Energy Resources—Fossil Fuels

The earliest and, at first, only energy source used by primitive people was the food they ate. Then, wood-fueled fires produced energy for cooking, heat, light, and protection from predators. As hunting societies became agricultural, people used energy provided by animals—horsepower and ox power. The world's total energy demands were quite small and could readily be met by these sources. Gradually, animals' labor was replaced by that of machines, new and more technologies were developed, and demand for manufactured goods rose. These factors all greatly increased the need for energy and need to search for new energy sources. It was first wood, then primarily the fossil fuels that eventually met those needs, and they continue to dominate our energy consumption. They also pose certain environmental problems. *All contribute to the carbondioxide pollution in the atmosphere, and several can present other significant hazards such as toxic spills and land subsidence (oil), or sulfur pollution, acid runoff, and mine collapse (coal).*

The term *fossil* refers to any remains or evidence of ancient life. Energy is stored in the chemical bonds of the organic compounds of living organisms. The ultimate source of that energy is the sun, which drives photosynthesis in plants.

The **fossil fuels** are those energy sources that formed from the remains of once living organisms. These include oil, natural gas, coal, and fuels derived from oil shale and tar sand. When we burn them, we are using that stored energy. The differences in the physical properties among the various fossil fuels arise from differences in the starting materials from which the fuels formed and in what happened to those materials after the organisms died and were buried within the earth.

Formation of Oil and Natural Gas Deposits

Petroleum is not a single chemical compound. Liquid petroleum, or **oil ,** comprises a variety of liquid hydrocarbon compounds (compounds made up of different proportions of the elements carbon and hydrogen). There are also gaseous hydrocarbons (**natural gas**), of which the compound methane (CH4) is the most common. How organic matter is transformed into liquid and gaseous hydrocarbons is not fully understood, but the main features of the process are outlined below.

The production of a large deposit of any fossil fuel requires a large initial accumulation of organic matter, which is rich in carbon and hydrogen. Another requirement is that the organic debris be buried quickly to protect it from the air so that decay by biological means or reaction with oxygen will not destroy it. Microscopic life is abundant over much of the oceans. When these organisms die, their remains can settle to the sea floor. There are also underwater areas near shore, such as on many continental shelves, where sediments derived from continental erosion accumulate rapidly. In such a setting, the starting requirements for the formation of oil are satisfied: There is an abundance of organic matter rapidly buried by sediment. Oil and much natural gas are believed to form from such accumulated marine microorganisms. Continental oil fields often reflect the presence of marine sedimentary rocks below the surface. Additional natural gas deposits not associated with oil may form from deposits of plant material in sediment on land. As burial continues, the organic matter begins to change. Pressures increase with the weight of the overlying sediment or rock; temperatures increase with depth in the earth; and slowly, over long periods of time, chemical reactions take place. These reactions break down the large, complex organic molecules into simpler, smaller hydrocarbon molecules. The nature of the hydrocarbons changes with time and continued heat and pressure. In the early stages of petroleum formation in a marine deposit, the deposit may consist mainly of larger hydrocarbon molecules (“heavy” hydrocarbons), which have the thick, nearly solid consistency of asphalt. As the petroleum matures, and as the breakdown of large molecules continues, successively “lighter” hydrocarbons are produced. Thick liquids give way to thinner ones, from which are derived lubricating oils, heating oils, and gasoline. In the final stages, most or all of the petroleum is further broken down into very simple, light, gaseous molecules—natural gas. Most of the maturation process occurs in the temperature range of 50° to 100°C. Above these temperatures, the remaining hydrocarbon is almost wholly methane; with further temperature increases, methane can be broken down and destroyed in turn.

A given oil field yields crude oil containing a distinctive mix of hydrocarbon compounds, depending on the history of the material. The refining process separates the different types of hydrocarbons for different uses. Some of the heavier hydrocarbons may also be broken up during refining into smaller, lighter molecules through a process called *cracking,* which allows some of the lighter compounds such as gasoline to be produced as needed from heavier components of crude oil.

