Resource Issues

When you have finished drinking a soda, do you pitch the can in the trash or place it in a recycling bin? In winter, if you feel cold, do you put on a sweater, or do you turn up the thermostat? Do you normally eat with disposable plates, cups, and plastic utensils, or do you use washable ceramic and stainless steel products? When you leave a room, do you turn off the lights and television?

When you buy a new motor vehicle, do you consider its fuel efficiency? Do you care that your family's sport-utility vehicle gets poorer gas mileage than your grandparent's big "old-fashioned" sedan?

People have always transformed Earth's land, water, and air for their benefit. But human actions in recent years have gone far beyond the impact of the past. The magnitude of transformations is disproportionately shared by North Americans; with only one-twentieth of Earth's population, North Americans consume one-fourth of the world's energy and generate one-fourth of many pollutants. Elsewhere in the world, 2 billion people live without clean water or sewers. One billion live in cities with unsafe sulfur dioxide levels.

Future generations will pay the price if we continue to mismanage Earth's resources. Our shortsightedness could lead to shortages of energy to heat homes and operate motor vehicles. Our carelessness has already led to unsafe drinking water and toxic air in some places.

Humans once believed Earth's resources to be infinite, or at least so vast that human actions could never harm or deplete them. But warnings from scientists, geographers, and governments are making it clear that resources are indeed a problem. Earth Day 1970 alerted the world to the magnitude of damage that people have done to the environment. Decades later we have learned much about the processes that produce environmental problems and the long-term consequences of environmental mismanagement.
CASE STUDY

Pollution in Mexico City

Eight-year-old Carlos and nine-year-old Maria, residents of Mexico City, did not go to school today. Many of their classmates also did not attend. And many of their teachers failed to report for work. These people did not leave their homes because they feared that breathing outside air in Mexico City would be too dangerous.

For much of the year a stationary cloud hangs over Mexico City, producing a gray-brown fog that irritates the eyes and burns the throat. Residents report frequent conjunctivitis and other eye disorders, skin rashes, bronchitis, other respiratory diseases, and increased susceptibility to heart attacks. The health benefits of outdoor sports such as soccer and running are outweighed by the health risks of breathing the air. Pregnant women are cautioned that living in Mexico City increases risk to fetal health.

This severe air pollution partly results from Mexico City's setting; it rests in a basin some 2,250 meters (about 7,400 feet) above sea level, surrounded by a semicircle of volcanic peaks as high as 5,545 meters (16,900 feet). This giant bowl is open only to the north. Prevailing winds from the north enter the basin and back polluted air against the surrounding mountains. Thus emissions from cars and factories are trapped close to the ground in a stationary cloud, especially in the winter, when the climate is cool and dry and winds are calm.

Because the city is at a high altitude, the level of available oxygen is low. Thus fossil fuels burn less completely than at lower altitudes, and burning them produces more carbon monoxide and ozone.

Three-fourths of the emissions come from burning fuels in more than 2 million motor vehicles. Natural phenomena (such as fires) and industrial sources account for much of the remainder of the air pollution. Many larger industries are concentrated to the northern part of the valley, so their emissions are blown across the city by the prevailing winds.

Air pollution is not Mexico City's only environmental problem. Inadequately treated sewage flows into nearby rivers, and 30 percent of the city's homes are not even connected to the sewer system. Solid waste is deposited at large municipal dumps, where 17,000 people known as pepenadores, or garbage pickers, survive by going through rubbish and, in many cases, actually live at the dump. Dust from fecal matter in unsewered areas increases skin and eye infections.

Plants and animals live in harmony with their environment, but people often do not. Geographers study the troubled relationship between human actions and the physical environment in which we live. From the perspective of human geographers, Earth offers a large menu of resources available for people to use. A resource is a substance in the environment that is useful to people, is economically and technologically feasible to access, and is socially acceptable to use. Resources include food, water, soil, plants, animals, and minerals.

The problem is that most resources are limited, and Earth has a tremendous number of consumers. Geographers observe two major misuses of resources:

1. We deplete scarce resources, especially petroleum, natural gas, and coal, for energy production.
2. We destroy resources through pollution of air, water, and soil.

These two misuses are the basic themes of this chapter.

As with other topics, geographers look first at where resources are distributed across space. Local diversity is pronounced in both supply and demand of resources. Some regions are relatively well endowed with minerals, water, and other resources, whereas other regions have limited suppliers. The reason why problems arise from this uneven distribution is that resources are often located in places different from their users. Differences in demand may arise from the uneven distribution of people across Earth or from variations in development.

Nowhere is the globalization trend more pronounced than in the study of resources. The global economy depends on the availability of natural resources to produce the goods and services that people demand. Global uniformity in cultural preferences means that people in different places value similar natural resources, although not everyone has the same access to them. In a global environment, all places are connected, so the misuse of a resource in one place affects the well-being of people everywhere.

To study resource problems, we also depend on our understanding of local scale. As geographers, we understand that our energy problems derive from depletion of resources in particular regions and from differences in how consumers use
resources in different places. We see that the pollution problem comes from the concentration of substances that harm the physical environment in particular regions.

**KEY ISSUE 1**

**Why Are Resources Being Depleted?**

- Energy resources
- Mineral resources

Natural resources have little value in and of themselves. Their value derives from their usefulness to humans, especially in production. Enterprises extract those resources for which humans are willing to pay a sufficiently high price to justify the investment. As the supply of a resource dwindles, consumers may be willing to pay higher prices, thus encouraging continued exploitation and further depletion of reserves rather than conservation for future generations.

Two kinds of natural resources are especially valuable to humans—minerals and energy resources. We depend on abundant, low-cost energy and minerals to run our industries, transport ourselves, and keep our homes comfortable. But we are depleting the global supply of some resources. More developed countries (MDCs) want to preserve current standards of living, and less developed countries (LDCs) are struggling to attain a better standard. All this demands tremendous resources, so as we deplete our current sources, we must develop alternative ones.

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**Energy Resources**

Historically, people relied on power supplied by themselves or by animals, known as animate power. Energy from burning wood or flowing water later supplemented animate power. Ever since the Industrial Revolution began in the late 1700s, humans have expanded their use of inanimate power, generated from machines. Humans have found the technology to harness the great potential energy stored in resources such as coal, oil, gas, and uranium.

Three of Earth’s substances provide five-sixths of the world’s energy—oil, natural gas, and coal (Figure 14–1). In MDCs the remainder comes primarily from nuclear, solar, and geothermal power. Burning wood and hydroelectric power provide much of the remaining energy in less developed societies.

Historically, the most important energy source worldwide was biomass fuel, such as wood, plant material, and animal waste. Biomass fuel is burned directly or converted to charcoal, alcohol, or methane gas. Biomass remains the most important source of fuel in some LDCs, but during the past 200 years MDCs have converted to other energy sources.

As a consequence of the Industrial Revolution, coal supplanted wood as the leading energy source in the late 1800s in North America and Western Europe. Petroleum was first pumped in 1859, but it was not an important resource until the diffusion of automobiles in the twentieth century. Natural gas was originally burned off as a waste product of oil drilling but now heats millions of homes.

Energy is used in three principal places—businesses, homes, and transportation. For U.S. businesses the main energy resource is coal, followed by natural gas and oil. Some businesses

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**Figure 14–1** U.S. energy consumption. U.S. energy consumption increased rapidly during the 1960s, but since the early 1970s it has increased at a much slower rate. The amount of energy derived from petroleum and natural gas increased rapidly in the 1960s, when use of coal stagnated.
directly burn coal in their own furnaces. Others rely on electricity, mostly generated at coal-burning power plants. At home, energy is used primarily for the heating of living space and water. Natural gas is the most common source, followed by petroleum (heating oil and kerosene). Almost all transportation systems operate on petroleum products, including automobiles, trucks, buses, airplanes, and most railroads. Only subways, streetcars, and some trains run on coal-generated electricity.

Petroleum, natural gas, and coal are known as fossil fuels. A **fossil fuel** is the residue of plants and animals that were buried millions of years ago. As sediment accumulated over these remains, intense pressure and chemical reactions slowly converted them into the fossil fuels we use today. When we burn these substances today, we are releasing energy originally stored in plants and animals millions of years ago.

Two characteristics of fossil fuels cause great concern for the future:

1. **The supply of fossil fuels is finite.** Once the present supply of fossil fuels is consumed, it is gone, and we must look to other resources for our energy. (Technically, fossil fuels are continually being formed, but the process takes millions of years, so humans must regard the current supply as essentially finite.)

2. **Fossil fuels are distributed unevenly around the globe.** Some regions enjoy a generous supply of fossil fuels, whereas others have little, and fossil fuels are not consumed in the same regions where they are produced.

### Finiteness of Fossil Fuels

To understand Earth's resources, we distinguish between those that are renewable and those that are not:

- **Renewable energy** is replaced continually, or at least within a human lifespan: solar energy, hydroelectric, geothermal, fusion, and wind are examples. Renewable energy has an essentially unlimited supply and is not depleted when used by people.

