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?

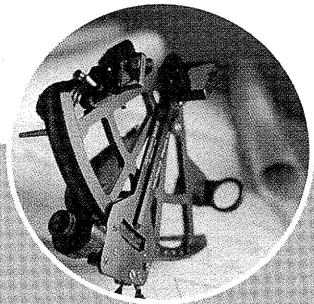
People have always transformed Earth's land, water, and air for their benefit. But human actions in recent years have gone far beyond the impact of the past. The magnitude of transformations is disproportionately shared by North Americans; with only one-twentieth of Earth's population, North Americans 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 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.

KEY ISSUES

1. **Why are resources being depleted?**
2. **Why are resources being polluted?**
3. **Why are resources reusable?**
4. **Why can resources be conserved?**



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. Nor did many of their classmates. 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. MDCs want to preserve current standards of living, and 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.

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, hydroelectric, and geothermal power. Burning wood provides 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 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 heating of living space and water. Natural gas is the most common source, followed by petroleum (heating oil

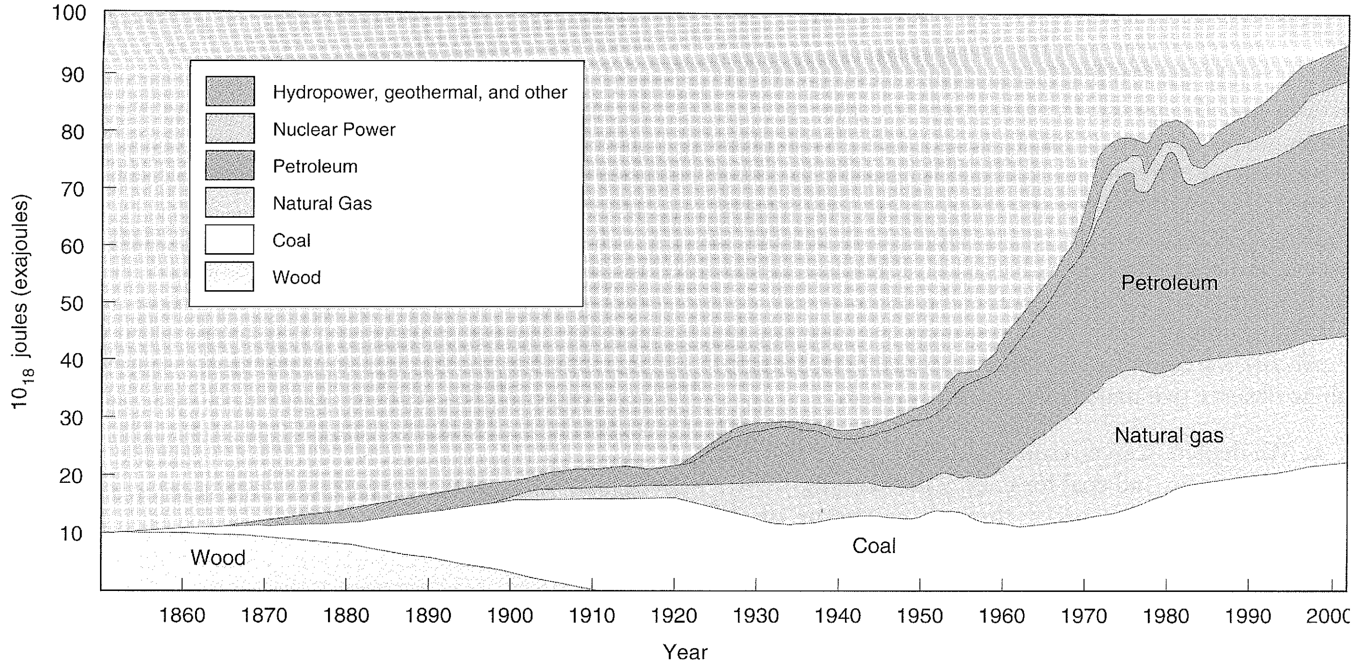


FIGURE 14-1 *U.S. energy consumption. U.S. energy consumption increased rapidly during the 1960s, but since the early 1970s it has increased at a much slower rate. The amount of energy derived from petroleum and natural gas increased rapidly in the 1960s, whereas use of coal stagnated.*

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 trillion barrels of petroleum, about 140 trillion cubic meters of natural gas, and about 1 quadrillion metric tons of coal.

But how many deposits in the world have not yet been discovered? The energy in undiscovered deposits that are thought to exist is a **potential reserve**. When a potential reserve is actually discovered, it is reclassified as a proven reserve. The World Energy Council estimates potential oil reserves of about 500 billion barrels, with the largest fields thought to lie beneath the South China Sea and northwestern China.

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 25 billion barrels a year, Earth's proven petroleum reserves of 1 trillion barrels will last 40 years.

New petroleum deposits are being discovered each year and added to the inventory of proven reserves (thus extending the number of years of remaining supply), but petroleum is being consumed at a more rapid rate than it is being found, and world demand is increasing by more than 1 percent annually. 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 80 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 much more oil than gas. However, if energy users switched from petroleum to natural gas, then the proven reserves of petroleum would last longer and natural gas would be depleted more quickly.

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

Extraction of Remaining Reserves. Although scientists differ on the volume of potential reserves, they agree that extracting proven reserves will grow harder. 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 already 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 perhaps special technology.

The largest, most accessible deposits of petroleum, natural gas, and coal already have been exploited. Newly discovered reserves generally are smaller and more remote, such as beneath the seafloor, where extraction is costly. Exploration cost has increased because methods are more elaborate and the probability of finding new reserves is less.

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 to extract them.

Utah, Wyoming, and Colorado contain more than 10 times the petroleum reserves of Saudi Arabia, but as oil shale. The cost of conventional oil resources must increase dramatically before these unconventional sources will become profitable. Even then the adverse environmental impacts of using these sources is likely to 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.

Two countries—China and the United States—are each responsible for producing one-fourth of the world's coal. India, Australia, South Africa, and Russia together produce another one-fourth (Figure 14-2). The United States also has one-fourth of the world's proven coal reserves. Russia and China together account for more than

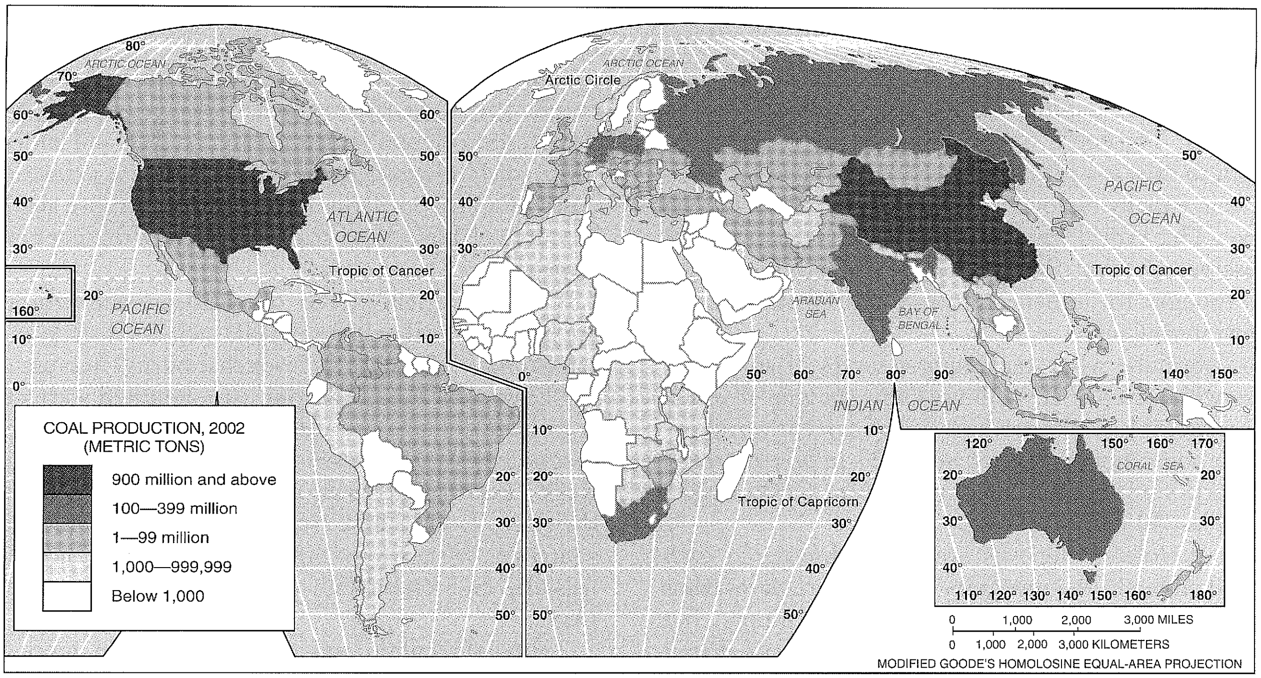
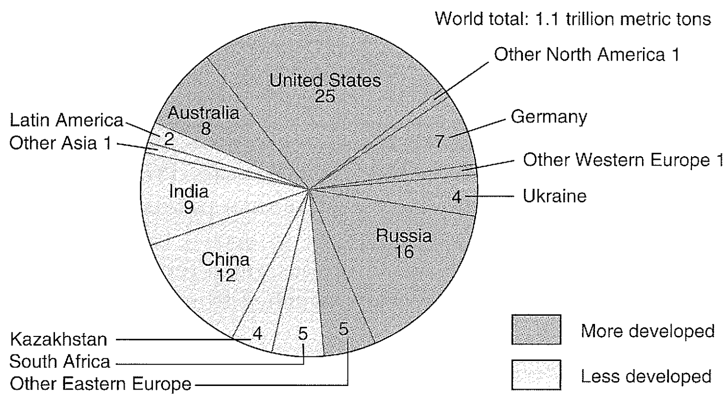


FIGURE 14–2 *Coal production and proven reserves. China and the United States are the largest producers. The United States and Russia have the largest proven reserves of coal.*



one-fourth. Another one-third of world coal reserves are in India, Australia, Germany, 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.

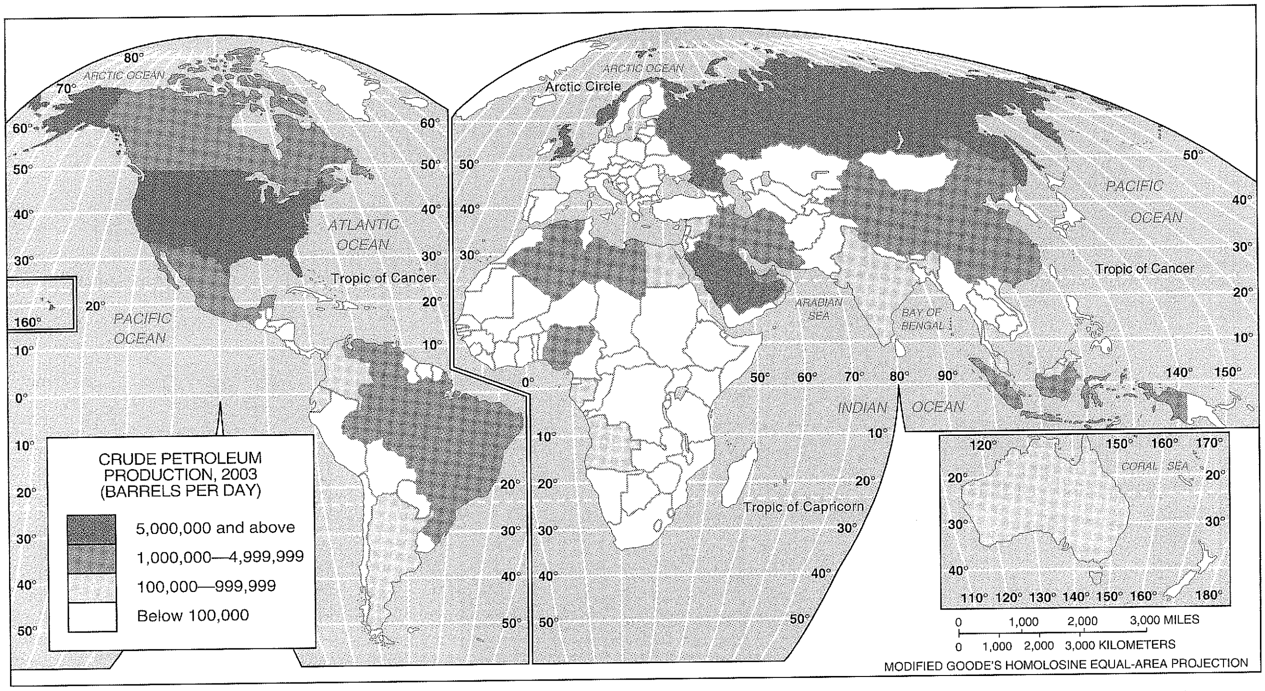
Five Middle Eastern countries have two-thirds of the world's oil reserves—about 25 percent in Saudi Arabia and 10 percent each in Iran, Iraq, Kuwait, and United Arab Emirates. Venezuela and Mexico have the most extensive proven reserves in the Western Hemisphere. The United States accounts for 10 percent of the world's annual production of petroleum but possesses only 2 percent of the proven reserves (Figure 14–3).