Oil and Gas Migration:

Once the solid organic matter is converted to liquids and/ or gases, the hydrocarbons can migrate out of the rocks in which they formed. Such migration is necessary if the oil or gas is to be collected into an economically valuable and practically usable deposit. The majority of petroleum source rocks are fine grained clastic sedimentary rocks of low permeability, from which it would be difficult to extract large quantities

of oil or gas quickly. Despite the low permeability, oil and gas are able to migrate out of their source rocks and through more permeable rocks over the long geologic time. The pores, holes, and cracks in rocks in which fluids can be trapped are commonly full of water. Most oils and all natural gases are less dense than water, so they tend to rise as well as to migrate laterally through the water-filled pores of permeable rocks. Unless stopped by impermeable rocks, oil and gas may keep rising right up to the earth's surface. At many known oil and gas seeps, these substances escape into the air or the oceans or flow out onto the ground. These natural seeps, which are one of nature's own pollution sources, are not very efficient sources of hydrocarbons for fuel if compared with present drilling and extraction processes, although asphalt from seeps in the Middle East was used in construction five thousand years ago.
Commercially, the most valuable deposits are those in which a large quantity of oil and/or gas has been concentrated and confined (trapped) by impermeable rocks in geologic structures. The reservoir rocks in which the oil or gas has accumulated should be relatively porous if a large quantity of petroleum is to be found in a small volume of rock and should also be relatively permeable so that the oil or gas flows out readily once a well is drilled into the reservoir. If the reservoir rocks are not naturally very permeable, it may be possible to fracture them artificially with explosives or with water or gas under high pressure to increase the rate at which oil or gas flows through them. The amount of time required for oil and gas to form is not known precisely. Since virtually no petroleum is found in rocks younger than 1 to 2 million years old, geologists infer that the process is comparatively slow. Even if it took only a few tens of thousands of years (a geologically short period), the world's oil and gas is being used up far faster than significant new supplies could be produced. Therefore, oil and natural gas are among the **nonrenewable** energy sources. We have an essentially finite supply with which to work.

Enhanced Oil Recovery

A few techniques are being developed to increase petroleum production from known deposits. An oil well initially yields its oil with minimal pumping, or even "gushes" on its own, because the oil and any associated gas are under pressure from overlying rocks, or perhaps because the oil is confined like water in an artesian system. Recovery using no techniques beyond pumping is *primary recovery*. When flow falls off, water may be pumped into the reservoir, filling empty pores and buoying up more oil to the well (*secondary recovery*). Primary and secondary recovery together extract an average of one-third of the oil in a given trap, though the figure varies greatly with the physical properties of the oil and host rocks in a given oil field.

On average, then, two-thirds of the oil in each deposit has historically been left in the ground. Thus, additional *enhanced recovery* methods have attracted much interest.

Enhanced recovery comprises a variety of methods beyond conventional secondary recovery. Permeability of rocks may be increased by deliberate fracturing, using explosives or even water under very high pressure. Carbon dioxide gas under pressure can be used to force out more oil. Hot water or steam may be pumped underground to warm thick, viscous oils so that they flow more easily and can be extracted more completely. There have also been experiments using detergents or other substances to break up the oil.

All of these methods add to the cost of oil extraction. That they are now being used at all is largely a consequence of higher oil prices in the last two decades and increased difficulty of locating new deposits. Researchers in the petroleum industry believe that, from a technological standpoint, up to an additional 40% of the oil initially in a reservoir might be extractable by enhanced recovery methods. This would substantially increase oil reserves.

A further positive feature of enhanced-recovery methods is that they can be applied to old oil fields that have already been discovered, developed by conventional methods, and abandoned, as well as to new discoveries. In other words, numerous areas in which these techniques could be used are already known, not waiting to be found.

It should, however, be kept in mind that enhanced recovery may involve increases problems such as ground subsidence or groundwater pollution that arise also with conventional recovery methods.

Even conventional drilling uses large volumes of drilling mud to cool and lubricate the drill bits. The drilling muds may become contaminated with oil and must be handled carefully to avoid polluting surface or ground water. When water is more extensively used in fracturing rock or warming the oil, the potential for pollution is correspondingly greater.