- **Nonrenewable energy** forms so slowly that for practical purposes it cannot be renewed. The fossil fuels, as well as nuclear energy, are examples.

As nonrenewable energy sources, the three main fossil fuels, once burned, are used up for all time. The world faces an energy problem in part because we are rapidly depleting the remaining supply of the three fossil fuels, especially petroleum. Because of dwindling supplies of fossil fuels, most of the buildings in which we live, work, and study will have to be heated another way. Cars, trucks, and buses will have to operate on some other energy source. The many plastic objects that we use (because they are made from petroleum) must be made with other materials.

We can use other resources for heat, fuel, and manufacturing, but they are likely to be more expensive and less convenient to use than fossil fuels. And converting from fossil fuels will likely disrupt our daily lives and cause us hardship.

### REMAINING SUPPLY OF FOSSIL FUELS.

How much of the fossil-fuel supply remains? Despite the critical importance of this question for the future, no one can answer it precisely. Because petroleum, natural gas, and coal are deposited beneath Earth's surface, considerable technology and skill are required to locate these substances and estimate their volume.

The amount of energy remaining in deposits that have been discovered is called a **proven reserve**. Proven reserves can be measured with reasonable accuracy—about 1.3 trillion barrels of petroleum, about 175 trillion cubic meters of natural gas, and about 1 quadrillion metric tons of coal.

To determine when remaining reserves of an energy source will be depleted, we must know the rate at which the resource is being consumed. At the current world petroleum consumption rate of about 26 billion barrels a year, Earth's proven petroleum reserves of 1.3 trillion barrels will last 50 years. If consumption increased, then the reserves would be depleted faster, and world demand is increasing by more than 1 percent annually.

However, some deposits in the world have not yet been discovered. The energy in deposits that are undiscovered but thought to exist is a **potential reserve**. When a potential reserve is actually discovered, it is reclassified as a proven reserve. But petroleum is being consumed at a more rapid rate than it is being found, so unless substantial new proven reserves are found—or consumption decreases sharply—the world's petroleum reserves will be depleted sometime in the twenty-first century.

Similarly, at current rates of use, the world's proven reserves of natural gas will last for about 60 years. Proven reserves of natural gas are less extensive than petroleum reserves, but the remaining supply is projected to last longer because the world currently uses 50 percent more oil than gas. However, energy users are expected to switch from petroleum to natural gas in the years ahead, extending the years of proven reserves of petroleum but depleting natural gas more quickly.

For coal the immediate future is less grim. At current consumption, proven coal reserves would last 175 years. More than one-half of U.S. electricity currently comes from power plants that burn coal.

### EXPANDING PRODUCTION.

Potential reserves can be converted to proven reserves in several ways (Figure 14–2). First, new technology may enhance recovery from already discovered fields. When it was first exploited, petroleum "gushed" from wells drilled into rock layers saturated with it. Coal was quarried in open pits.

But now extraction is harder. Sometimes pumping is not sufficient to remove petroleum, so water or carbon dioxide may be forced into wells to push out the remaining resource. Oil companies have reduced their expenditures for new drilling by about two-thirds since the 1980s. Coal mining continues in some thick, high-quality coal seams, both in open pits and underground, but more mining is being done in thinner, poorer-quality coal.

The problem of removing the last reserves from a proven field is comparable to wringing out a soaked towel. It is easy to quickly
remove the main volume of water, but the last few percent require more time and patience and special technology.

Second, new fields may yet lie undiscovered. Undoubtedly the largest, most accessible deposits of petroleum, natural gas, and coal have already been exploited. Newly discovered reserves are generally smaller and more remote, such as beneath the seafloor, where extraction is costly. Exploration costs have increased because methods are more elaborate and the probability of finding new reserves is less. But as energy prices climb, exploration costs may be justified.

Third, unconventional sources of petroleum and natural gas are being studied and developed, such as oil shale and tar sandstones. Oil shale is a “rock that burns” because of its tarlike content. Tar sandstones are saturated with a thick petroleum. They are called unconventional because methods currently used to extract resources won’t work—instead, the rocks must be “cooked” to melt out their petroleum. These are also known as unconventional sources because we do not currently have economically feasible, environmentally sound technology with which to extract them.

Canada has especially abundant oil sands in Alberta. Native Americans used the tar to caulk canoes in the eighteenth century. Utah, Wyoming, and Colorado also contain abundant oil shale. The shale must be extracted through mining, which can be environmentally damaging, and current technology makes refining the oil expensive. As with exploration, though, as energy prices rise, unconventional sources become economically feasible. Even then the adverse environmental impacts of using these sources may be high.

Uneven Distribution of Fossil Fuels

Geographers observe two important inequalities in the global distribution of fossil fuels:

1. Some regions have abundant reserves, whereas others have little.

2. Consumption of fossil fuels is much higher in some regions than in others.

Given the centrality of fossil fuels in a society’s economy and culture, unequal possession and consumption of fossil fuels have been major sources of global instability in the world.

LOCATION OF RESERVES. Why do some regions have abundant reserves of one or more fossil fuels, but other regions have little? This partly reflects how fossil fuels form.

Coal forms in tropical locations, in lush swampy areas rich in plants. Thanks to the slow movement of Earth’s drifting continents, the tropical swamps of 250 million years ago have relocated to the mid-latitudes. As a result, today’s main reserves of coal are in mid-latitude countries rather than in the tropics.

China is responsible for extracting 40 percent of the world’s coal, and the United States 20 percent. Australia, India, Russia, and South Africa together extract another one-fourth (Figure 14–3). The United States also has one-fourth of the world’s proven coal reserves. Russia and China together account for more than one-fourth. Another one-third of world coal reserves are in India, Australia, and South Africa.

Similarly, today’s sources of oil and natural gas formed millions of years ago from sediment deposited on the seafloor. Some oil and natural gas reserves still lie beneath such seas as the Persian Gulf and the North Sea, but other reserves are located beneath land that had been under water millions of years ago, when sea level was higher.

Five Middle Eastern countries have 60 percent of the world’s oil reserves—about 20 percent in Saudi Arabia and 10 percent each in Iran, Iraq, Kuwait, and United Arab Emirates. Venezuela and Mexico have the most extensive proven reserves in the Western Hemisphere. The United
States accounts for 10 percent of the world's annual production of petroleum but possesses only 2 percent of the proven reserves (Figure 14–4).

Canada is now thought to have 14 percent of world petroleum reserves, second behind Saudi Arabia. Despite challenges in extracting the petroleum, extensive deposits of oil in Alberta sands have been reclassified from potential to proven reserves in recent years because of rapidly escalating petroleum prices.

Russia accounts for one-fourth of world production of natural gas and possesses one-fourth of the world's proven reserves (Figure 14–5). The United States also accounts for one-fourth of world production but has only 3 percent of the world's reserves. Iran and Qatar each have around one-sixth of reserves.

Taken as a group, MDCs have historically possessed a disproportionately high percentage of the world's fossil-fuel reserves. Europe's nineteenth-century industrial development depended on its abundant coalfields, and extensive coal and petroleum supplies helped the United States to become the leading industrial power of the twentieth century. A handful of LDCs in Africa, Asia, and Latin America have extensive reserves of one or another of the fossil fuels, but most have little.

The MDCs produced most of the world's fossil fuels during the nineteenth and twentieth centuries. But this dominance is likely to end in the twenty-first century. Many of Europe's coal mines have closed in recent years, because either the coal was exhausted or the remaining supply was too expensive to extract, and the region's petroleum and natural gas (in the North Sea) account for small percentages of worldwide reserves. The United States still has extensive coal reserves, but its petroleum and natural gas reserves are being depleted rapidly. Japan has never had significant fossil-fuel reserves.

Most of the world's proven reserves (and probably potential reserves) are in a handful of Asian countries, especially China, the Middle East, and former Soviet Union republics. How these reserves are divided up between more developed and less developed countries (as well as among LDCs) is a critical issue for the world community in the twenty-first century.

**CONSUMPTION OF FOSSIL FUELS.** The global pattern of fossil-fuel consumption—like production—will shift in the twenty-first century. MDCs, with about one-fourth of the world's population, currently consume about three-fourths of the world's energy. Annual per capita consumption of energy exceeds 300 million BTUs in North America and 150 million BTUs in Western Europe, compared to under 25 million in
most LDCs (Figure 14–6). This high energy consumption by a modest percentage of the world’s population supports a lifestyle rich in food, goods, services, comfort, education, and travel. The sharp regional difference in energy consumption has two geographic consequences for the future:

- As they promote development and cope with high population growth, LDCs are consuming much more energy. China is already the second-largest consumer of energy behind the United States, 13 percent of the world’s energy in 2004. As a result of increased demand in LDCs, global consumption of petroleum is expected to increase by about 50 percent during the next two decades, whereas both coal and natural gas consumption are expected to double. The share of world energy consumed by LDCs has increased from 27 percent in 1990 to 35 percent in 2000 and 40 percent in 2005, and is expected to increase much more.