Russia accounts for one-fourth of world production of natural gas and possesses one-third of the world's proven reserves (Figure 14–4). The United States also accounts for one-fourth of world production but has only 3 percent of the world's reserves. The second most extensive reserves (one-sixth of world total) are in Iran.

Taken as a group, MDCs historically have 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,



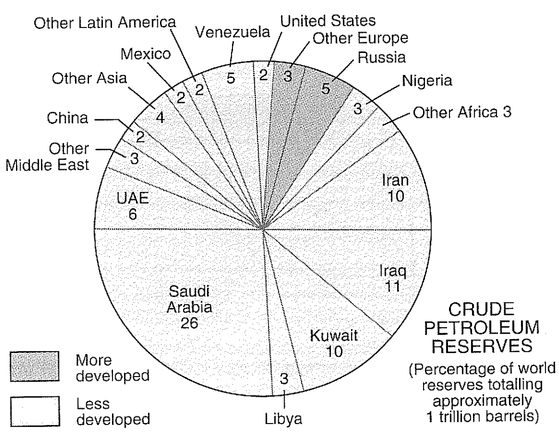


FIGURE 14–3 *Petroleum production and proven reserves. Saudi Arabia is the largest producer and has the largest proven reserves of petroleum. The United States is a major producer but has limited reserves.*

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 100 million BTUs in Western Europe, compared to under 25 million in most LDCs (Figure 14–5). 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 will consume much more energy. 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 will increase from about 25 percent today to 40 percent by 2010 and 60 percent by 2020.
- 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 52 percent in 1999. European countries and Japan have always depended on foreign petroleum because of limited domestic supplies.

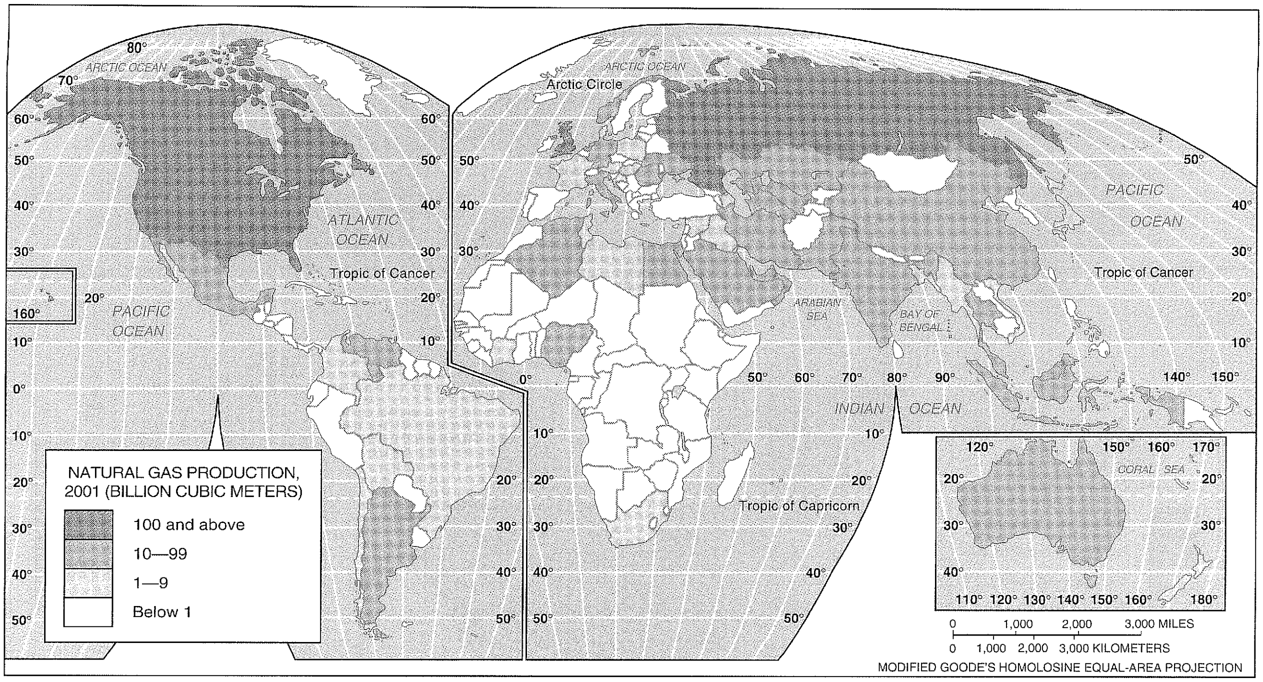
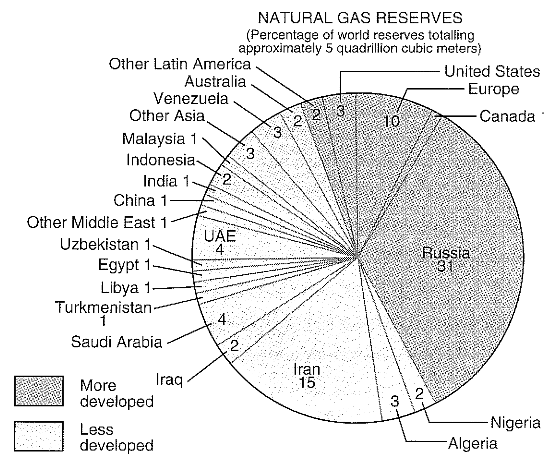


FIGURE 14-4 *Natural gas production and proven reserves. Russia is the largest producer and has the largest proven reserves of natural gas. The United States is a major producer but has limited reserves.*



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.

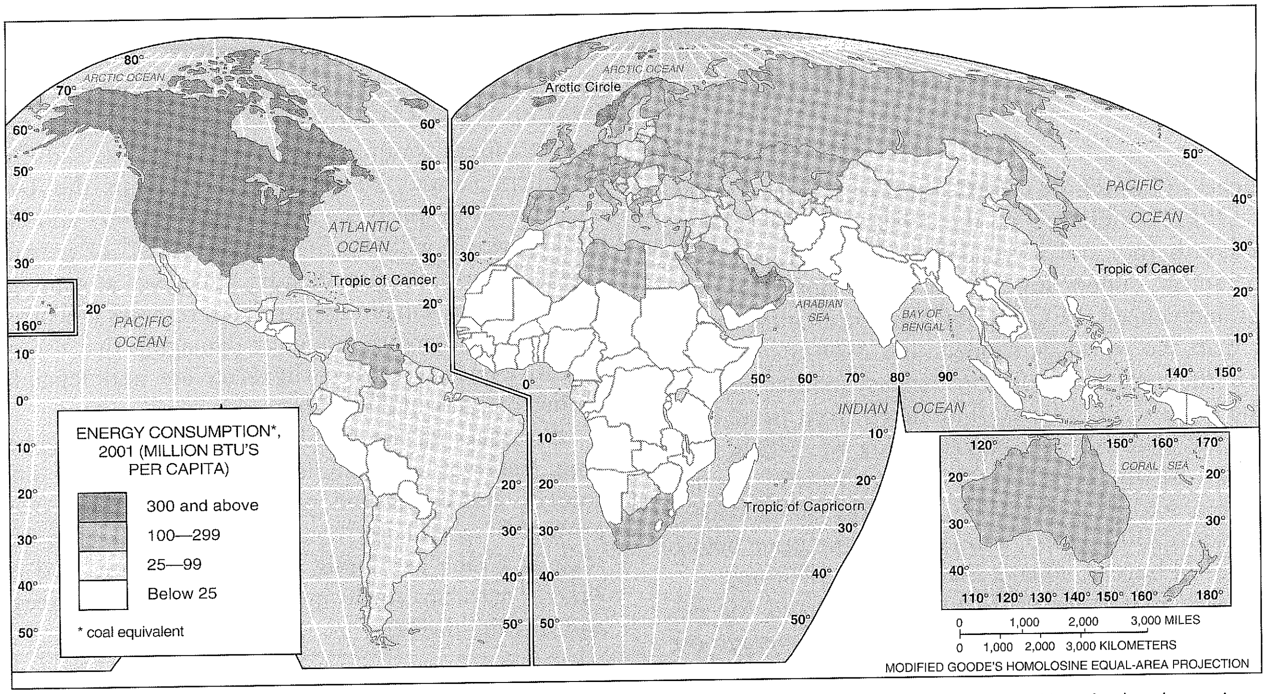
OPEC Policies During the 1970s. Several LDCs possessing substantial petroleum reserves created the Organization of Petroleum Exporting Countries (OPEC) in 1960. Arab OPEC members in the Middle East are Algeria, Iraq, Kuwait, Libya, Qatar, Saudi Arabia, and United Arab Emirates. Another Middle East OPEC 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. 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 have never regained their pre-boycott levels (recall Figure 11–21, which shows declining steel production in MDCs since the 1970s). Many



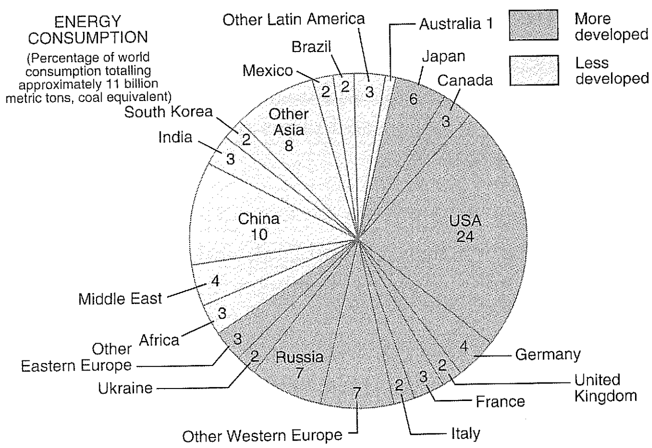


FIGURE 14–5 *Per capita energy consumption. More developed countries consume much more energy per capita than do less developed countries. The United States, with 5 percent of the world's population, consumes about one-fourth of the world's energy.*

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

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.

encouraged OPEC countries to invest in American and European real estate, banks, and other safe and profitable investments. Comparable investment opportunities were limited in LDCs.

Reduced Influence of OPEC. 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.

The price of petroleum plummeted from more than $30 to less than $10 per barrel during the 1980s. The price rose briefly to about $40 during the 1991 Persian Gulf War, settled at about $20 for most of the 1990s, then rose to $30 in 2000, still less than the price before the 1973–74 boycott when accounting for inflation.

Conservation measures dampened demand for petroleum in most developed countries. The average car driven in the United States got 14 miles per gallon in 1975, compared to 22 miles per gallon in 2000. The fuel efficiency of the average new car sold in the United States increased from 16 miles per gallon in 1975 to 27 miles per gallon in 2000. However, the number of vehicles driven in the United States doubled between 1975 and 2000, and the average vehicle was driven 10 percent more in 2000 than in 1975. Further, savings from more efficient cars have been offset by increased sales of gas-guzzling sport-utility vehicles and pickup trucks.

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 in 1973 to one-half in 1999. But oil imports climbed rapidly in the late twentieth century, from 1.2 billion barrels in 1985 to 3.2 billion barrels in 1999, and OPEC countries contributed to the overall increase in imports. Reliable allies Mexico, Venezuela, and Canada have joined Saudi Arabia as the principal sources of U.S. imports. Non-OPEC countries Angola, Colombia, Norway, and the United Kingdom registered large increases in exports to the United States during the late twentieth century (Figure 14–6), but so did OPEC members Kuwait and Iraq (even though the United States went to war twice against Iraq, in 1991 and 2003).

The world will not literally "run out" of petroleum during the twenty-first century. However at some point extracting the remaining petroleum reserves will prove so expensive and environmentally damaging that use of alternative energy sources will accelerate, and dependency on petroleum will diminish.

The issues for the world are whether dwindling petroleum reserves are handled wisely and other energy sources are substituted peacefully. Given the massive growth in petroleum consumption expected in LDCs such as China and India, the United States and other MDCs may have little influence over when prices rise and supplies decline.

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 by two-thirds between 1980 and 2000, whereas petroleum consumption increased by only one-fifth.

At the current rate of use, the world's proven reserves of about 140 trillion cubic meters of natural gas will last for about 80 years. Although the United States is a major producer of natural gas, proven reserves are limited.