Conservation

Conservation of oil and gas is a very important way to stretch remaining supplies. More and more individuals, businesses, and governments in industrialized societies are practicing energy conservation out of personal concern for the environment, from fear of running out of nonrenewable fuels, or simply for basic economic reasons when energy costs have rising. The combined effects of conservation and economic recession can

be seen in the U.S. energy consumption curve during the mid-1970s to mid- 1980s. However, beginning about 1990, energy consumption resumed rising steadily, reaching an all-time high in 2004 before slackening slightly. Some of the factors in rising energy consumption can be climatic—unusual heat in July and August, unusual cold in November and December—but other consumption increases are discretionary. Low gasoline prices, for example, make fuel-efficient cars and other fuel-conservation methods such as carpooling less urgent priorities for some consumers. Worldwide, too, the United States has long had relatively inexpensive gasoline and consumed it freely as a result.
Conservation can buy some much-needed time to develop alternative energy sources. However, world energy consumption will probably not decrease significantly in the near future. Even if industrialized countries consistently adopt more energy-efficient practices, demand in the many non industrialized countries is expected to continue to rise. Many technologically less-developed countries view industry and technology as keys to better, more prosperous lives for their people.

Oil Spills

Natural oil seeps are not unknown. The LaBrea Tar Pits of prehistoric times are an example. In fact, it is estimated that oil rising up through permeable rocks escapes into the ocean at the rate of 600,000 tons per year, though many natural seeps seal themselves as leakage decreases remaining pressure. Tankers that flush out their holds at sea continually add to the oil pollution of the oceans and, collectively, are a significant source of such pollution. The oil spills about which most people have been concerned, however, are the large, sudden, catastrophic spills that occur in two principal ways: from accidents during drilling of offshore oil wells and from wrecks of oil tankers at sea. Oil spills represent the largest negative impacts from the extraction and transportation of petroleum, although as a source of water pollution, they are less significant volumetrically than petroleum pollution from careless disposal of used oil, amounting to only about 5% of petroleum released into the environment. And although we tend to hear only about the occasional massive, disastrous spill, there are many more that go unreported in the media: The U.S. Coast Guard reports about 10,000 spills in and around U.S. waters each year, totaling 15 to 25 million gallons of oil annually.
Drilling accidents have been a growing concern as more areas of the continental shelves are opened to drilling. Normally, the drill hole is lined with a steel casing to prevent lateral leakage of the oil, but on occasion, the oil finds an escape route before the casing is complete. This is what happened in Santa Barbara in 1979, when a spill produced a 200-square-kilometer oil slick. Alternatively, drillers may unexpectedly hit a high-

pressure pocket that causes a blowout. This was the cause of a spill in the Gulf of Mexico in 1979. And in 2005, Hurricane Katrina damaged oil drilling, processing, and storage facilities in the Gulf of Mexico, causing more than 100 spills totaling over 8 million gallons of oil!

Tanker disasters are potentially becoming larger all the time. The largest single marine spill ever resulted from the wreck of the *Amoco Cadiz* near Portsall, France, in 1978; the bill for cleaning up what could be recovered of the 1.6 million barrels spilled was more than $50 million, and at that, negative environmental impacts were still detectable seven years later. In 1991, the Gulf war demonstrated yet another possible cause of major oil spills: destruction of major pipelines and refinery facilities.

When an oil spill occurs, the oil, being less dense than water, floats. The lightest, most volatile hydrocarbons start to evaporate initially, decreasing the volume of the spill somewhat but polluting the air. Then a slow decomposition process sets in, due to sunlight and bacterial action. After several months, the mass may be reduced to about 15% of the starting quantity, and what is left is mainly thick asphalt lumps. These can persist for many months more. Oil is toxic to marine life, causes water birds to drown when it soaks their feathers, may kill fish and shellfish populations, and can severely damage the economies of beach areas.