- Because MDCs consume more energy than they produce, they must import more fossil fuels, especially petroleum, from LDCs. The United States and Western Europe import more than half their petroleum, and Japan more than 90 percent. However, because of development and population growth in LDCs, the MDCs will face greater competition in obtaining the world’s remaining supplies of fossil fuels.

Control of World Petroleum

The sharpest conflicts over energy will be centered on the world’s limited proven reserves of petroleum. The United States produced more petroleum than it consumed during the first half of the twentieth century. Beginning in the 1950s the handful of large transnational companies then in control of international petroleum distribution determined that extracting domestic petroleum was more expensive than importing it from the Middle East. Thus U.S. petroleum imports increased from 14 percent of total consumption in 1954 to 43 percent in 2005.

European countries and Japan have always depended on foreign petroleum because of limited domestic supplies. China changed from a net exporter to an importer of petroleum during the 1990s.

The MDCs import most of their petroleum from the Middle East, where most of the world’s proven reserves are concentrated. Both U.S. and Western European transnational companies originally exploited Middle Eastern petroleum fields and sold the petroleum at a low price to consumers in MDCs. At first, Western companies set oil prices and paid the Middle Eastern governments only a small percentage of their oil profits. But government
policies changed in the petroleum-producing countries, especially during the 1970s. Foreign-owned petroleum fields were either nationalized or more tightly controlled, and prices were set by governments rather than by petroleum companies.

OPEC. Several LDCs possessing substantial petroleum reserves created the Organization of Petroleum Exporting Countries (OPEC) in 1960. Arab OPEC members in the Middle East are Algeria, Iraq, Kuwait, Libya, Qatar, Saudi Arabia, and United Arab Emirates. Another Middle East OPEC member, Iran, is not Arab. OPEC countries elsewhere in the world include Indonesia, Nigeria, and Venezuela. Ecuador was a member until 1993.

OPEC's Arab members were angry at North American and Western European countries for supporting Israel during that nation's 1973 war with the Arab states of Egypt, Jordan, and Syria. So during the winter of 1973–74, they flexed their new economic muscle with a boycott—Arab OPEC states refused to sell petroleum to the nations that had supported Israel.

Soon gasoline supplies dwindled in MDCs. Each U.S. gasoline station was rationed a small quantity of fuel, which ran out early in the day. Long lines formed at gas stations, and some motorists waited all night for fuel. Gasoline was rationed by license plate number (cars with licenses ending in an odd number could buy only on odd-numbered days). European countries took more drastic action—the Netherlands, for example, banned all but emergency motor vehicle travel on Sundays.

OPEC lifted the boycott in 1974 but raised petroleum prices from $3 per barrel to more than $35 by 1981. Prices at U.S. gas pumps soared from an average of 39 cents in 1973 to $1.38 in 1981 (Figure 14–7). To import oil, U.S. consumers spent $3 billion in 1970, but $80 billion in 1980.

The rapid escalation in petroleum prices caused severe economic problems in MDCs during the 1970s. Production of steel, motor vehicles, and other energy-dependent industries plummeted in the United States in the wake of the 1973–74 boycott and has never regained preboycott levels (recall Figure 11–19, which shows declining steel production in MDCs since the 1970s). Many manufacturers were forced out of business by soaring energy costs, and the survivors were forced to restructure their operations to regain international competitiveness.

The LDCs were hurt even more. They depended on low-cost petroleum imports to spur industrial growth. Their fertilizer costs shot up, because many fertilizers are derived from oil. North American and Western European states cushioned themselves by creating a profitable return path for money that was going to OPEC: they encouraged OPEC countries to
in American and European real estate, banks, and other safe and profitable investments. Comparable investment opportunities were limited in LDCs.

Internal conflicts weakened OPEC's influence in the 1980s and 1990s. Iraq warred with Iran and invaded Kuwait, and Libya grew more radical, supporting terrorists. By not acting together, individual OPEC members produced more petroleum than the world demanded, and MDCs stockpiled some of the surplus as protection against another boycott.

**CHANGING SUPPLY AND DEMAND.** The price of petroleum plummeted during the 1980s and settled during the 1990s at the lowest level in modern history, adjusting for inflation. The United States and other major consuming nations entered the twenty-first century optimistic that oil prices would remain low for some time.

Conservation measures dampened demand for petroleum in most developed countries during the late twentieth century. The average vehicle driven in the United States got 14 miles per gallon in 1975, compared to 22 miles per gallon in 2000. The United States reduced its dependency on imported oil in the immediate wake of the 1970s shocks, and the share of imports from OPEC countries declined from two-thirds during the 1970s to one-third during the 1980s.

With petroleum prices remaining low through the 1990s, though, consumption increased. Americans bought more

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**FIGURE 14-6** Per capita energy consumption. More developed countries consume much more energy per capita than do less developed countries. The United States, with 5 percent of the world's population, consumes 22 percent of the world's energy.

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Gas lines, 1973. The Organization of Petroleum Exporting Countries refused to sell petroleum to North American and Western European countries for a few months during the winter of 1973-74 to protest Western countries' support for Israel in the October 1973 war. Motorists in the United States, such as these in Los Angeles, waited in long lines to purchase gas. Note that the cars are in line to enter the Shell station in the background. The Exxon station in the foreground is closed because it already ran out of its day's allotment of fuel. Back in 1973, Americans regarded Exxon's posted price of 74¢ for a gallon of regular gas to be outrageously high.
Nonrenewable Substitutes for Petroleum

As petroleum supplies dwindle, the two other principal fossil fuels—natural gas and coal—are short-run substitutes. Nuclear energy also figures prominently in short-term energy planning.

**NATURAL GAS.** Natural gas is cheaper to burn and is less polluting than petroleum and coal, and in the twentieth century supplies were less subject to disruptions for political reasons. Consequently, world natural gas consumption increased 4 percent per year during the 1980s, from 54 to 75 quad BTUs, at a time when oil consumption was virtually unchanged, from 131 to 136 quad BTUs. Since 1990, natural gas consumption has increased 3 percent per year, only slightly more rapidly than the 2 percent annual growth rate for petroleum.

At the current rate of use, the world’s proven reserves of about 175 trillion cubic meters of natural gas will last for about 60 years. Although the United States is a major producer of natural gas, proven reserves are limited. Obtaining natural gas from the two major sources of reserves—Russia and Iran—will be difficult. Reserves are in relatively inaccessible locations, and political differences limit trade between the United States and Iran.

Within North America, pipelines carry natural gas to industrial and residential users from producing fields in Texas, Louisiana, and Oklahoma, as well as from Alberta, Canada. But it is difficult to ship natural gas across oceans. Pipelines are not possible, although transport is possible in liquefied natural gas (LNG) form, a method currently used primarily to reach Asian markets.

**COAL.** At current consumption, the world’s proven coal reserves of 1 quadrillion metric tons can last nearly 200 years. Coal is especially important to the United States, which possesses large proven reserves (refer to Figure 14–3). But problems—air pollution, mine safety, land subsidence, and economics—hinder expanded use of coal.

Uncontrolled burning of coal releases several pollutants, such as sulfur oxides, hydrocarbons, carbon dioxide, and particulates (“soot”), into the atmosphere. Many communities suffered from coal-polluted air earlier in this century and encouraged their industries to switch to cleaner-burning natural gas and oil.
The U.S. Clean Air Act now requires utilities to use better-quality coal or to install "scrubbers" on smokestacks. These methods can work; Pittsburgh, Pennsylvania, once noted for terrible air pollution when coal was burned for steel mills and glass factories, today has remarkably clean air. But coal-fired power plants still pump copious carbon dioxide into the atmosphere.

Historically, mining was an especially dangerous occupation. One thousand miners once died annually in the United States, especially in underground mines. Miners also are prone to "black lung" disease, for which the U.S. government pays several billion dollars per year in compensation.

Strictly enforced U.S. mine safety laws, improved mine ventilation, intensive safety programs, automation of mining, and a smaller workforce have made the American coal industry much safer. The annual number of deaths in U.S. mines now averages less than 100. But that figure could rise if mining operations expanded.

Both surface mining and underground mining can cause environmental damage. Underground mining may release acidic groundwater that may pollute water by draining into streams, and subsidence or sinking of the ground can damage buildings. The removal of trees and other vegetation during surface mining can cause soil erosion. In the United States the mining industry is highly regulated, and most companies today have a good record of "cleaning up after themselves." But less sensitive mining practices in the past have left a legacy of environmental damage.

Although heavy, bulky, and expensive to transport, coal must be shipped long distances, because most of the factories and power plants using it are far from the coalfields. Ironically, the principal methods of transporting coal—barge, rail, or truck—are all powered by petroleum. A considerable amount of energy thus is expended to mine and transport coal so that it can be used to generate energy somewhere else.

NUCLEAR ENERGY. The big advantage of nuclear power is the large amount of energy released from a small amount of material. One kilogram of enriched nuclear fuel contains more than 2 million times the energy in 1 kilogram of coal.