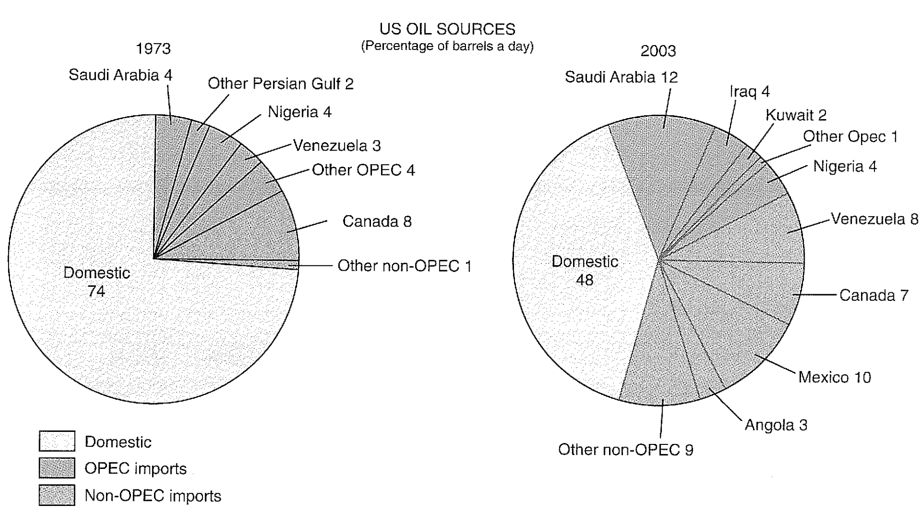


FIGURE 14–6 *U.S. petroleum imports, 1973 and 2003. The United States imported 52 percent of its crude oil in 2003, compared to only 26 percent in 1973. Total consumption increased from 4.5 billion barrels in 1973 to 6.1 billion barrels in 2003.*

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 in 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 several hundred years. Coal is especially important to the United States, which possesses large proven reserves (refer to Figure 14–2). But problems hinder expanded use of coal: air pollution, mine safety, land subsidence, and economics.

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.

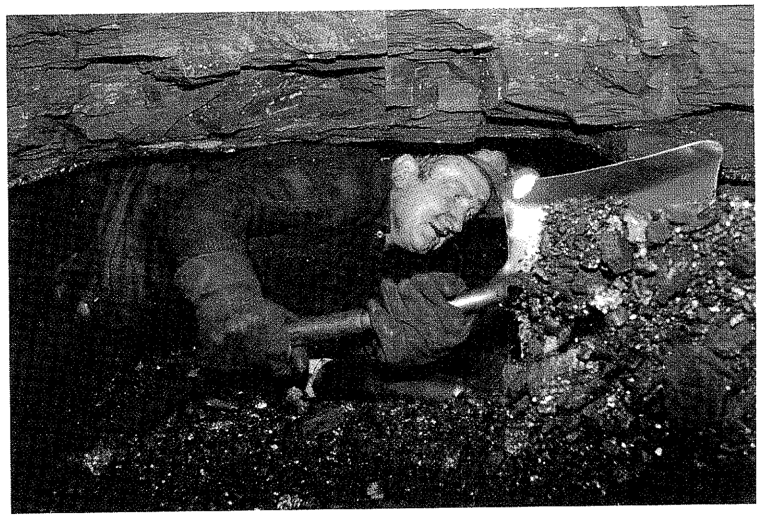
The U.S. Clean Air Act now requires utilities to use better-quality coal or to install "scrubbers" on smokestacks. These methods can work; Pittsburgh, Pennsylvania, once noted for terrible air pollution when coal was burned for steel mills and glass factories, today has remarkably clean air. But coal-fired 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. Annual U.S. mine mortality now is 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.



Coal mining. A coalminer wedged in a narrow seam digs coal with a shovel.

Nuclear Energy. The big advantage of nuclear power is the large amount of energy that is 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 14–7). Lithuania and France obtain more than three-fourths of their electricity from nuclear power, Belgium, Bulgaria, Slovakia, and Ukraine about one-half each. About one-fifth of electricity in the United States comes from nuclear power, about one-third in Japan.

Dependency on nuclear power varies widely among U.S. states. Nuclear power accounts for more than one-half of electricity in New Hampshire, New Jersey, South Carolina, and Vermont (Figure 14–8). 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**. 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 10 times higher than normal in Ukraine and

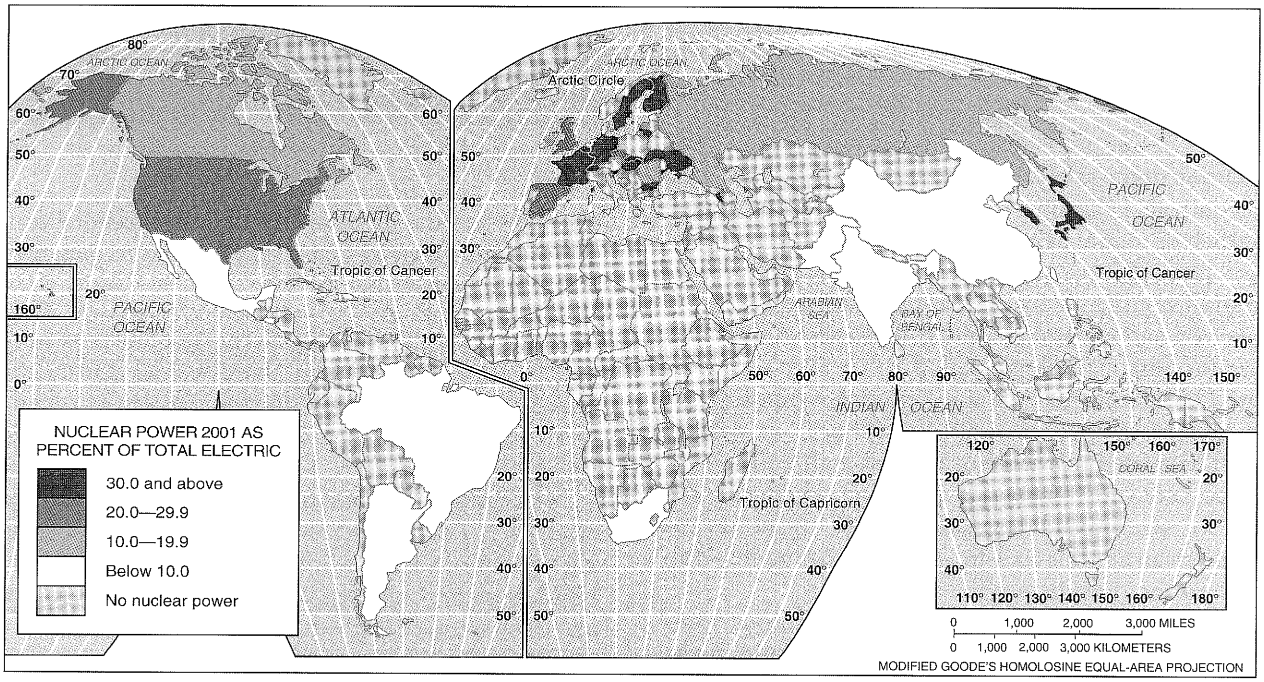


FIGURE 14-7 *Nuclear power as percent of electricity. Nuclear power has been especially attractive to more developed countries in Europe that lack abundant reserves of either petroleum or coal.*

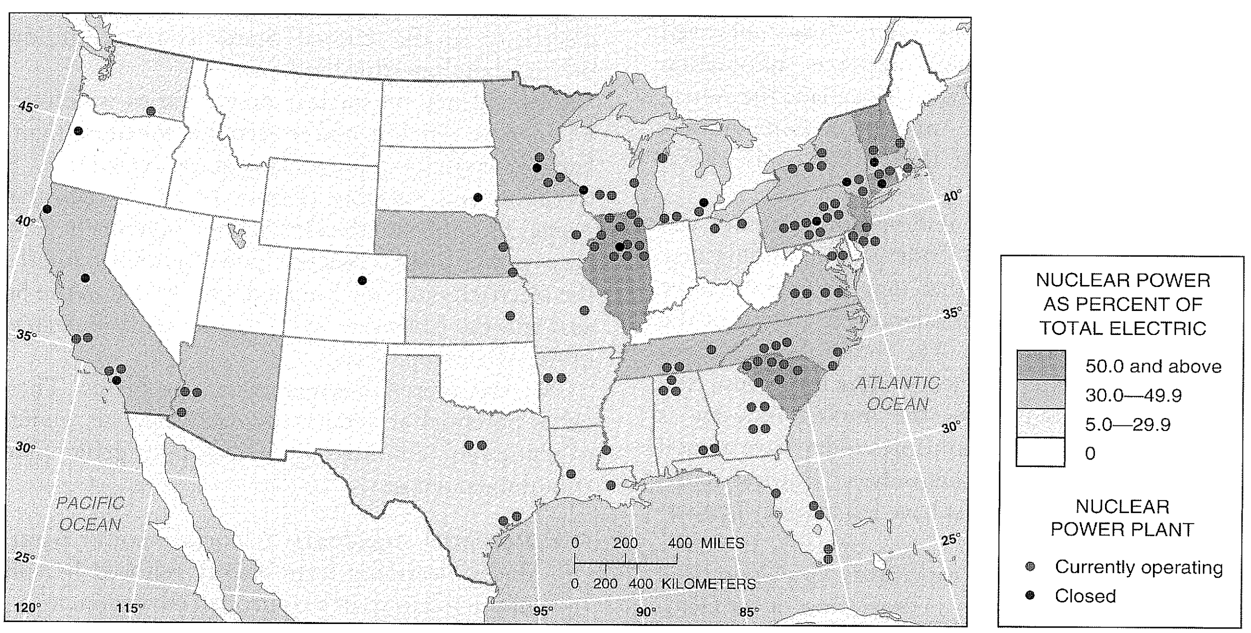


FIGURE 14-8 *U.S. nuclear power plants and nuclear power as percent of electricity by state. Nuclear power is an important source of electricity in a number of northeastern and midwestern states. At a number of locations, more than one nuclear plant has been built.*

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**. 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?

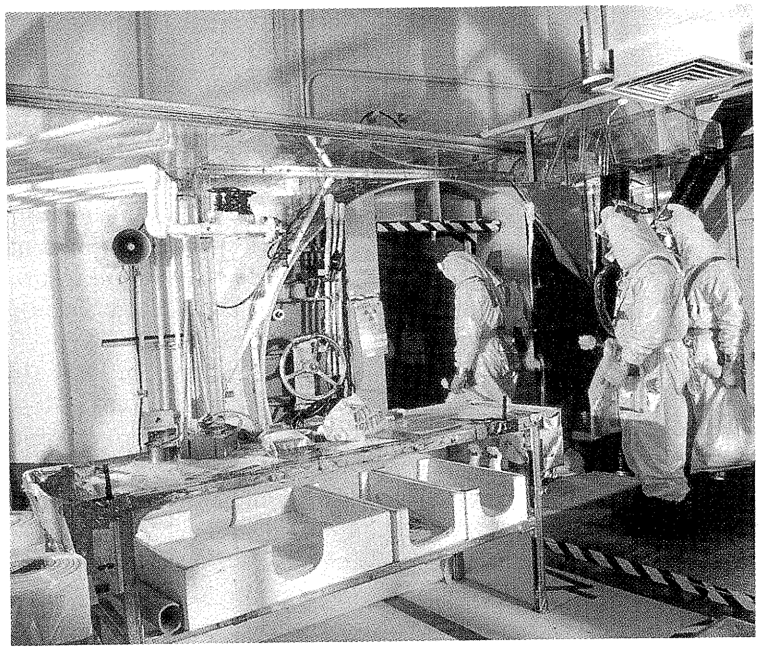
3. **Bomb Material**. Nuclear power has been used in warfare twice, in August 1945, when the United States dropped an atomic bomb on first Hiroshima and then Nagasaki, Japan, ending World War II. Since then, the Soviet Union (now Russia), the United Kingdom, France, China, and India have tested nuclear weapons, and several other countries are actively developing them, although they have not so stated publicly. No government has dared to use them in a war, because leaders have recognized that a full-scale nuclear conflict could terminate human civilization. But the black market could provide terrorists with enough plutonium to construct nuclear weapons.

   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 60 years at current rates of use. And they are not distributed uniformly around the world—two-thirds of the world's proven uranium reserves are in Australia, the United States, South Africa, and Canada. (Russia and China probably rank among world leaders in production and proven reserves, but their levels are unknown.)

   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



Nuclear power plant. Workers at Three Mile Island nuclear power plant in Pennsylvania clean up the Plexiglas contamination control cubicles.

risks, few breeder reactors have been built, and none are in the United States.