A variety of approaches to damage control following an oil spill have been tried. In calm seas, if a spill is small, it may be contained by floating barriers and picked up by specially designed "skimmer ships" that can skim up to fifty barrels of oil per hour off the water surface. Some attempts have been made to soak up oil spills with peat moss, wood shavings, and even chicken feathers. Large spills or spills in rough seas are a greater problem. When the tanker *Torrey Canyon* broke up off Land's End, England, in 1967, several strategies were tried, none very successfully. First, an attempt was made to burn off the spill. This did not really work very well, and in any event, it would have produced a lot of air pollution.

Some French workers used ground chalk to absorb and sink the oil. Sinking agents like chalk, sand, clay, and ash can be effective in removing an oil spill from the sea surface, but the oil is no healthier for marine life on the ocean bottom. Furthermore, the oil may separate out again later and resurface.

The British mixed some 2 million gallons of detergent with part of the spill, hoping to break up the spill so that decomposition would work more rapidly. The detergents, in turn, turned out to be toxic to some organisms, too.

Such experiences, in which many cleanup methods are tried but none is notably effective, are typical. Perhaps the best, most environmentally benign prospect for future oil spills is the development of specialized, "oil-hungry" microorganisms that will eat the spill for food and thus get rid of it. Scientists are currently developing suitable bacterial strains. For the time being, no good short-term solution exists to the problems posed by a major oil spill. Preventive measures can be increased—for instance, double-hulled tankers are now mandatory for oil tankers in Prince William Sound, Alaska— but as long as demand for petroleum remains high, some accidents are, perhaps, inevitable.

Questions for Review

1. A society's level of technological development strongly influences its per-capita energy consumption. Explain.
2. What are fossil fuels?
3. Briefly describe how oil and gas deposits form and mature.
4. What is enhanced oil recovery, and why is it of interest? Give two examples of the method.
5. what are the sources and causes of oil spills ? and what cleanup strategies have Economically and environmentally ?

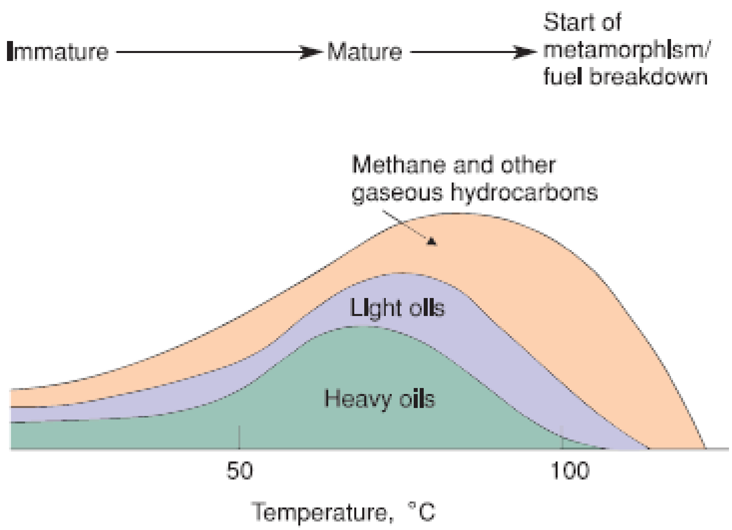

Figure 14.3

The process of petroleum maturation in a marine deposit, in simplified form.