Nuclear power supplies about one-sixth of the world's electricity. The United States is responsible for generating one-third of the world's nuclear power, France and Japan together another one-third. About 30 countries make some use of nuclear power.

The countries most highly dependent on nuclear power are clustered in Europe (Figure 14–9). Nuclear power supplies more than three-fourths of electricity in Lithuania and France and more than one-half in Belgium, Bulgaria, Slovakia, and Ukraine. One-fifth of electricity is generated by nuclear power in Japan, the United States, and several other European countries.

Dependency on nuclear power varies widely among U.S. states. Nuclear power accounts for nearly three-fourths of electricity in Vermont and around one-half of electricity in Connecticut, Illinois, New Hampshire, New Jersey, and South Carolina (Figure 14–10). At the other extreme, 19 states and the District of Columbia have no nuclear power plants. Nuclear power provides one-half of the electricity in New England, one-fourth in the Southeast and the Midwest, and only one-tenth in states west of the Mississippi River.

Nuclear power presents serious problems. These include potential accidents, radioactive waste, generation of plutonium, a limited uranium supply, geographic distribution, and cost.

1. Potential Accidents from Nuclear. A nuclear power plant produces electricity from energy released by splitting uranium atoms in a controlled environment, a process called fission. One product of all nuclear reactions is radioactive waste, certain types of which are lethal to people exposed to it. Elaborate safety precautions are taken to prevent nuclear fuel from leaking from a power plant.

Nuclear power plants cannot explode, like a nuclear bomb, because the quantities of uranium are too small and cannot be brought together fast enough. However, it is possible to have a runaway reaction, which overheats the reactor, causing a meltdown, possible steam explosions, and scattering of radioactive material into the atmosphere. This happened in 1986 at Chernobyl, then in the Soviet Union and now in the north of Ukraine, near the Belarus border.

The Soviet Union reported at the time that the Chernobyl accident caused 28 deaths because of exposure to high radiation doses. Following the accident, the 135,000 people living within a 30-kilometer (18-mile) radius were forced to move to other homes. Despite the evacuation, in the first decade after the accident, cases of thyroid cancer were ten times higher than normal in Ukraine and 84 times higher than normal in southern Belarus, where most of the fallout hit.

The impact of the Chernobyl accident extended through Europe. Most European governments temporarily banned the sale of milk and fresh vegetables, which were contaminated with radioactive fallout. Half of the eventual victims may be residents of European countries other than Ukraine and Belarus.

American nuclear plants are designed with strong, thick containment buildings surrounding the reactors. But nuclear plants built by the former Soviet Union lack containment buildings and often have defective parts. At a Soviet-built plant in East Germany, 11 of 12 cooling pumps were disabled by a fire and power failure. Had the twelfth pump failed, a meltdown, with its inevitable release of strong
radioactive materials, likely would have killed the 50,000 inhabitants of the nearby city of Greifswald. This 1975 accident went unreported for 15 years, making the case for all nuclear plants to be open for inspection.

2. Radioactive Waste from Nuclear. When nuclear fuel fissions, the waste is highly radioactive and lethal and remains so for many years. Plutonium can be harvested from it for making nuclear weapons. Pipes, concrete, and water near the fissioning fuel also become “hot” with radioactivity.

   No one has yet devised permanent storage for radioactive waste. The waste cannot be burned or chemically treated; it must be isolated for several thousand years until it loses its radioactivity. Spent fuel in the United States is stored “temporarily” in cooling tanks at nuclear power plants, but these tanks are nearly full.

   The United States is Earth’s third-largest country in land area, yet it has failed to find a suitable underground storage site because of worry about groundwater contamination. Proposals abound: burial at sea, in abandoned mines, in deep layers of rock salt, or rocketing it into the Sun. But the universal response is NIMBY, which stands for “Not In My Back Yard.” People do not want a storage facility near their community.

   The time required for radioactive waste to decay to a safe level is far longer than any country or civilization has existed. What government, army, or other human institution will survive for several thousand years to safeguard the stored waste?

3. Bomb Material from Nuclear. Nuclear power has been used in warfare twice, in August 1945, when the United States dropped an atomic bomb on first Hiroshima and then Nagasaki, Japan, ending World War II. No government has dared to use them in a war since then, because leaders have recognized that a full-scale nuclear conflict could terminate human civilization.

   The United States and the Soviet Union (now Russia) each have several thousand nuclear weapons. China, France, and the United Kingdom have several hundred nuclear weapons each, India and Pakistan several dozen each, and North Korea a handful. Israel is suspected of possessing nuclear weapons but has not admitted to it, and Iran has been developing the capability. Other countries have initiated nuclear programs over the years but have not advanced to the weapons stage. The diffusion of nuclear programs to countries sympathetic to terrorists has been particularly worrying to the rest of the world.

   A few years ago a Princeton University student wrote a term paper outlining how to make a nuclear weapon. Most of his information came from an encyclopedia and a few unclassified government documents. More chilling, following publicity about his paper, several organizations and
foreign governments contacted him for assistance in making a bomb.

4. **Limited Uranium Reserves.** Like fossil fuels, proven uranium reserves are limited—about 70 years at current rates of use. And they are not distributed uniformly around the world: one-fourth of the world’s proven uranium reserves are in Australia and one-sixth are in Kazakhstan.

The chemical composition of natural uranium further aggravates the scarcity problem. Uranium ore naturally contains only 0.7 percent U-235, and a greater concentration is needed for power generation.

Uranium is a nonrenewable resource—the world’s reserves of minable uranium ore are limited, just like coal or petroleum. Proven uranium reserves could be depleted in three more decades. A **breeder reactor** turns uranium into a renewable resource by generating plutonium, also a nuclear fuel. However, plutonium is more lethal than uranium and could cause more deaths and injuries in an accident. It is also easier to fashion into a bomb. Because of these risks, few breeder reactors have been built, and none are in the United States.

5. **High Cost of Nuclear Power.** Nuclear power plants cost several billion dollars to build, primarily because of elaborate safety measures. Without double and triple backup systems, nuclear energy would be too dangerous to use. Uranium is mined in one place, refined in another, and used in still another. The complexities of safe transportation add cost. As a result, the cost of generating electricity is much higher from nuclear plants than from coal-burning plants.

The future of nuclear power has been seriously hurt by the combination of high risk and cost. Most countries in North America and Western Europe have curtailed construction of new plants. Italy closed its nuclear power plants in 1987. Sweden, which had been receiving half of its electricity from nuclear power, closed two nuclear reactors in 2005. Even in France, where over three-fourths of electricity is generated from nuclear power, public opposition inhibits new development. Nuclear power will decline in other countries as older nuclear plants are closed and not replaced.

On the other hand, countries without nuclear power are moving toward introducing it, including Poland, Turkey, Indonesia, and Vietnam. Australia, with the most extensive reserves of uranium, is debating expansion of nuclear power. Advances in safety and reactor technology, combined with the high cost of other power sources, are driving the renewed interest.

**Figure 14-10** U.S. nuclear power plants and nuclear power as percent of electricity by state. Nuclear power is an important source of electricity in a number of northeastern and midwestern states. Each dot represents one reactor; more than one reactor is operating at many plants.

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**Mineral Resources**

Earth has 92 natural elements, but about 99 percent of the crust is composed of eight elements—oxygen, silicon, aluminum, iron, calcium, sodium, potassium, and magnesium. Oxygen alone accounts for nearly one-half of the crust and silicon more than one-fourth. The eight most common elements combine with thousands of rare ones to form approximately 3,000 different minerals, all with their own properties of hardness, color, and density, as well spatial distribution (Figure 14-11). Each mineral is potentially a resource, if people find a use for it.

Because a mineral is valued primarily for its mechanical or chemical properties, the definition of which minerals constitute resources evolves as technology and economies change. When a new technological process or product is invented, demand can suddenly increase for a mineral that had little use in the past.

For example, demand for col-tan (short for columbite-tantalum) was low until the 1990s, when sales rapidly escalated for cell phones and notebook computers with capacitors made from col-tan. Conversely, when a new process or product replaces an older one, demand may decline for a mineral important in the past. For example,
Nonmetallic Minerals

Building stones, including large stones, coarse gravel, and fine sand, account for 90 percent of nonmetallic mineral extraction. These minerals are fashioned into structures, roads, monuments, tools, and many other objects of daily use. The rocks and earthen materials used for building purposes are so common that differences in distribution are of little consequence at the international scale, at least.

Nonmetallic minerals are also used for fertilizer. All crops must have at least some quantity of these minerals and obtain some of what they need from the soil. Because soils are often deficient in these minerals, farmers add them.

Important nonmetallic mineral sources of fertilizers include phosphorus, potassium, calcium, and sulfur. All four are abundant elements in nature with wide distributions. However, mining is highly clustered where the minerals are most easily and cheaply extracted.