5. **Cost.** 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. Sweden, which received nearly half of its electricity from nuclear power in the 1980s, plans to abandon its nuclear power plants completely by the year 2010. 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.

Mineral Resources

Earth has 92 natural elements, but about 99 percent of the crust is composed of 8 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 14–9). Each mineral potentially is 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.

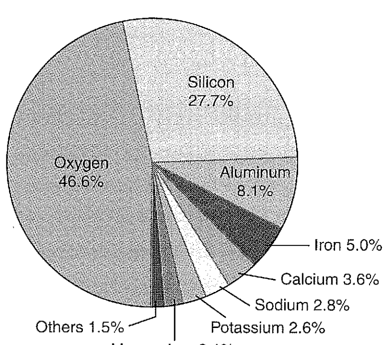


FIGURE 14–9 *Elements in Earth's crust. Oxygen comprises nearly one-half of Earth's crust, Silicon more than one-fourth, and six elements nearly all of the remainder.*

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. The world's largest col-tan reserves are in the eastern part of the Congo Democratic Republic, site of a civil war. Revenues from the sale of col-tan finance the armies fighting the civil war.

Conversely, when a new process or product replaces an older one, demand may decline for a mineral important in the past. For example, when the price of copper rose rapidly in the 1970s, plumbers began to substitute polyvinyl chloride (PVC). Today PVC has largely replaced copper pipe for plumbing in new buildings.

Mineral deposits are not uniformly distributed around the world. A handful of countries account for most of the world's supply of particular minerals. Countries such as Australia and South Africa rank among leading producers of a wide variety of minerals, whereas other countries have abundant supplies of only one mineral. Further, the leading producers at this time are not always the countries with the most extensive reserves, an indication that the relative fortunes of states may change in the future.

Minerals are either metallic or nonmetallic. In weight, more than 90 percent of the minerals that humans use are nonmetallic, but metallic minerals are important for economic activities and so carry relatively high value.

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.

- 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 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.

- 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.
- The United States and Canada are responsible for one-third of the world's sulfur production, with another one-third coming from Russia, China, and Japan.

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. Three-fourths of the world's diamonds are currently mined in Australia, Congo Democratic Republic, and Russia. However, one-half of the reserves are clustered in Congo and Botswana.

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), ductile (able to be drawn into fine wire), and 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 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 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 more than one-half in China, Brazil, and Australia (Figure 14–10). Two-thirds of the reserves are in China, Russia, Ukraine,

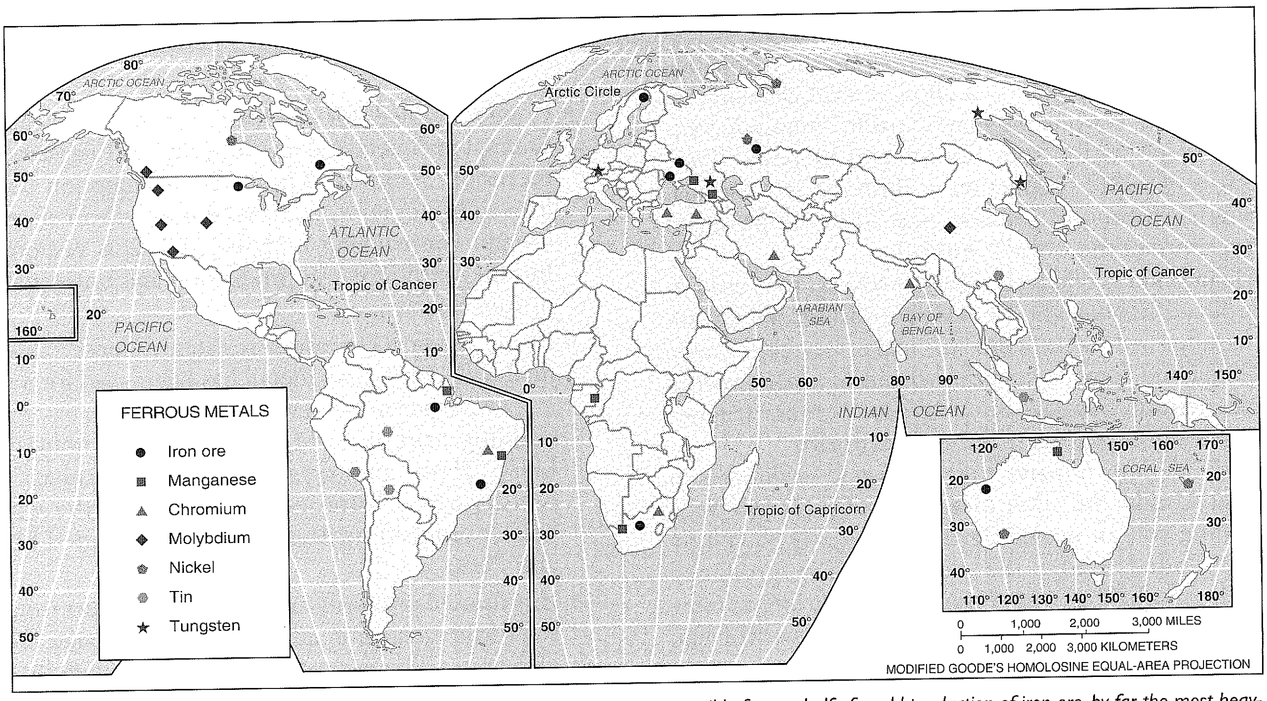


FIGURE 14–10 *Production of ferrous metals. Brazil, Australia, and China are responsible for one-half of world production of iron ore, by far the most heavily utilized ferrous metal.*

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 90 percent of world manganese production are seven countries, led by South Africa and also including Australia, Brazil, China, Gabon, India, and Ukraine. 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, three-fourths of which is mined in South Africa, 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. Two-thirds of world production is clustered in Australia, South Africa, and Canada, and Australia possesses one-third of the world's reserves.
- Magnesium is relatively light yet strong, so is used to produce lightweight, corrosion-resistant alloys, especially with aluminum to make beverage cans. China and Canada supply two-thirds 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 world's largest producer, with 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 five thousand years as an alloy of copper for making bronze. China, Indonesia, and Peru extract three-fourths of the world's tin, and 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 nearly 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 of corrosion. Aluminum has replaced copper wire in high-tension power transmission lines, and is used to make paints, foil, and jewelry.

The most economically feasible source of aluminum is extracting it from bauxite ore. Australia is responsible for mining 40 percent of the world's bauxite ore, and Guinea has the largest proven reserves, one-third of world total (Figure 14–11). 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. Two-thirds of the world's lead is supplied by Australia, China, United States, and Peru.
- Zinc is used primarily as a coating to protect iron and steel from corrosion and as an alloy to make bronze and brass. The same four leading suppliers of lead plus Canada are responsible for two-thirds of the world's mining of zinc sulfide ore, from which zinc is extracted.

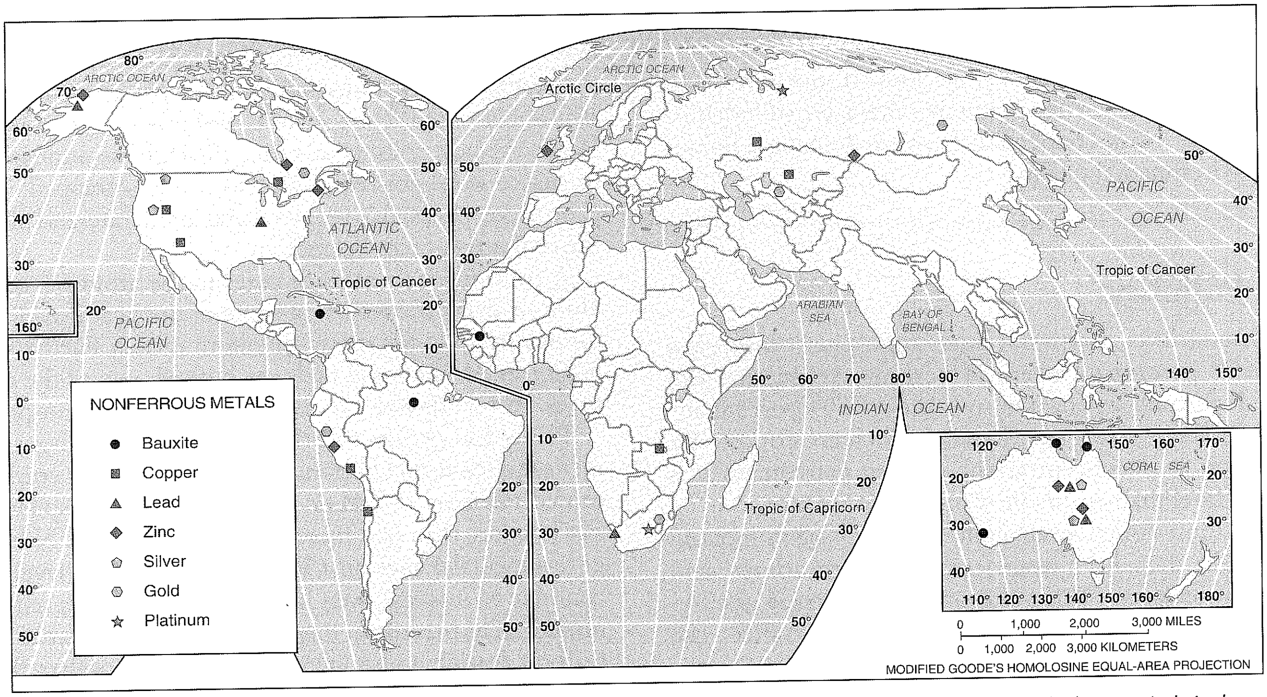


FIGURE 14–11 *Production of nonferrous metals. Australia is responsible for one-third of world production of bauxite, from which aluminum is derived, with Guinea, Jamaica, and Brazil responsible for another one-third.*

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. Silver, associated with copper, lead, and zinc deposits, is often mined at great depths. More than one-half of current production, as well as reserves, are in Mexico, Peru, Australia, the United States, and Canada. Three-fourths of the world's gold is mined in eight countries: South Africa, the United States, Australia, China, Canada, Russia, Peru, and Indonesia. 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. The principal use of the platinum group is in motor-vehicle catalytic converters to treat exhaust emissions, as well as fuel cells. 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 eventually are 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 generally are 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 comprises 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, therefore 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. The level will continue to increase even if fossil-fuel burning is reduced immediately, 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 14–12). The buildup of carbon dioxide contributed to the warming, 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 trace gases in the atmosphere. In a real greenhouse, the interior gets very warm when its windows remain closed on a sunny day.

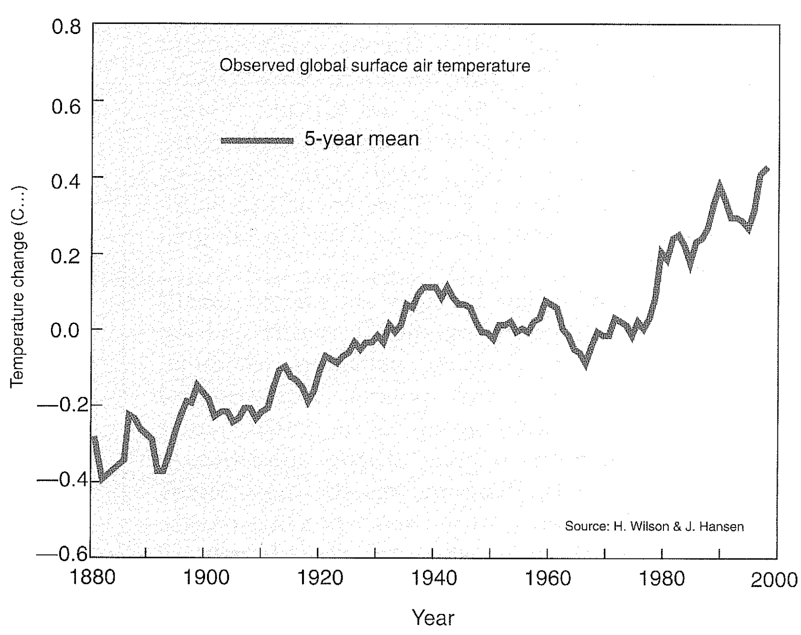
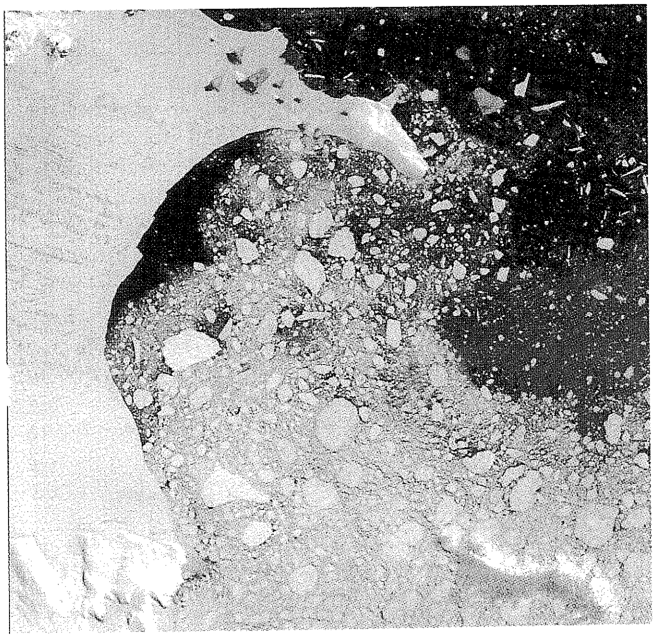


FIGURE 14–12 *Global warming. The chart shows an increase in the annual mean temperature for Earth between 1880 and 1999. Figures are the annual deviations from the mean between 1951 and 1980.*



Antarctica. The Larsen B ice shelf, part of Antarctica, breaks into ice floes, captured in a Landsat-7 satellite image. The breakup has been attributed to global warming.