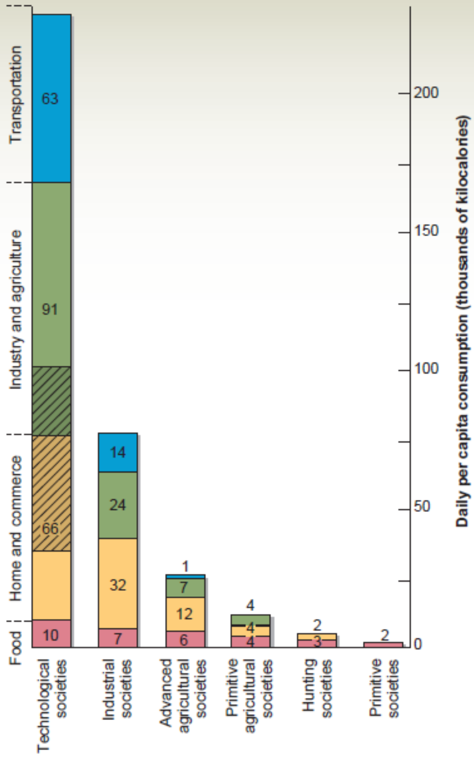

Figure 14.1

As societies evolve from primitive to agricultural to industrialized, the daily per capita consumption of energy increases sharply. The body needs, on average, about 2000 kilocalories per day to live (the "kilocalorie," a measure of energy, is the food calorie that dieters count). However, in the United States in 2007, per capita energy consumption was 230,000 kilocalories per day: 40% for residential/commercial uses, 32% for industry, 29% for transportation. Of the total, about 40% was consumed in the generation of electricity. Note that, as societies advance, even the energy associated with the food individuals eat increases. Members of modern societies do not consume 10,000 kilocalories of food energy directly, but behind the 2,000 or so actually consumed are large additional energy expenditures associated with agriculture, food processing, and preservation, and even the conversion of plants to meat by animals, which in turn are consumed as food. The shaded area in the far left bar of the graph is electricity usage.

Source: Graph after Earl Cook, "The Flow of Energy in an Industrialized Society," Scientific American, *© 1971.*

Table 14.1 Fuels Derived from Liquid Petroleum and Gas

	Material	Principal Uses
Heavier hydrocarbons	waxes (for example, paraffin)	candles
↑	heavy (residual) oils	heavy fuel oils for ships, power plants, and industrial boilers
	medium oils	kerosene, diesel fuels, aviation (jet) fuels, power plants, and domestic and industrial boilers
	light oils	gasoline, benzene, and aviation fuels for propeller-driven aircraft
↓	"bottled gas" (mainly butane, C_4H_{10})	primarily domestic use
Lighter hydrocarbons	natural gas (mostly methane, CH_4)	domestic/industrial use and power plants

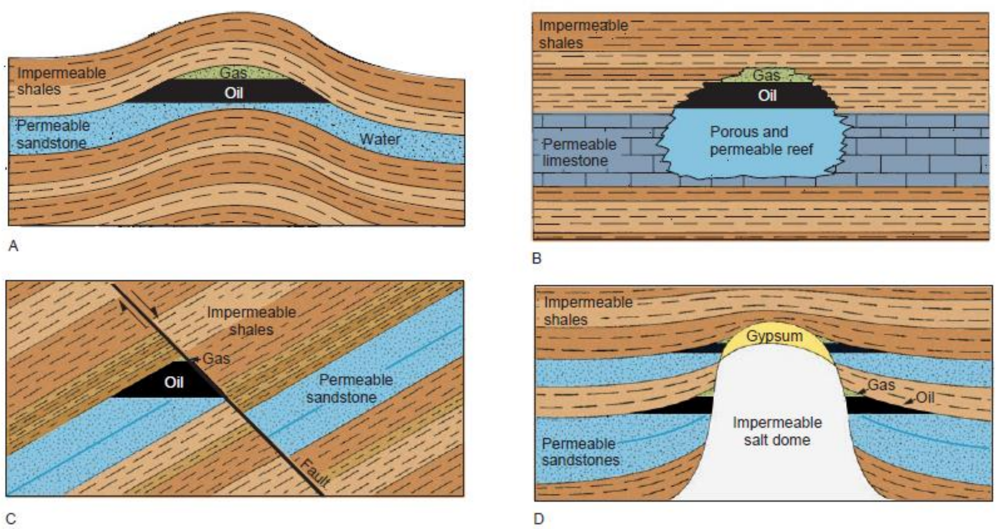

Figure 14.4

Types of petroleum traps. (A) A simple fold trap. (B) Petroleum accumulated in a fossilized ancient coral reef. (C) A fault trap. (D) Petroleum trapped against an impermeable salt dome, which has risen up from a buried evaporite deposit.