- Phosphorus is essential to plant growth, but it is easily exhausted in cultivation. The chief source of phosphorus is phosphate rock (apatite), found among the marine sediments of old seabeds. One-fourth of the world's supply of phosphate rock is mined in the United States, another one-third in Morocco and China. Morocco possesses one-half of the world's reserves.
- Most potassium is obtained from the evaporation of saltwater. Principal sources of potassium include former Soviet Union countries, Canada, and the United States, as well as from the Dead Sea shared by Israel and Jordan.
- Calcium, essential for formation of strong bones and teeth, is especially important for growing corn. High levels of calcium are concentrated in subhumid soils such as the plains.
and prairies of the Western United States and Canada, as well as Russia's steppes.

- Sulfur is used to make insecticides and herbicides, as well as fertilizers. The United States and Canada are responsible for one-fourth of the world's sulfur production, with another one-fifth coming from China and Russia.

Nitrogen, obtained from the atmosphere, is an even more important fertilizer. Capturing it from the atmosphere utilizes a lot of energy, so its supply and demand are more closely associated with issues of energy resources rather than the other fertilizer elements.

Although only a small percentage of nonmetallic minerals in weight, gemstones are valued especially highly for their color and brilliance when cut and polished. Diamonds are especially useful in manufacturing, because they are the strongest and hardest known material and have the highest thermal conductivity of any material at room temperature. Two-thirds of the world's diamonds are currently mined in Australia, Botswana, and Russia.

**Metallic Minerals**

Metallic minerals have properties that are especially valuable for fashioning machinery, vehicles, and other essential components of an industrialized society. They are to varying degrees malleable (able to be hammered into thin plates) and ductile (able to be drawn into fine wire) and are conductors of heat and electricity. Each metal possesses these qualities in different combinations and degrees and therefore has its distinctive set of uses.

Many metals are also capable of combining with other metals to form alloys with yet other distinctive properties. A mineral bearing a metal such as aluminum or iron is known as an ore. Nearly all ore contains at least some metallic mineral, although the concentration is often too low to justify extracting it.

Metals are known as ferrous or nonferrous:

- **Ferrous** is derived from the Latin word for iron, and the symbol for iron in the periodic table of elements is Fe. The term "ferrous" refers to iron ore and other alloys used in the production of iron and steel.
- **Nonferrous** metals are those utilized to make products other than iron and steel. The most abundant nonferrous metal is aluminum.

World supply of most metals is high, including the most widely used ferrous metal (iron) and the most widely used nonferrous metal (aluminum). However, reserves of some metals are low, posing a challenge to manufacturers to find economically feasible substitutes.

**FERROUS METALS.** By far the world's most widely used ferrous metal is iron, which accounts for 5 percent of Earth's crust by weight and 95 percent of ferrous metal mineral extraction. It is also found on the Sun and other stars and is thought to be the main component of Earth's core.

Iron is prized for its many assets: a good conductor of heat and electricity, able to be attracted by a magnet and to be magnetized, and malleable into useful shapes. Humans began fashioning tools and weapons from the silver-gray metal about 2000 B.C. The critical importance of iron to the past four thousand years of human history is reflected by the application of the term "Iron Age" to the period. Iron remains an important element in every modern society, from least to most developed.

Mining of iron ore, from which iron is extracted, is concentrated in a handful of countries, including two-thirds in China, Brazil, and Australia. Two-thirds of the reserves are in China, Russia, Ukraine, and Australia. Major importers of iron ore include the leading steel-producing countries of Western Europe plus Japan, where domestic sources are lacking. Although a major producer, the United States also imports iron ore, because the country's most easily accessible domestic deposits near Lake Superior have limited reserves.

Because of the high cost of transporting large quantities of iron ore, accessibility to market is an especially important determinant in the selection of deposits for exploitation, more so than for other metals used in smaller amounts. Iron deposits of indifferent quality but close to market are actively mined, whereas large known deposits in remote areas are ignored for now, although they may become more important in the future once more accessible deposits are exhausted.

Other less common ferrous metals are important for alloying with iron to produce steel. Important alloying elements in abundant supply include manganese, chromium, titanium, magnesium, and molybdenum:

- Manganese is an especially vital alloying metal for making steel because it imparts toughness and carries off undesirable sulfur and oxygen. Manganese ore is a relatively plentiful element in Earth's crust, so total world supply is not a problem. Responsible for two-thirds of world manganese production are four countries, led by South Africa and also including Australia, Brazil, and Gabon. South Africa has more than one-half of the reserves, and Ukraine another one-fourth.
- Chromium is a principal component of stainless steel, because it helps keep a sharp cutting edge even at high temperatures. Chromium is extracted from chromite ore, one-half of which is mined in South Africa and one-third in Kazakhstan and India.
- Titanium is a lightweight, high-strength, corrosion-resistant metal used as an alloy of steel although its main use is as white pigment in paint. Titanium is extracted primarily from the mineral ilmenite. Sixty percent of world production is clustered in Australia, South Africa, and Canada. Australia possesses one-third of the world's reserves.
- Magnesium is relatively light yet strong, so it is used to produce lightweight, corrosion-resistant alloys, especially with aluminum to make beverage cans. China supplies three-fourths of the world's magnesium. Supplies are abundant because magnesium can be removed from seawater brine.
- Molybdenum imparts toughness and resilience to steel. Unlike the other rare metals discussed here, a leading role in providing this mineral is played by the United States, the leading producer, with one-third of world production; Chile accounts for one-fourth and China for one-sixth. The United
States has one-half of the reserves, primarily in Colorado and Idaho, as well as Arizona, New Mexico, and Utah.

Supplies of other alloying elements, notably nickel, tin, and tungsten, are limited:

- Nickel is used primarily for stainless steel and high-temperature and electrical alloys. World reserves are only around 100 years at current rates of use. Russia, Australia, and Canada are responsible for one-half of current production, and Australia possesses one-third of the world's reserves.
- Tin, valued for its corrosion-resistant properties, is used for plating iron and steel and has been used for more than 5,000 years as an alloy of copper for making bronze. China extracts two-fifths of the world's tin, Indonesia one-fourth, and Peru one-sixth. China has the largest reserves. World reserves are estimated at only around 50 years.
- Tungsten makes very hard alloys with steel and is used to manufacture tungsten carbide for cutting tools. China is responsible for 90 percent of world production and one-half of world reserves.

**NONFERROUS METALS.** Rarely used commercially prior to the twentieth century, aluminum is now in greater demand than any metal except iron. Aluminum has replaced some iron and steel components in motor vehicles and airplanes because it is lighter, stronger, and more resistant to corrosion. Aluminum has replaced copper wire in high-tension power transmission lines and is used to make paint, foil, and jewelry.

The most economically feasible way of obtaining aluminum is to extract it from bauxite ore. Australia is responsible for mining one-third of the world's bauxite ore, and Guinea has the largest proven reserves with one-third of world total. However, world supply of aluminum is so large—more than 1,000 years at current rates of use—that it is essentially regarded as inexhaustible at realistic projections of future demand.

Three other especially important nonferrous elements are copper, lead, and zinc:

- Copper, valued for its high ductility, malleability, thermal and electrical conductivity, and resistance to corrosion, ranks third in metal consumption behind iron and aluminum and is used primarily in electronics and constructing buildings. Chile is responsible for one-third of world production and one-fourth of proven reserves.
- Lead, a very corrosion-resistant, dense, ductile, malleable, blue-gray metal, has been used for a variety of purposes for several thousand years, first in building materials and pipes, then in ammunition, brass, glass, and crystal, and now primarily in motor-vehicle batteries. Australia and China each supply one-fourth of the world's lead.
- Zinc is used primarily as a coating to protect iron and steel from corrosion and as an alloy to make bronze and brass. Again, China is the leading producer, with one-fourth of world total. Australia and Peru together supply another one-fourth.

World supplies are extremely limited—less than 60 years for copper, 25 years for lead, and 45 years for zinc.

Nonferrous metals also include precious metals—silver, gold, and the platinum group. Silver and gold have been prized since ancient times for their beauty and durability. In addition to jewelry, both silver and gold are used in a variety of industrial applications, such as electrical and electronic products, and silver is a component of photographic film, whereas gold is important in dentistry. The principal use of the platinum group is in motor-vehicle catalytic converters to treat exhaust emissions, as well as fuel cells.

- Silver, associated with copper, lead, and zinc deposits, is often mined at great depths. One-half of current production and reserves are in Peru, China, Mexico, and Australia.
- One-third of the world's gold is mined in three countries—South Africa, Australia, and the United States. South Africa has more than one-third of the world's gold reserves.
- The platinum group includes six related metals that commonly occur together in nature and are especially scarce: platinum, palladium, rhodium, ruthenium, iridium, and osmium. Platinum has the most highly clustered distribution of the major precious metals: South Africa is responsible for three-fourths of current production and nearly 90 percent of proven reserves.

**KEY ISSUE 2**

**Why Are Resources Being Polluted?**

- Air pollution
- Water pollution
- Land pollution

In our consideration of resources, consumption is half of the equation—waste disposal is the other half. All of the resources we use are eventually returned to the atmosphere, bodies of water, or land surface, through burning, rinsing, or discarding.