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, 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 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.

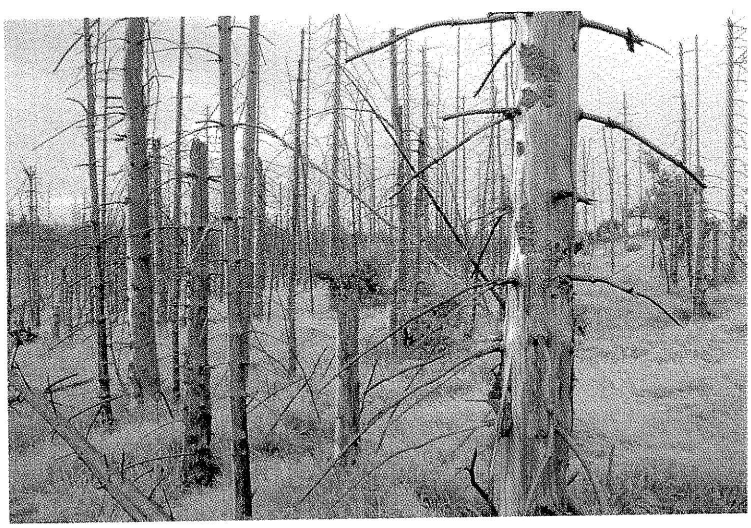
Sulfur oxides and nitrogen oxides, emitted by burning fossil fuels, enter the atmosphere, where they combine with oxygen and water. Tiny droplets of sulfuric acid and nitric acid form and return to Earth's surface as **acid deposition**. When dissolved in water, the acids may fall as **acid precipitation**—rain, 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 soil 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 cut theirs in half, 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



Acid precipitation has killed a large percentage of the trees in the forests of the Czech Republic, including these near the city of Most. 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.

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. 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 very 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.

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 14–13).

The problem of acid precipitation is compounded by the fact that pollutants emitted in one country cause

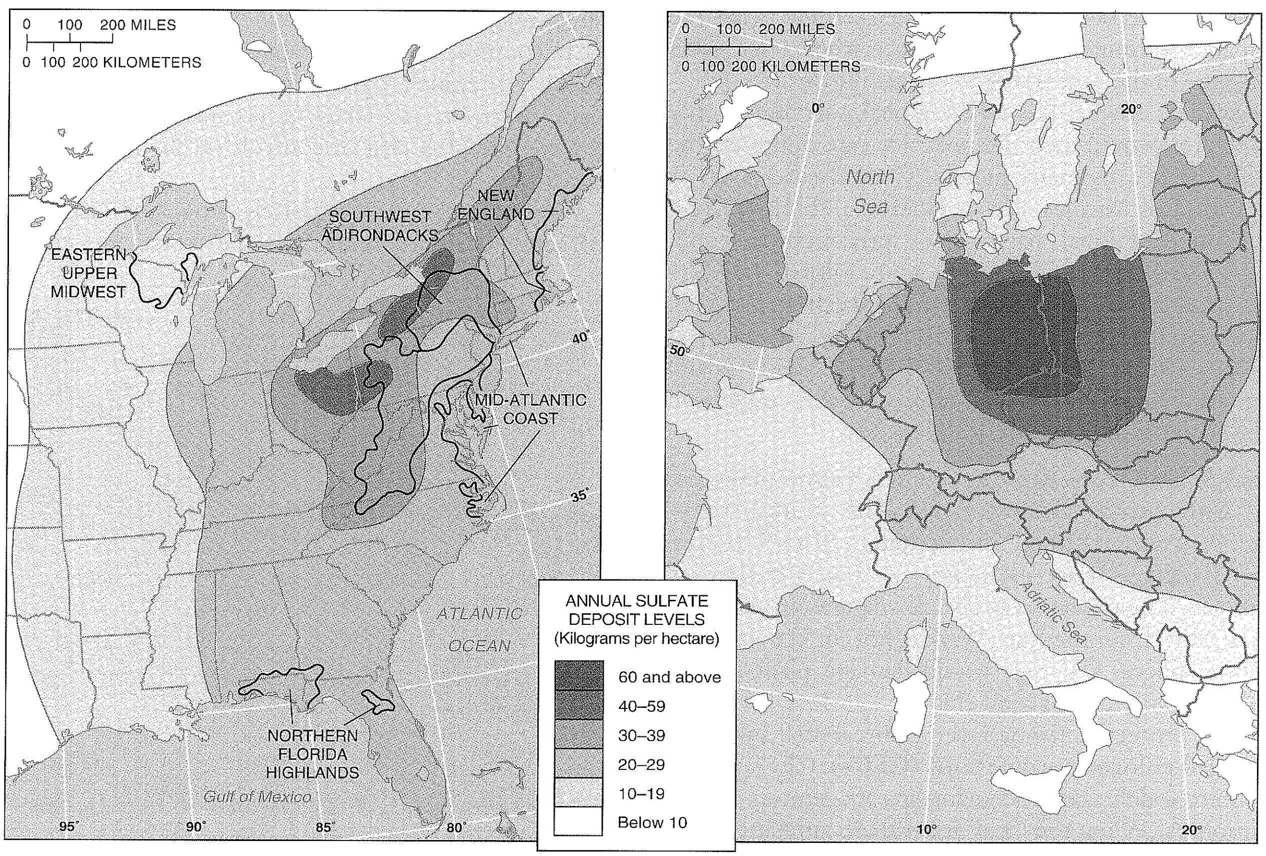


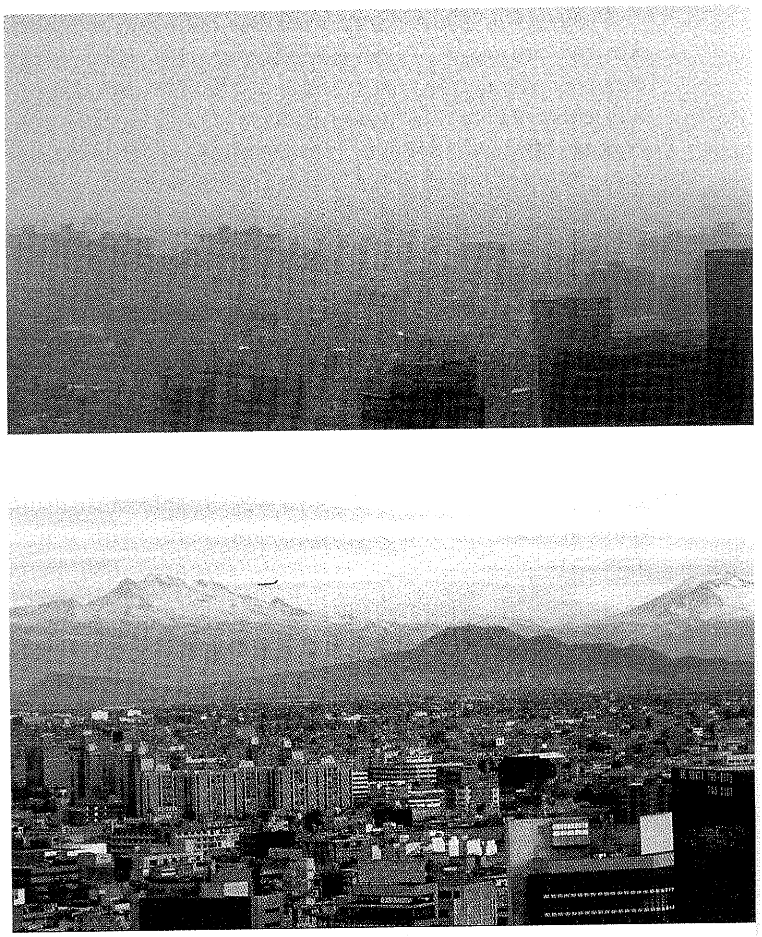
FIGURE 14–13 *Acid deposition in North America and Europe. Levels exceeding 20 kg/ha are considered threatening. (left) Because of prevailing wind patterns across North America, damage is generally found to the east of the emissions. (right) Deposition levels in eastern Germany are higher than anywhere in the United States, although elsewhere in central Europe levels are comparable to those in the eastern United States.*

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 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.



Mexico City suffers from a combination of circumstances that lead to significant air pollution problems. The city lies in a mountain basin that limits dispersion of pollutants, and motor vehicle traffic is heavy. (top) Smog blankets Mexico City January 9, 1996, in this view looking south from Paseo de la Reforma. (bottom) Same view one week earlier on a day with clean air.

Local Scale Air Pollution

At the local scale, air pollution is especially severe in places where emission sources are concentrated, such as 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 quarter century since the U.S. government has required catalytic converters on motor vehicles, carbon monoxide emissions have been reduced by more than three-fourths, nitrogen oxide and hydrocarbon emissions 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 nearly 10,000 liters (2,400 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

CONTEMPORARY GEOGRAPHIC TOOLS

Monitoring the Disappearing of the Aral Sea

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. Recently available 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 from its sensor known as Advanced Very High Resolution Radiometer Measurement (AVHRR) operating aboard a series of polar-orbiting operational environmental satellites. AVHRR data can monitor daily changes in land-water boundaries, vegetation, and other environmental conditions. Ironically, the Russian satellite RESURS-01 has provided even more precise imagery of the Aral since 1995.

The 1996 RESURS-01 satellite image (Figure 14-1.1) shows a large island dividing the Aral Sea into east and west portions. The two red patches are agricultural areas around the two rivers that feed into the Aral, the Amu Dar'ya from the south and the Syr Dar'ya from the north. A 1975 photograph (Figure 14-1.2) shows the large island just beginning to form.

The 1995 RESURS-01 image (Figure 14-1.3) shows the same view of the Aral one year earlier than the image in Figure 14-1.1. By using GIS to overlay the two images and

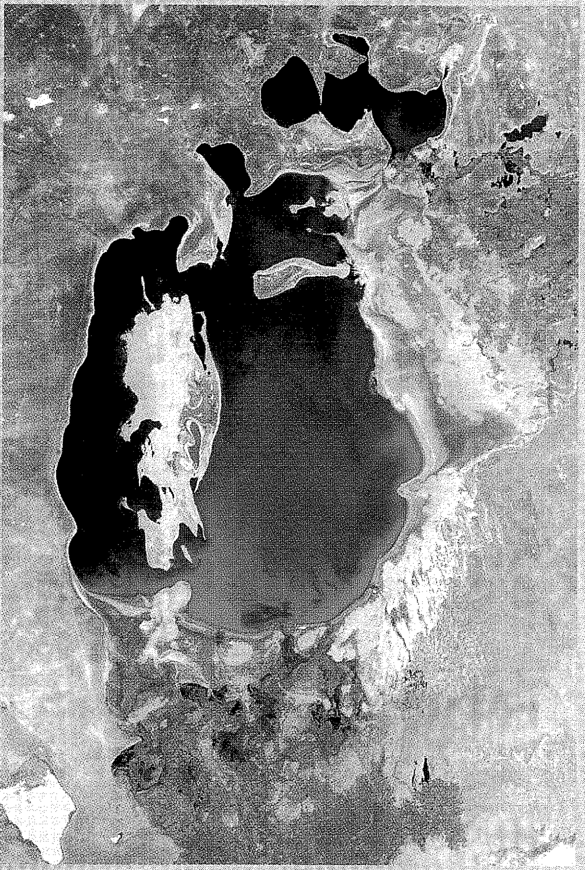


FIGURE 14-1.1 *Aral Sea 1996.*

decompose some waste without adverse impact on 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

FIGURE 14-1.2 *Aral Sea 1975.*

changing the colors, the extent of loss in one year can be measured (Figure 14-1.4). In one year the Aral decreased in area by 3,885 square kilometers (1,550 square miles) and in volume by 36 km^3 (1.3 billion cubic feet). The GIS displays an especially severe decline on the east side of the sea.

