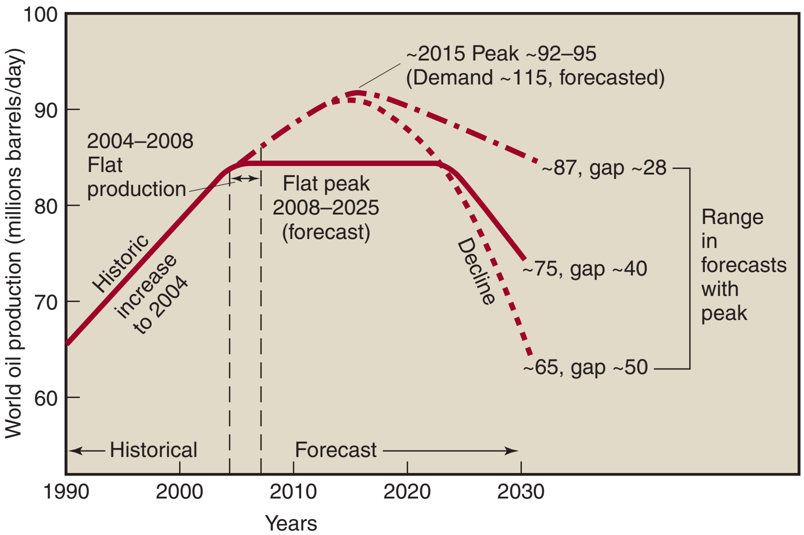


FIGURE 15.19 Peak oil with two scenarios: a long, flat peak with production as it is today; and a sharper peak in about 2015. In either case, there are significant shortages (gap between production and demand). (*Source*: Data from P. Roberts, "Tapped Out," *National Geographic* 213, no. 6 (2008):86–91.)

SUMMARY

- The United States has an energy problem caused by dependence on fossil fuels, especially oil. Maximum global production (peak oil) is expected between 2020 and 2050, followed by a decline in production. The challenge is to plan now for the decline in oil supply and a shift to alternative energy sources.
- Fossil fuels are forms of stored solar energy. Most are created from the incomplete biological decomposition of dead and buried organic material that is converted by complex chemical reactions in the geologic cycle.
- Because fossil fuels are nonrenewable, we will eventually have to develop other sources to meet our energy demands. We must decide when the transition to alternative fuels will occur and what the impacts of the transition will be.
- Environmental impacts related to oil and natural gas include those associated with exploration and development (damage to fragile ecosystems, water pollution, air pollution, and waste disposal); those associated with refining and processing (pollution of soil, water, and air); and those associated with burning oil and gas for energy to power automobiles, produce electricity, run industrial machinery, heat homes, and so on (air pollution).
- Coal is an energy source that is particularly damaging to the environment. The environmental impacts of mining, processing, transporting, and using coal are many. Mining coal can cause fires, subsidence, acid mine drainage, and difficulties related to land reclamation. Burning coal can release air pollutants, including sulfur dioxide and carbon dioxide, and produces a large volume of combustion products and by-products, such as ash, slag, and calcium sulfite (from scrubbing). The environmental objective for coal is to develop a zero-emission power plant.

REEXAMINING THEMES AND ISSUES

Human Population

As the human population (particularly in developed countries, such as the United States) has increased, so has the total impact from the use of fossil fuels. Total impact is the impact per person times the total number of people. Reducing the impact will require that all countries adopt a new energy paradigm emphasizing use of the minimum energy needed to complete a task (end use) rather than the current prodigious overuse of energy.

Sustainability

It has been argued that we cannot achieve sustainable development and maintenance of a quality environment for future generations if we continue to increase our use of fossil fuels. Achieving sustainability will require wider use of a variety of alternative renewable energy sources and less dependence on fossil fuels.

Global Perspective

The global environment has been significantly affected by burning fossil fuels. This is particularly true for the atmosphere, where fast-moving processes operate (see Chapters 20 and 21). Solutions to global problems from burning fossil fuels are implemented at the local and regional levels, where the fuels are consumed.

Urban World

The burning of fossil fuels in urban areas has a long history of problems. Not too many years ago, black soot from burning coal covered the buildings of most major cities of the world, and historical pollution events killed thousands of people. Today, we are striving to improve our urban environments and reduce urban environmental degradation from burning fossil fuels.

People and Nature

Our exploration, extraction, and use of fossil fuels have changed nature in fundamental ways—from the composition of the atmosphere and the disturbance of coal mines to the pollution of ground and surface waters. Some people still buy giant SUVs supposedly to connect with nature, but using them causes more air pollution than do automobiles and, if used off-road, often degrades nature.

Science and Values

Scientific evidence of the adverse effects of burning fossil fuels is well documented. The controversy over their use is linked to our values. Do we value burning huge amounts of fossil fuels to increase economic growth more highly than we value living in a quality environment? Economic growth is possible without damaging the environment; developing a sustainable energy policy that doesn't harm the environment is possible with present technology. What is required are changes in values and lifestyle that are linked to energy production and use, human well-being, and environmental quality.

KEY TERMS

allowance trading **321**
coal **314**
crude oil **306**
fossil fuels **305**
methane hydrate **310**
natural gas **306**
oil shale **321**
peak oil **304**
scrubbing **320**
synfuels **321**
tar sands **322**

STUDY QUESTIONS

1. Assuming that oil production will peak in about 2020 and then decline about 3% per year, when will production be half of that in 2020? What could be the consequences, both good and bad? Why? How might negative consequences be avoided?
2. Compare the potential environmental consequences of burning oil, burning natural gas, and burning coal.
3. What actions can you personally take to reduce consumption of fossil fuels?
4. What environmental and economic problems could result from a rapid transition from fossil fuels to alternative sources?
5. The transition from wood to fossil fuels took about 100 years. How long do you think the transition from fossil fuels to alternative energy sources will take? What will determine the time of transition?
6. What are some of the technical solutions to reducing air-pollutant emissions from burning coal? Which are best? Why?
7. What do you think of the idea of allowance trading as a potential solution to reducing pollution from burning coal?
8. Do you think we can develop a zero-emission coal-burning power plant? What about for natural gas?
9. Discuss how the rising cost of energy is linked to food supply and environmental problems.
10. What are the ethical issues associated with the energy problems? Is a child born in 2050 more important than a child today? Why or why not?

FURTHER READING

Boyl, G., B. Everett, and J. Ramage, ***Energy Systems and Sustainability*** (Oxford (UK): Oxford University Press, 2003). An excellent discussion of fossil fuel.

British Petroleum Company, ***B.P. Statistical Review of World Energy*** (London: British Petroleum Company, 2010). Good, up-to-date statistics on fossil fuels.