We rely on air, water, and land to remove and disperse our waste. Not all human actions harm the environment, for every resource can accept some waste. When we send household cleaners and chemicals into a river, the river may dilute them until their concentration is insignificant. However, when more waste is added than a resource can accommodate, we have pollution. Pollution levels are generally greater where people are concentrated. The actions of many people in a small area are likely to exceed the capacity of the environment to absorb the waste.

When we discard something, we never really eliminate that product but simply put it somewhere else. It may cause pollution, depending on where we placed it. Natural processes may transport pollutants from one part of the environment to another. Discharges to the air often turn up in rivers, and wastes dumped in landfills can produce gases that leak into the atmosphere.

Not all pollution is caused by humans. Natural pollution occurs when volcanoes erupt, spewing vast quantities of ash, cinders, sulfur gases, and steam into the atmosphere. Erosion from floods can clog streams with silt. However, our focus here is on the pollution that humans cause.
In the following sections, we look at air, water, and land pollution. Each has distinctive characteristics that illustrate the close connection between human activities and environmental quality.

**Air Pollution**

At ground level, Earth’s average atmosphere is made up of about 78 percent nitrogen, 21 percent oxygen, and less than 1 percent argon. The remaining 0.04 percent includes several trace gases, some of which are critical. **Air pollution** is a concentration of trace substances at a greater level than occurs in average air.

The most common air pollutants are carbon monoxide, sulfur dioxide, nitrogen oxides, hydrocarbons, and solid particulates. Concentrations of these trace gases in the air can damage property and adversely affect the health of people, other animals, and plants.

Three human activities generate most air pollution—motor vehicles, industry, and power plants. In all three cases, pollution results from the burning of fossil fuels. Burning gasoline or diesel oil in cars, trucks, buses, and motorcycles produces carbon monoxide, hydrocarbons, nitrogen oxides, and other pollutants. Factories and power plants produce sulfur dioxides and solid particulates, primarily from burning coal.

Air pollution concerns geographers at three scales—global, regional, and local. We can examine distinctive problems associated with air pollution at each scale.

**Global-Scale Air Pollution**

At the global scale, air pollution may contribute to global warming. It also may be damaging the atmosphere’s ozone layer.

**GLOBAL WARMING.** Human actions, especially the burning of fossil fuels, may be causing Earth’s temperature to rise. Earth is warmed by sunlight that passes through the atmosphere, strikes the surface, and is converted to heat. When the heat tries to pass back through the atmosphere to space, some gets through and some is trapped. This process keeps Earth’s temperatures moderate and allows life to flourish on the planet.

A concentration of trace gases in the atmosphere can block or delay the return of some of the heat leaving the surface heading for space, thereby raising Earth’s temperatures. When fossil fuels are burned, one of the trace gases, carbon dioxide, is discharged into the atmosphere.

Plants and oceans absorb much of the discharges, but increased fossil-fuel burning during the past 200 years has caused the level of carbon dioxide in the atmosphere to rise by more than one-fourth, according to the UN Intergovernmental Panel on Climate Change. Even if fossil-fuel burning is reduced immediately, the level will continue to increase because of lingering effects of past emissions. Carbon dioxide is also increasing in the atmosphere from the burning and rotting of trees cut in the rain forests.

The average temperature of Earth’s surface has increased by 1° Celsius (2° Fahrenheit) during the past century (Figure 14–13). Contributing to the warming has been the buildup of carbon dioxide emissions at an annual rate of more than 1 percent, although scientists disagree on whether it caused most or only a small percentage of the warming. Unless carbon dioxide emissions are sharply curtailed in the near future, average temperatures at the surface of Earth will increase by several degrees over the next century.

The anticipated increase in Earth’s temperature, caused by carbon dioxide trapping some of the radiation emitted by the surface, is called the **greenhouse effect**. The term is somewhat misleading, because a greenhouse does not work in the same way as do trace gases in the atmosphere. In a real greenhouse, the interior gets very warm when its windows remain closed on a sunny day. The Sun’s light energy passes through the glass into the greenhouse and is converted to heat, while the heat trapped inside the building is unable to escape out through the glass. Although an imprecise analogy, “greenhouse effect” has been a widely adopted term to evoke the anticipated warming of Earth’s surface when trace gases block some of the heat trying to escape into space.

Regardless of what it is called, global warming of only a few degrees could melt the polar ice caps and raise the level of the oceans many meters. Coastal cities such as New York,
GLOBAL FORCES, LOCAL IMPACTS
Climate Change in the South Pacific

One consequence of global warming is a rise in the level of the oceans. The large percentage of the world’s population—including one-half of Americans—who live near the sea face increased threat of flooding. The threat is especially severe for island countries in the Pacific Ocean—they could be wiped off the map entirely.

Threatened Pacific island microstates include Kiribati, Micronesia, Nauru, Palau, Samoa, Solomon Islands, Tonga, and Tuvalu. Tuvalu, for example, which gained its independence from the United Kingdom in 1978, consists of nine islands with a combined area of 26 square kilometers (10 square miles) spread across 600 kilometers (360 miles).

Tuvalu is one of the most isolated locations on Earth: in the middle of the South Pacific Ocean 4,000 kilometers (2,500 miles) from Australia (Figure 14–1.1). Its 11,000 inhabitants survive on fish, limited agriculture, and imported food. To raise money, it exports small quantities of copra (dried coconut meat); sells stamps, coins, and handcrafts; and leases fishing rights to U.S. and Japanese ships.

Despite its extreme isolation, global forces threaten Tuvalu’s existence. Rising sea levels from global warming threaten Tuvalu because the highest elevation on its nine islands is only 5 meters (15 feet). The capital Funafuti, home to 5,000 of the country’s 11,000 inhabitants, is at sea level.

Tuvalu and other Pacific island microstates are atolls, that is, made of coral reefs. A coral is a small sedentary marine animal having a horny or calcareous skeleton. Corals form colonies, and the skeletons build up to form coral reefs.

Coral is very fragile. Humans are attracted to coral to admire its beauty and diversity of species supported, but handling coral can kill it. The threat of global warming to coral is especially severe: coral stays alive in only a narrow range of ocean temperatures, between 23°C and 25°C (73°F to 77°F).

Tuvalu has an emergency response plan to rising sea levels: the 11,000 inhabitants will be evacuated to Australia and New Zealand. A small isolated country, lacking in most resources, will disappear.

Los Angeles, Rio de Janeiro, and Hong Kong would flood. Global patterns of precipitation could shift—some deserts could receive more rainfall, but currently productive agricultural regions, such as the U.S. Midwest, could become too dry for farming. Humans can adapt to a warmer planet, but the shifts in coastlines and precipitation patterns could require massive migration and be accompanied by political disputes.

GLOBAL-SCALE OZONE DAMAGE. Earth’s atmosphere has zones with distinct characteristics. The stratosphere—the zone between 15 and 50 kilometers (9 to 30 miles) above Earth’s surface—contains a concentration of ozone gas. The ozone layer absorbs dangerous ultraviolet (UV) rays from the Sun. Were it not for the ozone in the stratosphere, UV rays would damage plants, cause skin cancer, and disrupt food chains.

Earth’s protective ozone layer is threatened by pollutants called chlorofluorocarbons (CFCs). CFCs such as freon were widely used as coolants in refrigerators and air conditioners. When they leak from these appliances, the CFCs are carried into

FIGURE 14–1.1 Tuvalu, a 26-square-kilometer (10-square-mile) Pacific island country of 10,000 inhabitants, fears it will disappear under rising sea levels caused by global warming.
the stratosphere, where they break down Earth's protective layer of ozone gas. The 1987 Montreal Protocol called for MDCs to cease using CFCs by 2000, and for LDCs to cease by 2010.

Regional-Scale Air Pollution

At the regional scale, air pollution may damage a region's vegetation and water supply through acid deposition. Industrialized, densely populated regions in Europe and eastern North America are especially affected by acid deposition.

Sulfur oxides and nitrogen oxides, emitted by burning fossil fuels, enter the atmosphere, where they combine with oxygen and water. Tiny droplets of sulfuric acid and nitric acid form and return to Earth's surface as acid deposition. When dissolved in water, the acids may fall as acid precipitation—rain, snow, or fog. The acids can also be deposited in dust. Before they reach the surface, these acidic droplets might be carried hundreds of kilometers.

Acid precipitation has damaged lakes, killing fish and plants. Aquatic life has been completely eliminated from 4 percent of the lakes in the eastern United States and Canada; another 5 percent of the lakes in the eastern United States and 20 percent in eastern Canada have acidity levels that threaten some species.

On land, concentrations of acid in the soil can injure plants by depriving them of nutrients and can harm worms and insects. Acid precipitation has contributed to the decline of the red spruce tree at higher elevations. Buildings and monuments made of marble and limestone have suffered corrosion from acid rain; engravings on old marble tombstones may be illegible as a result.

The United States has reduced sulfur dioxide emissions significantly since the 1970s. Many Western European countries have also made substantial cuts, largely by reducing coal use. Despite this progress, acid precipitation continues to damage forests and lakes. Governments are reluctant to impose the high cost of controls on their industries and consumers.