Overall, the Aral declined from about 68,000 square kilometers in 1960 to 46,000 square kilometers in 1985 (when better-quality monitoring began) and 29,000 square kilometers in 1998. Volume of water in the sea declined from about 1,040 km^3 in 1960 to 468 in 1985 and 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 now 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 lie tens of kilometers from the rapidly receding shore.

FIGURE 14-1.3 *Aral Sea 1995.*

FIGURE 14-1.4 *Change in Aral Sea 1995–96.*

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—a "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 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.

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 byproduct—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 14–14). Food products, plastics, and

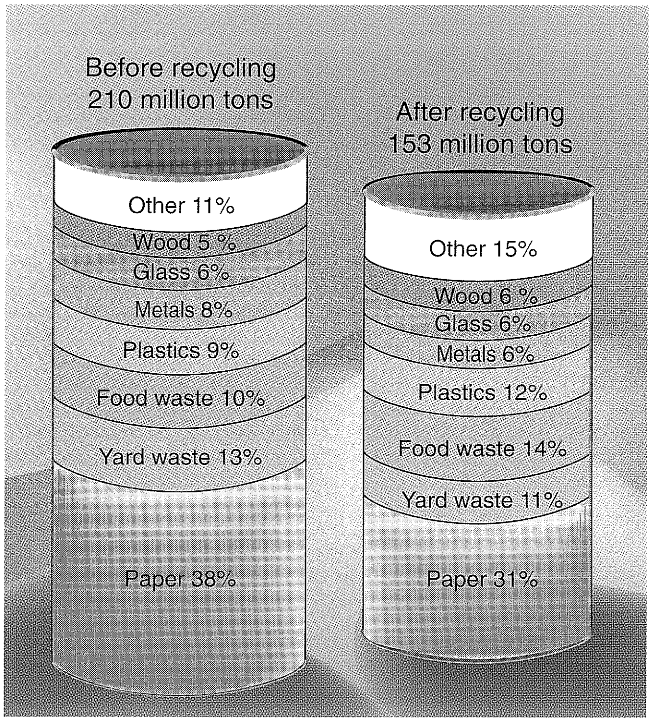


FIGURE 14–14 *Sources of solid waste. Paper products account for the largest percentage of U.S. solid waste, followed by food products and yard rubbish. Plastics and metals are comparatively small percentages of solid waste.*

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.

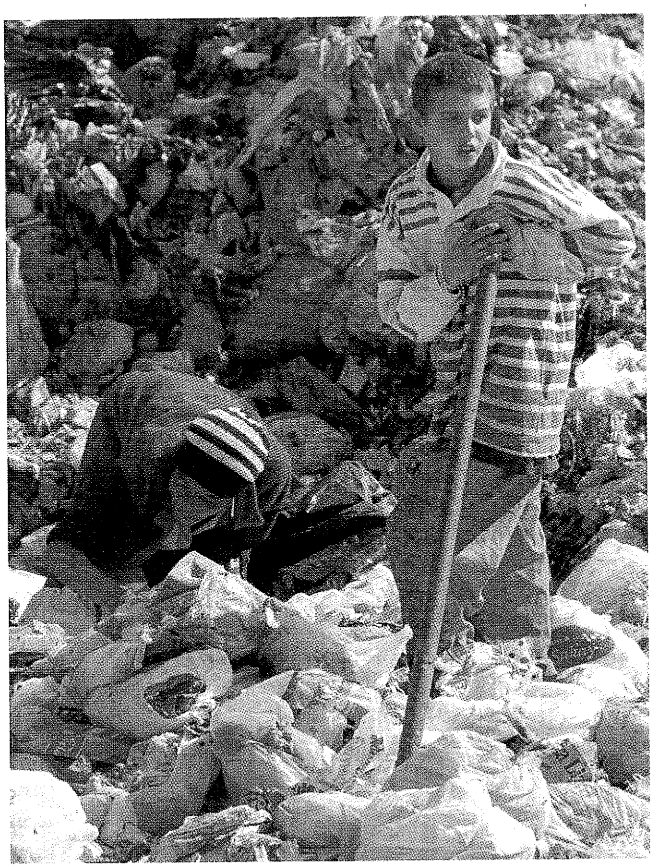
Some consumers demonstrate obvious unconcern for the environment by discarding waste along roadsides and sidewalks, where they cause visual pollution. But even consumers who carefully dispose of solid waste are contributing to a major pollution problem. A particularly severe threat is posed by the careless 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 70 percent 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.

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.

Eventually, landfills fill up. To preserve landfill space, many communities prohibit discarding bulky yard waste like grass clippings, weeds, and leaves. Many communities have closed them. Few new ones are being built, because landfills can contaminate groundwater and devalue property, and no one wants to live near one.



Garbage dump outside São Paulo, Brazil. Poor children pick through the garbage for items that can be used or sold.

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

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 quarter century.

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

Toxic Pollutants

Disposing of toxic wastes is especially difficult. 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.

Toxic wastes include heavy metals (including mercury, cadmium, and zinc), PCB oils from electrical equipment, cyanides, strong solvents, acids, and caustics. 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 2.5 billion kilograms (6 billion pounds) of toxic chemicals are discharged in the United States. About one-fourth of the discharges are by ten companies (DuPont, Monsanto, American Cyanimid, B.P. America, Renco Holdings, 3M, Vulcan Materials, General Motors, Eastman Kodak, and Phelps Dodge).

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. Discharging of unwanted byproducts into the environment can be replaced with recycling of them into resources.

Renewing Resources

Energy poses an especially strong challenge in substituting renewable resources for nonrenewable ones. Although renewable resources can be harnessed for energy, continued reliance on the three main nonrenewable fossil fuels—petroleum, natural gas, and coal—continues to be the cheaper alternative.

About 6 percent of energy consumed in the United States is generated by renewable sources. Biomass accounts for more than 50 percent and hydroelectric more than 40 percent. Other renewable energy sources include geothermal, fusion, and solar. Fusion is not a practical source at this time, but may be in the future.

Solar Energy

Solar energy supplied by the Sun is the ultimate renewable resource. The Sun's remaining life is estimated at 5 billion years, and humans appear incapable of destroying or depleting that resource. The Sun's energy is free and ubiquitous and cannot be exclusively owned, bought, or sold by any particular individual or enterprise. Utilizing the Sun as a resource does not damage the environment or cause pollution, as does extraction and burning of nonrenewable fossil fuels.

Passive Solar Energy. Solar energy is harnessed through either passive or active means. **Passive solar energy systems** capture energy without special devices. Passive solar energy systems use south-facing windows and dark surfaces to heat and light buildings on sunny days. The Sun's rays penetrate the windows and are converted to heat. Humans act as passive solar energy collectors when they are warmed by sunlight. Dark objects absorb more energy, so wearing dark clothing warms a person even more when exposed to sunlight.

Reliance on passive solar energy increased during the nineteenth century when construction innovations first permitted hanging of massive glass "curtains" on a thin steel frame. One popular type of building that utilized the new glass and steel technology in the nineteenth century was the greenhouse, in which people could grow and view vegetation that required more warmth to flourish than the local climate permitted. Early skyscrapers made effective use of passive solar energy.

With electricity and petroleum cheap and abundant, passive solar energy did not play a major role in construction of homes and commercial buildings through most of the twentieth century. Consumers looked for alternative energy sources during World War II when fossil fuels were rationed. A major glass manufacturer Libbey-Owens-Ford Glass Co. responded by publishing a book *Your Solar House* in 1947. But resumption of abundant supplies of cheap petroleum after World War II killed consumer demand for solar energy and conservation for a generation.

Interest in passive solar energy resumed when petroleum prices rapidly escalated during the 1970s. The largest contributor to increased use of passive solar energy has been through advances in glass technology. including double and triple pane windows with much higher insulating values, low-E (low emissivity) glass coated to let heat in but not out, windows filled with argon or other gases to increase insulating values beyond windows with just air, and phase-change technologies that can switch from opaque to translucent when a voltage is applied to them.

Active Solar Energy. Active solar energy systems collect solar energy and convert it either to heat energy or to electricity. The conversion can be accomplished either directly or indirectly.

In direct electric conversion, solar radiation is captured with **photovoltaic cells**, which convert light energy to electrical energy. Bell Laboratories invented the photovoltaic cell in 1954. Each cell generates only a small electric current, but large numbers of them wired together produce significant electricity.

Photovoltaic cells are made primarily of silicon, the second most abundant element in Earth's crust, also used in computers. When the silicon is combined with one or more other materials, it exhibits distinctive electrical properties in the presence of sunlight, known as the photovoltaic effect. Electrons excited by the light move through the silicon, producing direct current (DC) electricity.

In indirect electric conversion, solar radiation is first converted to heat, then to electricity. The Sun's rays are concentrated by reflectors onto a pipe filled with synthetic oil. The heat from the oil-filled pipe generates steam to run turbines. In heat conversion, solar radiation is concentrated with large reflectors and lenses to heat water or rocks. These store the energy for use at night and on cloudy days. A place that receives relatively little sunlight can still use solar energy by using more reflectors and lenses and larger storage containers.

Other Energy Sources

Other energy sources include hydroelectric, geothermal, biomass, and fusion. The first three are currently used but offer limited prospects for expansion. Fusion is not a practical source at this time but may be in the future.

Hydroelectric Power. Water has been a source of mechanical power since before recorded history. It turned water wheels, and the rotational motion was used to grind grain, saw timber, pump water, and operate machines. Over the last hundred years the energy of moving water has been used to generate electricity, called **hydroelectric power**.

Hydroelectric power is the world's second-most popular source of electricity, after coal, supplying about one-fourth of worldwide demand. The United States, though, obtains only about 3 percent of its energy through hydroelectric power, and little growth is anticipated, because few acceptable sites to build new dams remain.

Hydroelectric power has drawbacks. Dams may flood formerly usable land, cause erosion, and upset ecosystems. Political problems can result from building dams on rivers that flow through more than one country. Turkey's recently built dam on the Euphrates River was strongly opposed by Syria and Iraq, through which the river also passes. The new dam diverts too much water from the river and makes its water saltier.

Geothermal Energy. Earth's interior is hot from natural nuclear reactions. Toward the surface, heat is especially pronounced in volcanic areas. The hot rocks can encounter groundwater, producing heated water or steam that can be tapped by wells. Energy from this hot water or steam is called **geothermal energy**.

Harnessing geothermal energy is most feasible at the rifts along Earth's surface where crustal plates meet. These rifts also are the sites of many earthquakes and volcanoes. Geothermal energy is being tapped in several locations, including California, Italy, New Zealand, and Japan, and other rift sites are being explored. Iceland and Indonesia make extensive use of this resource. Ironically, in Iceland, an island named for its glaciers, nearly all homes and businesses in the capital of Reykjavik are heated with geothermal steam.

Biomass. Forms of biomass, such as sugarcane, corn, and soybeans, can be processed into motor vehicle fuels. Brazil in particular makes extensive use of biomass to fuel its cars and trucks. Potential for increasing the use of biomass for fuel is limited for several reasons. Burning biomass may be inefficient, because the energy used to produce the crops may be as much as the energy supplied by the crops. When wood is burned for fuel instead of being left in the forest, the fertility of the forest may be reduced. The most important limitation on using biomass for energy is that it already serves other essential purposes: providing much of Earth's food, clothing, and shelter.

Nuclear Fusion. Some nuclear power problems could be solved with nuclear **fusion**, which is the fusing of hydrogen atoms to form helium. Fusion releases spectacular amounts of energy—a gnat-sized amount of hydrogen releases the energy of thousands of tons of coal. But fusion can occur only at very high temperatures (millions of degrees). Such high temperatures have been briefly achieved in hydrogen bomb tests but not on a sustained basis in a power-plant reactor, given present technology.

Alternatives such as fusion do not offer immediate solutions to energy shortages in the twenty-first century but may become more practical if the price of current energy sources substantially rises. Earth possesses a variety of energy resources, but the era of dependency on nonrenewable fossil fuels for energy will constitute a remarkably short period of human history.

Uses for Renewable Energy

Efforts to utilize more renewable energy are focused on two sectors: electricity and motor vehicles. Alternatives to fossil fuels are currently available in both cases, though the cost is too high to be competitive in most situations.