Geographers are particularly interested in the effects of acid precipitation because the worst damage is not experienced at the same location as the emission of the pollutants. Within the United States the major generators of acid deposition are in Ohio and other industrial states along the southern Great Lakes. However, the severest effects of acid rain are felt in several areas farther east (Figure 14–14).

The problem of acid precipitation is compounded by the fact that pollutants emitted in one country cause adverse impacts in another. Acid rain falling in Ontario, Canada, for example, can be traced to emissions from coal-burning power plants in the U.S. Great Lakes. Government officials at the source of the pollution may be reluctant to impose strong controls on the offending factories because they fear damaging the local economy.

Eastern Europe has suffered especially severely from acid precipitation, a legacy of Communist policies that encouraged the construction of factories and power plants without pollution-control devices. Destruction of forests is widespread because of

![Map of Acid Deposition in North America and Europe](image)

**FIGURE 14–14** Acid deposition in North America and Europe. Levels exceeding 20 kg/ha are considered threatening. (left) Because of prevailing wind patterns across North America, damage is generally found to the east of the emissions. (right) Deposition levels in eastern Germany are higher than anywhere in the United States, although elsewhere in central Europe levels are comparable to those in the eastern United States.
Acid precipitation has killed a large percentage of the trees in the forests of the Czech Republic. Emissions of sulfur dioxide and nitrogen oxides from factories and power plants built without pollution control devices in the former Communist East Germany and Czechoslovakia caused this widespread death of trees.

Acid rain emitted from Eastern Europe’s major industrial region (southeastern Germany, southern Poland, and northern Czech Republic). Affected by acid precipitation more than any other European state, the Czech Republic has suffered severe damage in more than 80 percent of the Bohemian Forest and more than one-third of its other forests.

The destruction of trees has harmed Eastern Europe’s seasonal water flow. In dense forests, snow used to melt slowly and trickle into rivers. Now, on the barren sites, it melts and drains quickly, causing flooding in the spring and water shortages in the summer.

Perhaps the most severe impact is on human life. One-third of the residents of St. Petersburg, Russia’s second-largest city, suffer from upper respiratory tract ailments as a result of the intense air pollution. A 40-year-old man living in Poland’s polluted southern industrial area has a life expectancy 10 years less than his father had at the same age. Poland is estimated to have between 20,000 and 50,000 additional deaths per year due to pollution.

**Local-Scale Air Pollution**

At the local scale, air pollution is especially severe in places where emission sources are concentrated, such as in urban areas. The air above urban areas may be especially polluted because a large number of factories, motor vehicles, and other polluters emit residuals in a concentrated area. Weather conditions may make it difficult for the emissions to dissipate.

Urban air pollution has three basic components:

1. **Carbon Monoxide.** Proper burning in power plants and vehicles produces carbon dioxide, but improper combustion produces carbon monoxide. Breathing carbon monoxide reduces the oxygen level in blood, impairs vision and alertness, and threatens those with breathing problems.

2. **Hydrocarbons** also result from improper fuel combustion, as well as evaporation of paint solvents. Hydrocarbons and nitrogen oxides in the presence of sunlight form **photochemical smog**, which causes respiratory problems, stinging in the eyes, and an ugly haze over cities.

3. **Particulates** include dust and smoke particles. The dark plume of smoke from a factory stack and the exhaust of a diesel truck are examples of particulates being emitted.

The severity of air pollution resulting from emissions of carbon monoxide, hydrocarbons, and particulates depends on the weather. The worst urban air pollution occurs when winds are slight, skies are clear, and a temperature inversion exists. When the wind blows, it disperses pollutants, and when it is calm, pollutants build. Sunlight provides the energy for the formation of smog. Air is normally cooler at higher elevations, but during temperature inversions—in which air is warmer at higher elevations—pollutants are trapped near the ground.

According to the U.S. Environmental Protection Agency, the worst U.S. city for concentrations of carbon monoxide and second worst for particulates is Denver, where residents call the smog “the brown cloud.” The Rocky Mountains help trap the gases and produce a permanent temperature inversion. Ironically, the beautiful view of the mountains, which attracted so many migrants to Denver, is often obscured by smog.

The problem is not confined to MDCs. Santiago, Chile, nestled between the Pacific Ocean and the Andes Mountains, suffers severe smog problems. Motor vehicles are also responsible for much of the pollution in Santiago, especially particulates from burning diesel fuel, combined with dust kicked up from dirt streets. Mexico City’s serious air pollution problem is discussed in the opening case study.

Progress in controlling urban air pollution is mixed. Air has improved in developed countries where strict clean-air regulations are enforced. Changes in automobile engines, manufacturing processes, and electric generation all have helped. For example, in the three decades since the U.S. government has required catalytic converters on motor vehicles, carbon monoxide emissions have been reduced by more than three-fourths, and nitrogen oxide and hydrocarbon emissions have been reduced by more than 95 percent. But more people are driving, offsetting gains made by emission controls. Limited emission controls in LDCs are contributing to severe urban air pollution.

**Water Pollution**

Water serves many human purposes. People must drink water to survive, and they cook and bathe with water. The typical U.S. urban resident consumes 680 liters (180 gallons) of water per day for drinking, cooking, and bathing. Water provides a location for boating, swimming, fishing, and other recreation activities. People consume fish and other aquatic life. These uses depend on fresh, clean, unpolluted water.

Clean water is not always available, because people also use water for purposes that pollute it. Manufacturers use water each year to process food and manufacture goods. People discharge waste down the drain and into water. Farmers let waste wash away into water. When all of these uses are included, the average American consumes 5,300 liters (1,400 gallons) of water per day. By polluting water, humans harm the health of aquatic life and the health of land-based life (including humans themselves).
Pollution is widespread, because it is easy to dump waste into a river and let the water carry it downstream where it becomes someone else's problem. Water can decompose some waste without adversely impacting other activities, but the volume exceeds the capacity of many rivers and lakes to accommodate it.

Water Pollution Sources

Three main sources generate most water pollution:

- **Water-Using Industries.** Industries such as steel, chemicals, paper products, and food processing are major water polluters. Each requires a large amount of water in the manufacturing process and generates a lot of wastewater. Food processors, for example, wash pesticides and chemicals from fruit and vegetables. They also use water to remove skins, stems, and other parts. Water can also be polluted by industrial accidents, such as petroleum spills from ocean tankers and leaks from underground tanks at gasoline stations.

- **Municipal Sewage.** In MDCs, sewers carry wastewater from sinks, bathtubs, and toilets to a municipal treatment plant, where most—but not all—of the pollutants are removed. The treated wastewater is then typically dumped back into a river or lake. In LDCs, sewer systems are rare, and wastewater usually drains untreated into rivers and lakes.

- **Agriculture.** Fertilizers and pesticides spread on fields to increase agricultural productivity are carried into rivers and lakes by the irrigation system or natural runoff. Expanded use of these products may help to avoid a global food crisis, yet they destroy aquatic life by polluting rivers.

These three sources of pollution can be divided into point sources and nonpoint sources. Point-source pollution enters a stream at a specific location, whereas nonpoint-source pollution comes from a large diffuse area. Manufacturers and municipal sewage systems tend to pollute through point sources, such as a pipe from a wastewater treatment plant.

Farmers tend to pollute through nonpoint sources, such as by permitting fertilizer to wash from a field during a storm. Point-source pollutants are usually smaller in quantity and much easier to control. Nonpoint-sources usually pollute in greater quantities and are much harder to control.

Impact on Aquatic Life

Polluted water can harm aquatic life. Aquatic plants and animals consume oxygen, but so does the decomposing organic waste that humans dump in the water. The oxygen consumed by the decomposing organic waste constitutes the *biochemical oxygen demand (BOD).* If too much waste is discharged into the water, the water becomes oxygen starved and fish die.

This condition is typical when water becomes loaded with municipal sewage or industrial waste. The sewage and industrial pollutants consume so much oxygen that the water can become unlivable for normal plants and animals, creating a “dead” stream or lake. Similarly, when runoff carries fertilizer from farm fields into streams or lakes, the fertilizer nourishes excessive aquatic plant production—“pond scum” of algae—that consumes too much oxygen. Either type of pollution unbalances the normal oxygen level, threatening aquatic plants and animals.

Some of the residuals may become concentrated in the fish, making them unsafe for human consumption. For example, salmon from the Great Lakes became unfit to eat because of high concentrations of the pesticide DDT, which was washed into streams from farm fields.

Many factories and power plants use water for cooling and then discharge the warm water back into the river or lake. The warm water may not be polluted with chemicals, but it raises the temperature of the body of water it enters. Fish adapted to cold water, such as salmon and trout, might not be able to survive in the warmer water.

Wastewater and Disease

Since passage of the U.S. Clean Water Act and equivalent laws in other developed countries, most treatment plants meet high water-quality standards. Improved treatment procedures have resulted in cleaner rivers and lakes in MDCs. One dramatic example is the River Thames, which passes through London.
One of the world’s most extreme instances of water pollution is the Aral Sea in the former Soviet Union, now divided between the countries of Kazakhstan and Uzbekistan. The world’s fourth-largest lake in 1960, the Aral has been shrinking rapidly in area and volume and could disappear altogether by 2020.

The destruction of the Aral Sea over several decades was little known, and denied by the Soviet Union. Satellite imagery has enabled geographers and other scientists to document without question the extent of the destruction of the Aral and to monitor precisely the speed of destruction.

Photographs from airplanes and space shuttles provided scientists with anecdotal evidence that the Aral Sea was shrinking. Systematic monitoring of the Aral began with images obtained by the National Oceanic and Atmospheric Administration (NOAA) beginning in 1984. The National Aeronautic and Space Administration (NASA) launched two satellites named Terra and Aqua as part of its Earth Observing System begun in 1990 to collect even more precise images and data from Earth’s surface, including the Aral Sea.

Figure 14–2.1 was captured by the Moderate Resolution Imaging Spectroradiometer (MODIS) on the Aqua satellite on August 12, 2003. It shows the Aral Sea now divided into western and eastern portions. Comparison with a 1975 photograph shows small islands barely visible in the center of the sea (Figure 14–2.2).

Figure 14–2.3 shows the Aral Sea in 1989, shortly after better monitoring started. It shows a large island forming in the middle of the sea. The 1989 image was taken by a Landsat satellite, one of a series launched beginning in 1972 to support the Landsat Program jointly managed by NASA and the U.S. Geological Survey (USGS).

Overall, the Aral declined from about 68,000 square kilometers in 1960 to 46,000 square kilometers in 1995. Volume of water in the sea declined from about 1,040 km³ in 1960 to 468 in 1985 and to 181 in 1998.

The Aral Sea died because the Soviet Union diverted its tributary rivers, the Amu Dar’ya and the Syr Dar’ya, beginning in 1954, to irrigate cotton fields. Ironically, the cotton is withering because winds pick up salt from the exposed lakebed and deposit it on the cotton fields.

Carp, sturgeon, and other fish species have disappeared, the last fish dying in 1983. Large ships lie aground in salt flats that were once the lakebed, outside of abandoned fishing villages that now lay tens of kilometers from the rapidly receding shore.

The government of Kazakhstan announced a plan in 2003 to save the northern part of the Aral Sea (in the upper right of Figure 14–1.1). At the heart of the plan is construction of a dam to cut off the northern and southern portions. The purpose is to raise the water level and reduce the salinity in the north. The southern portion will disappear altogether in the years ahead.

Prior to the Industrial Revolution, the Thames was a major food source for Londoners. Some apprentice workers even went on strike in the early 1800s because their masters fed them too much fish. During the Industrial Revolution, the Thames became the principal location for dumping waste. The fish died, and the water grew unsafe to drink. The river became so dark, murky, and smelly that novelist Charles Dickens called the Thames “London’s Styx,” after the underworld river that the dead had to cross in Greek mythology.

The British government began a massive cleanup during the 1960s to restore the Thames to health. Regulations prohibited industrial dumping, and sewage systems were modernized to improve treatment. A salmon was caught in the Thames just upstream from London in 1982, the first since 1833. Salmon are particularly sensitive to pollution, and for nearly 150 years the Thames was too polluted for salmon to survive.

Although LDCs generate less wastewater per person than do MDCs, they have less capacity to treat their wastewater. In LDCs, sewage often flows untreated directly into rivers. The drinking water, usually removed from the same rivers, may be inadequately treated as well. And in squatter settlements on the edge of rapidly growing cities, running water and sewers may be
totally lacking. The combination of untreated water and poor sanitation makes drinking water deadly in LDCs. Waterborne diseases such as cholera, typhoid, and dysentery are major causes of death.

In LDCs, pollution may be a small price to pay for participating in a global economy. Industrialization may take a higher priority than clean water. MDCs caused most of the water pollution in the past. Now they possess the wealth and technology to clean up polluted rivers and lakes.

**Land Pollution**

When we consume a product, we also consume an unwanted by-product—a glass, metal, paper, or plastic box, wrapper, or container in which the product is packaged. About 2 kilograms (4 pounds) of solid waste per person is generated daily in the United States, including about 60 percent from residences and 40 percent from businesses.

Paper products, such as corrugated cardboard and newspapers, account for the largest percentage of solid waste in the United States, especially among residences and retailers (Figure 14–15). Food products, plastics, and rubbish cleanup from yards, such as grass clippings and leaves, are other important sources of solid waste. Manufacturers discard large quantities of metals as well as paper.

Some consumers demonstrate obvious unconcern for the environment by discarding waste along roadsides and sidewalks, where they cause visual pollution. But even consumers who carefully dispose of solid waste are contributing to a major pollution problem. A particularly severe threat is posed by the careless discharge of toxic waste.

**Solid Waste Disposal**

The sanitary landfill is by far the most common strategy for disposal of solid waste in the United States: more than one-half of the country's waste is trucked to landfills and buried under soil. This strategy is opposite of our disposal of gaseous and liquid wastes: we disperse air and water pollutants into the atmosphere, rivers, and eventually the ocean, but we concentrate solid waste in thousands of landfills.

![Figure 14–15 Sources of solid waste, 2005. Paper products account for the largest percentage of U.S. solid waste, followed by yard rubbish and food waste. One-third of the solid waste is recycled.](image-url)
Concentration would seem to eliminate solid-waste pollution, but it may only hide it—temporarily. Chemicals released by the decomposing solid waste can leak from the landfill into groundwater. This can contaminate water wells, soil, and nearby streams.

The number of landfills in the United States has declined by three-fourths since 1990. Thousands of small-town "dumps" have been closed and replaced by a small number of large regional ones. Better compaction methods, combined with expansion in the land area of some of the large regional ones, have resulted in expanded landfill capacity. At the same time, the two principal alternatives to disposing solid waste in landfills—incineration and recycling—have both increased rapidly.

Some communities now pay to use landfills elsewhere. New Jersey and New York are two states that regularly try to dispose of their solid waste by transporting it out of state. New York City exports 25,000 tons of trash a day to other communities. Passaic County, New Jersey, hauls waste 400 kilometers (250 miles) west to Johnstown, Pennsylvania. San Francisco trucks solid waste to Altamont, California, 100 kilometers (60 miles) away.

**INCINERATION.** Burning the trash reduces its bulk by about three-fourths, and the remaining ash demands far less landfill space. Incineration also provides energy—the incinerator's heat can boil water to produce steam heat or to operate a turbine that generates electricity. Given the shortage of space in landfills, the percentage of solid waste that is burned has increased rapidly during the past three decades, to one-sixth of solid waste.

However, solid waste, a mixture of many materials, may burn inefficiently. Burning releases some toxins into the air, and some remain in the ash. Thus solving one pollution problem may increase another.

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**Hazardous Waste**

Disposing of hazardous waste is especially difficult. Hazardous wastes include heavy metals (including mercury, cadmium, and zinc), PCB oils from electrical equipment, cyanides, strong solvents, acids, and caustics. These may have been unwanted by-products generated in manufacturing or discarded after usage. If poisonous industrial residuals are not carefully placed in protective containers, the chemicals may leach into the soil and contaminate groundwater or escape into the atmosphere. Breathing air or consuming water contaminated with toxic wastes can cause cancer, mutations, chronic ailments, and even immediate death.

Burial of wastes was once believed to be sufficient to handle the disposal problem, but many of the burial sites have leaked. One of the most notorious is Love Canal, near Niagara Falls, New York. The Hooker Chemicals and Plastic Company buried toxic wastes in metal drums during the 1930s. A school and several hundred homes were built on the site in 1953. Erosion eventually exposed the metal drums, and in 1976 they began to give off a strong stench and slime oozed from them.

Residents at Love Canal reported a high incidence of liver ailments, nervous disorders, and other health problems. After four babies were born with birth defects on the same block, New York State officials relocated most of the families and began an expensive cleanup effort. Love Canal is not unique. Toxic wastes have been improperly disposed of at thousands of dumps.

Companies in the United States that release chemicals classified as toxic by the Environmental Protection Agency (E.P.A.) must report the amounts released. About 30 million tons of hazardous wastes were discharged in the United States in 2003. Five companies were responsible for at least 1 million tons each: BP Products in Texas City, Texas; Rubicon in Geismar, Louisiana; Cytec Industries in Waggaman, Louisiana; DuPont in Pass Christian, Mississippi; and BP Amoco in Lima, Ohio.

As toxic-waste disposal sites become increasingly hard to find, some European and North American firms have tried to transport their waste to West Africa, often unscrupulously. Some firms have signed contracts with West African countries, whereas others have found isolated locations to dump waste without official consent.

**KEY ISSUE 3**

**Why Are Resources Reusable?**

- Renewing resources
- Recycling resources

Depletion and destruction of resources can be reduced through reusing resources. Nonrenewable resources can be replaced with renewable ones. The discharging of unwanted by-products into the environment can be replaced with the recycling of them into resources.