Electricity. In MDCs, solar energy is used primarily as a substitute for electricity in heating water. Rooftop devices collect, heat, and store water for apartment buildings in Israel and Japan and individual homes in the United States. Solar-generated electricity is used in spacecraft, light-powered calculators, and at remote sites where conventional power is unavailable, such as California's Mojave Desert.

Solar power can be produced at a central station and distributed by an electric company, as coal- and nuclear-generated electricity is now supplied. However, public and private utility companies have had little interest in solar technology with coal still relatively cheap and investment in nuclear facilities already substantial. Initial cost of installing a solar water heater is higher than hooking into the central power system, but may be justified if an individual plans to stay in the same house for a long time.

The largest and fastest growing market for photovoltaic cells are the two billion people who lack electricity in LDCs, especially residents of remote villages. For example, in Kenya, more homes have been electrified in recent years using photovoltaic cells than by hooking up to the central power grid. In Morocco, solar panels are sold in bazaars and open markets, next to carpets and tinware.

The cost of cells must drop and their efficiency must improve for solar power to expand rapidly, with or without government support. Solar energy will become more attractive as other energy sources become more expensive. A bright future for solar energy is indicated, for petroleum companies now own the major U.S. manufacturers of photovoltaic cells.

Motor Vehicles. The most serious obstacle to decreasing reliance on nonrenewable energy is its importance as automotive fuel. Electric vehicles have been introduced to the market in recent years but have been withdrawn. Emphasis is now being placed on fuel cell technology.

Of the 4,000 cars sold in the United States in 1900, 38 percent were powered by electricity, 40 percent by steam, and only 22 percent by gasoline. The electric car was especially popular in large cities of the Northeast, such as New York and Philadelphia, where their relative quietness and cleanliness made them popular as taxicabs. Women also preferred electric cars because they were easier to start than gasoline- or steam-powered ones.

The main shortcomings of the electric car in 1900 remain unchanged a century later. Compared to gasoline, the electric-powered vehicle has a more limited range and costs more to operate. The use of electric vehicles is expanding in MDCs, primarily to reduce air pollution rather than to conserve the nonrenewable resource of petroleum.

Limitations with electric power have led motor-vehicle producers to consider fuel cells instead. Fuel cells convert hydrogen and oxygen into water, producing electricity and heat in the process. The electricity can be used to power motors or other electrical devices.

The oxygen for the fuel cell reaction comes from the air so is free and ubiquitous. Obtaining the hydrogen is more problematic. Hydrogen can be extracted from natural gas, propane, methanol, and other fuels, but the process generates heat and other gases and depends on nonrenewable sources. Getting tanks of liquid or gaseous hydrogen to motorists will require a new distribution system.

As long as petroleum is perceived as cheap and unlimited in supply, alternative fuel vehicles have limited popularity. It will take a major increase in world petroleum prices or disruption in supplies to bring alternative fuel vehicles to the market in large numbers. If that happens, by the middle of the twenty-first century large gasoline-powered vehicles would be limited to specialized tasks—or consigned to museums.

Recycling Resources

Unwanted byproducts are usually "thrown away," perhaps in a "trash can." **Recycling** is the separation, collection, processing, marketing, and reuse of the unwanted material. Recycling increased in the United States from 7 percent of all solid waste in 1970 to 10 percent in 1980, 17 percent in 1990, and 28 percent in 1999.

As a result of recycling, about 64 million of the 230 million tons of solid waste generated in the United States in 1999 did not have to go to landfills and incinerators, compared to 34 million of 200 million tons generated in 1990. In other words, the amount of solid waste generated by Americans increased by 30 million tons during the 1990s, and all of that additional waste was recycled.

The percentage of recovered materials varies widely by product: 97 percent of discarded auto batteries are recycled, compared to only 2 percent of plastics. Recycling is done on about 40 percent of plastic soft-drink bottles, 42 percent of paper, 55 percent of aluminum beer and soft-drink cans, 57 percent of steel packaging, and 52 percent of major appliances.

Recycling Collection

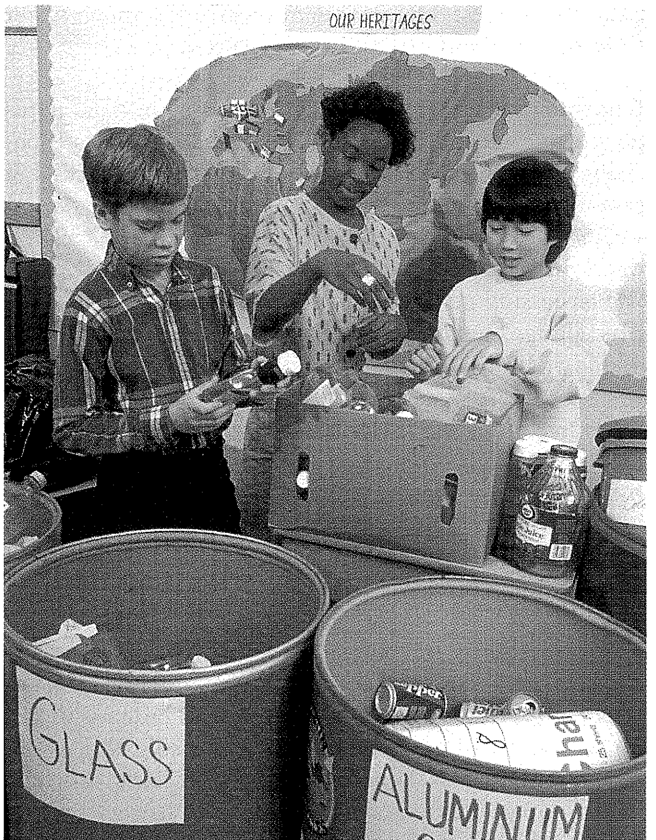
Recycling involves two main series of activities. First, materials that would otherwise be "thrown away" are collected and sorted. Then the materials are manufactured into new products for which a market exists.

Pick-up and Processing. Recyclables are collected in four primary methods: curbside, drop-off centers, buy-back centers, and deposit programs.

Curbside programs require consumers to place recyclables at the curb in a separate container than the nonrecycled trash at a specified time each week, either at the same or different time as the other trash. The trash collector usually supplies homes with specially marked containers for the recyclable items.

Drop-off centers are sites for individuals to leave recyclable materials, typically several large containers placed a central location. A separate container is designated for each type of recyclable material. The containers are periodically emptied by a processor or recycler but otherwise are left unattended.

Buy-back centers are commercial operations that pay consumers for recyclable materials, especially aluminum cans, but also sometimes plastic containers and glass



Recycling. Separating waste and recycling as much as possible is a way that each individual can make a difference in environmental quality, and it can be taught at a young age, such as this sixth-grade class.

bottles. These materials are usually not processed at the buy-back center.

Deposit programs involve return of glass and aluminum containers to retailers. The price a consumer pays for a beverage includes a deposit fee of 5¢ or 10¢, which the retailer refunds when the container is returned.

Regardless of the collection method, recyclables are sent to a materials recovery facility to be sorted and prepared into marketable commodities for manufacturing. Recyclables are bought and sold just like any other commodity: typical prices in recent years have included 10¢ per pound for plastic, $30 per ton for clear glass, $50 per ton for newspaper, $60 per ton for used steel cans, and $165 per ton for computer paper. Prices for the materials change and fluctuate with the market.

Manufacturing. Once cleaned and separated, the recyclables are ready to be manufactured into a marketable product. Four major manufacturing sectors accounted for more than half of the recycling activity: paper mills, steel mills, plastic converters, and iron and steel foundries.

Common household items that contain recycled materials include newspapers and paper towels; aluminum, plastic, and glass soft drink containers; steel cans; and plastic laundry detergent bottles. Recycled materials also are used in such industrial applications as recovered glass in roadway asphalt ("glassphalt") or recovered plastic in carpeting, park benches, and pedestrian bridges.

Most types of paper can be recycled. Newspapers have been recycled profitably for decades, and recycling of other paper is growing, especially computer paper. Rapid increases in the price of virgin paper pulp prices have stimulated construction of more plants capable of using waste paper. The key to recycling is collecting large quantities of clean, well-sorted, uncontaminated, and dry paper.

The principal obstacle to recycling of plastic is that plastic types must not be mixed, yet it is impossible to tell one type from another by sight or touch. Even a small amount of the wrong type of plastic can ruin the melt. The plastic industry has responded to this problem by developing a series of numbers marked inside triangles on the bottom of containers. Types 1 and 2 are commonly recycled, the others generally are not.

Glass is 100 percent recyclable and can be used repeatedly with no loss in quality. The process of creating new glass from old is also extremely efficient, producing virtually no waste or unwanted byproducts. However, although unbroken clear glass is valuable, mixed color glass is nearly worthless and broken glass is hard to sort.

Scrap aluminum is readily accepted for recycling, although other metals are rarely accepted. The principal source of recycled aluminum is beverage containers. Aluminum cans began to replace glass bottles for beer during the 1950s and for soft drinks during the 1960s.

Other Pollution by Reduction Strategies

In addition to recycling, two other basic strategies can reduce pollution. The amount of waste discharged into the environment can be reduced, or the capacity of the environment to accept discharges can be expanded.

Reducing Discharges. Pollution can be prevented if the amount of waste being discharged into the environment is reduced to a level that the environment can assimilate. Although consumers purchase more "throw-away" packages than in the past, the packaging material itself is much less bulky. Glass bottles weigh less today than a generation ago, as do plastic jugs. Higher manufacturing and shipping costs following the 1973 energy crisis induced companies to cut costs by reducing the bulk of their packaging.

The mix of various inputs can be adjusted to produce a higher ratio of product to waste. For example, gasoline for motor vehicles once contained lead. But most of the lead was discharged through the exhaust pipe and contributed to air pollution. To reduce the generation of lead—once a significant waste—automakers modified engines so that they operate on unleaded instead of leaded gasoline.

The amount of waste can also be reduced if the production system produces less of the product—or if production ceases altogether—because of lower consumer demand. The creation of fewer products would result in the production of less waste as well. If consumers drive less, then they will use less gasoline and therefore generate less pollution.

Emissions-trading systems can reduce discharges, especially into the atmosphere. To reduce sulfur dioxide discharges, the United States introduced a market through an amendment to the 1990 Clean Air Act. Power companies can buy and sell allowances to emit sulfur dioxide. Dirty power companies have found it cheaper to install pollution control devices to reduce pollution and sell some of their allowances. In Canada, Ontario's emissions reduction trading sets emissions caps and creates a market for trading allowances and credits within the caps.

The Chicago Climate Exchange opened in 2003 to promote reduction of greenhouse gases. Companies participating in the Chicago Climate Exchange set voluntary targets for emissions reduction. If the company exceeds its targets it can trade or sell the excess reduction to another participating company that isn't meeting its targets.

Increasing Environmental Capacity. The second way to handle pollution is to increase the capacity of the environment to accept the discharges. The capacity of air, water, and land to accept waste is not fixed, but varies among places and at different times.

Adding a particular amount of wastewater to a stream may or may not constitute pollution, depending on the flow of the water. A deep, fast-flowing river has a greater capacity to absorb wastewater than a shallow, slow-moving one. Wastewater can be stored when the river level is low and released when the river is high.

Similarly, exhaust released into stagnant air irritates, whereas exhaust released in windy conditions is quickly dispersed. Industries and utilities reduce local air pollution by building taller smokestacks, which better disperse gases at greater heights.

Environmental capacity can also be increased by transforming the waste so that it is discharged into a resource that has the capacity to assimilate it. Matter can be transformed among gaseous, liquid, and solid states and discharged into air, water, or land.

For example, a coal-burning power plant can discharge gases into the atmosphere, causing air pollution. To reduce air pollution, wet scrubbers are installed to wash particulates from the gas before it is released to the atmosphere. Wet scrubbers capture the particulates in water, which then can be discharged into a stream. If the stream is polluted by the discharge, then the wastewater can be cleaned in a settling basin where the particulates drop out. This transforms the residue into a solid waste for disposal on land.

A Coking Plant: Using All Reduction Strategies

A coking plant provides an example of applying all pollution-reduction strategies—recycling, reducing discharges, and increasing environmental capacity (Figure 14–15). The main input into a coking plant is a mixture of coal types, and the intended product is coke, which becomes an input in steel production. The coal is placed in a blast furnace and cooked at very high temperatures to form coke. Four unwanted byproducts result: gases, tars, oils, and heat.

Discharging the heat into the environment can cause air pollution. To reduce air pollution from the heat, a coking plant increases the capacity of the environment to accept discharges in two ways. First, the hot coke is taken to a quench station and doused with water to cool it. This process transforms the residual (hot gas) into a liquid (dirty water) as well as another gas (steam). In this way, the waste is transformed and discharged into different parts of the environment. Then the steam is discharged into the environment from a tall smokestack, an example of making more efficient use of whatever initially received the discharge (air).

The coking plant also minimizes pollution by reducing discharges. The dirty water produced at the quench station is reused to cool more hot coke, an example of recycling in the same production process. Meanwhile, the three unwanted byproducts from the blast furnace (other than heat)—gases, tars, and oils—are captured and sold to other companies for recycling in other processes. The other alternative for reducing discharges—changing the mix of coal used as inputs—is also employed, because the amount of gases emitted by the burning of coke varies depending on the mix of coal.

Comparing Pollution Reduction Strategies

Relying on an increase in the capacity of the environment to accept discharges is risky. Because we do not always know the environment's capacity to assimilate a particular waste, we are likely to exceed it at times. Recent history is filled with examples of wastes discharged in the environment with the belief that they would be dispersed or isolated safely: CFCs in the stratosphere, garbage offshore, and toxic chemicals beneath Love Canal.

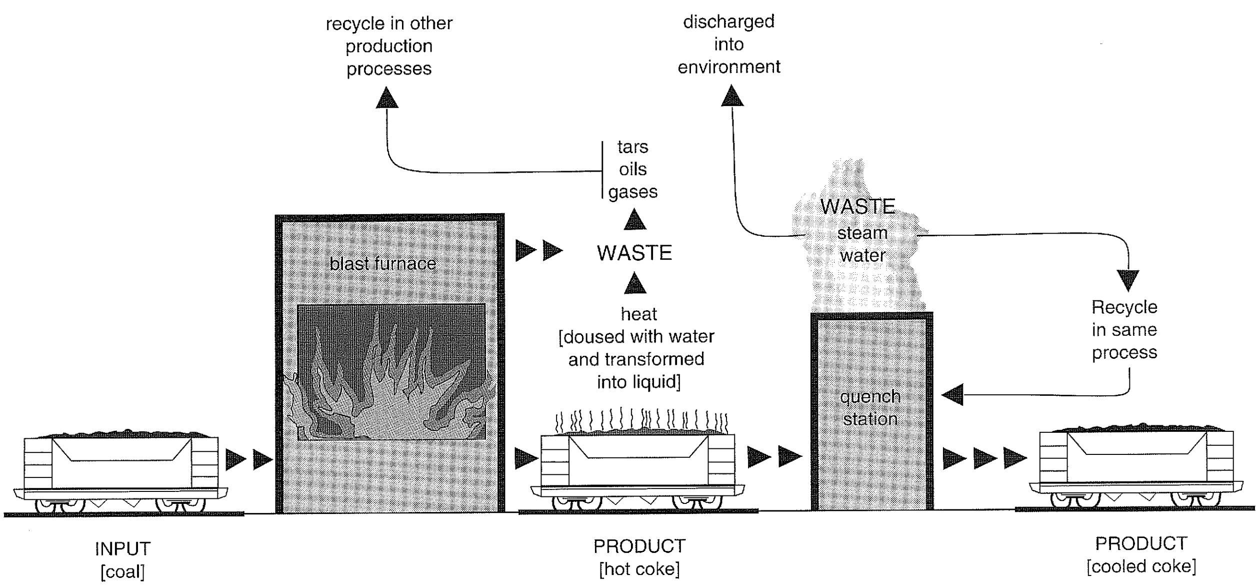


FIGURE 14–15 *A coking plant, used for steelmaking, illustrates the application of principal alternatives for reducing pollution:*

1. *Recycle discharge (by reusing quenching water).*
2. *Reduce discharges of waste (by purchasing cleaner-burning coal).*
3. *Increase environmental capacity.*
   a. *Use current resources more efficiently (use taller smokestack for discharging steam).*
   b. *Discharge elsewhere into environment (transform heat into liquid and gaseous residuals).*

Dispersed wastes may remain harmful. Tall smokestacks built to reduce sulfur dioxide discharges around coal-burning industries and metal smelters were successful at dispersing sulfur over a larger area. But the result of the dispersal was that acid precipitation (containing sulfur) fell hundreds of kilometers away, polluting vegetation and lakes over a wide area.

Many pollutants are mobile. They often travel from air to soil, or soil to water. A pollutant like sulfur dioxide might exist at tolerable levels in the air, but it damages trees when it accumulates in the soil. In view of the many uncertainties associated with increasing environmental capacity, reducing discharges into the environment (by either changing the production process or recycling) is usually the preferred alternative.

Although the environment has the capacity to accept some discharges, consumers must learn to use this environmental capacity most efficiently. At the same time, consumers must learn to waste less, either by reducing the consumption of products that result in waste or by recycling more. With careful management, we can enjoy the benefits of both industrial development and a cleaner, safer environment.

KEY ISSUE 4

Why Can Resources Be Conserved?

- Sustainable development
- Biodiversity

Because it is one part natural science and one part social science, geography is especially sensitive to the importance of protecting the natural environment while meeting human needs. "Conservation" is a concept that reflects balance between nature and society.

Conservation is the sustainable use and management of natural resources such as wildlife, water, air, and Earth deposits to meet human needs, including food, medicine, and recreation. Renewable resources such as trees are conserved if they are consumed at a less rapid rate than they can be replaced. Nonrenewable resources such as fossil fuels are conserved if remaining reserves are maintained for future generations.

Conservation differs from **preservation**, which is maintenance of resources in their present condition, with as little human impact as possible. The value of nature does not derive from human needs and interests, but from the fact that every plant and animal living on Earth has a right to exist and should be preserved regardless of the cost.

The concept of preservation does not regard nature as a resource for human use. In contrast, conservation is compatible with development but only if natural resources are utilized in a careful rather than a wasteful manner. An increasingly important approach to careful utilization of resources is sustainable development, based on promotion of biodiversity.

Sustainable Development

Sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs," according to the United Nations. Through sustainable development, humans can improve their quality of life while protecting Earth's resources for the benefit of future generations.

The concept of sustainable development is based on limiting the use of renewable resources to the level at which the environment can continue to supply them indefinitely. The amount of timber cut down in a forest or the number of fish removed from a body of water can be controlled at a level that does not reduce future supplies.

Sustainability and Economic Growth

The UN's "sustainable development" was defined in the 1987 Brundtland Report, named for the World Commission on Environment and Development's chair, Gro Harlem Brundtland, former Prime Minister of Norway. Titled *Our Common Future*, the Brundtland Report was a landmark in recognizing sustainable development as a combination of environmental and economic elements.

The Brundtland Report argued that sustainable development had to recognize the importance of economic growth while conserving natural resources. Environmental protection, economic growth, and social equity are linked because economic development aimed at reducing poverty can at the same time threaten the environment.

Plans to protect the environment would fail unless LDCs could promote economic growth in order to meet basic needs of employment, food, energy, water, and sanitation. "Environment and development are not separate challenges: they are inexorably linked," concluded the Brundtland Report. "Development cannot exist on a deteriorating environmental base; the environment cannot be protected when growth leaves out of account the costs of environmental protection."

A rising level of economic development generates increased pollution, at least until a country reaches a GDP of about $5,000 per person, according to economists Gene Grossman and Alan Krueger (Figure 14–16). In the early stages of industrialization, pollution-control devices are an unpopular luxury that makes cars and other consumer goods more expensive. Consequently, twentieth-century environmental improvements in the more developed countries of North America and Western Europe are likely to be offset by increased pollution in LDCs during the twenty-first century.

The Brundtland Report was optimistic that environmental protection could be promoted at the same time as economic growth and social equity. By gradually changing development practices, economic growth, and social equity can be made compatible with protecting the environment and conserving resources.

In recent years the World Bank and other international development agencies have embraced the concept of sustainable development. Planning for development

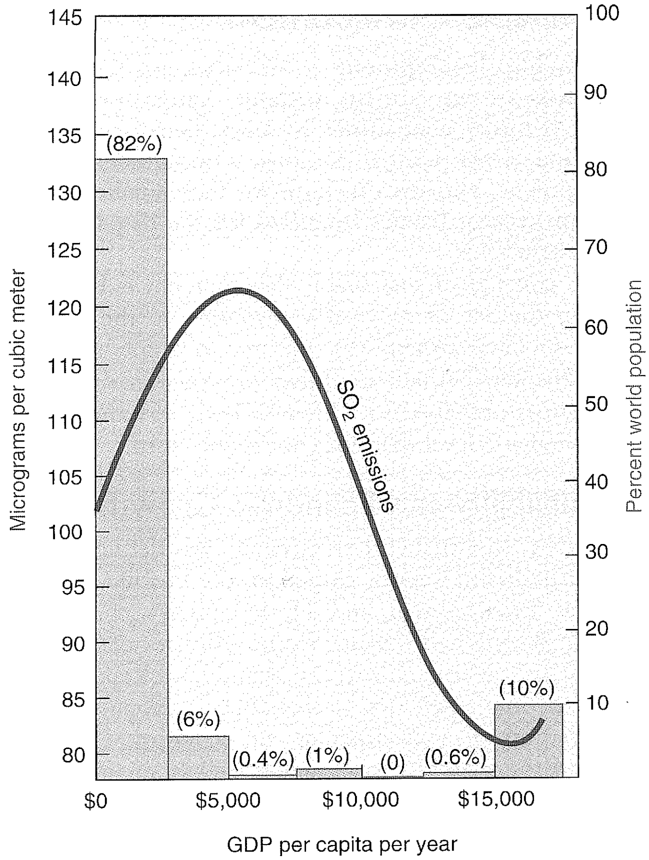


FIGURE 14-16 *Pollution compared to a country's wealth. As a country's GDP per capita increases, discharge of sulfur dioxide increases, until GDP reaches about $5,000. Then, discharges tend to decrease as a country begins to spend money on pollution-control devices. The green bars show the percentage of people in each GDP per capita group.*

involves consideration of many more environmental and social issues today than was the case in the past.

Sustainability's Critics

Some environmentally oriented critics have argued that it is too late to discuss sustainability. The World Wildlife Federation (WWF), for example, claims that the world surpassed its sustainable level around 1980.

The WWF Living Planet Report reaches its pessimistic conclusion by comparing the amount of land that humans are currently using with the amount of "biologically productive" land on Earth. "Biologically productive land" is defined as the amount of land required to produce the resources currently consumed and handle the wastes currently generated by the world's 6-plus billion people at current levels of technology.

The WWF calculates that humans are currently using about 13 hectares of Earth's land area, including 3 billion hectares for cropland, 2 billion for forest, 7 billion for energy, and 1 billion for fishing, grazing, and built-up areas. However, according to the WWF, Earth has only 11.4 hectares of biologically productive land, so humans are already using all of the productive land and none is left for future growth.

Other criticize sustainability from the opposite perspective: human activities have not exceeded Earth's capacity, because resource availability has no maximum. Earth's resources have no absolute limit, because the definition of resources changes drastically and unpredictably over time. Environmental improvements can be achieved through careful assessment of the outer limits of Earth's capacity.

Critics and defenders of sustainable development agree that one important recommendation of the UN report has not been implemented: increased international cooperation to reduce the gap between more developed and less developed countries. Only if resources are distributed in a more equitable manner can LDCs reduce the gap with MDCs in level of development.

Biodiversity

Biological diversity, or **biodiversity** for short, refers to the variety of species across Earth as a whole or in a specific place. Biodiversity is an important development concept because it is a way of summing the total value of Earth's resources available for human use. Sustainable development is promoted when biodiversity of a particular place or Earth as a whole is protected.

Biological and Geographic Biodiversity

Species variety can be understood from several perspectives. Geographers are especially concerned with biogeographic diversity, whereas biologists are especially concerned with genetic diversity. For biologists, biodiversity refers particularly to the maintenance of genetic diversity within populations of plants and animals. Genetic diversity embraces species variation in genetic material, such as genes and chromosomes.

Scientists have classified about 2.5 million species, including 900,000 insects, 41,000 vertebrates, and 250,000 plants, and more than a million invertebrates, fungi, algae, and microorganisms. About 1.4 million species have been given names. Estimates of Earth's total number of species range from 3 to 100 million, with 10 million as a median "guess," meaning that humans have not yet "discovered," classified, and named most of Earth's species.

New species are constantly being identified—for example, three new bird species are found annually—but human actions are exterminating species more rapidly than they are "discovering" new ones. Human actions are responsible for the extinctions by destroying habitats, primarily through pollution of air and water, removal of existing plants and animals, and introduction of foreign or exotic species.

For geographers, biodiversity is measurement of the number of species within a specific region or habitat. A community containing a large number of species is said to be species-rich, whereas an area with few species is species-poor.

Two communities may have the same number of species and the same total population of individuals, yet one may be more diverse than the other, depending on the distribution of the total population among the various species. A community with a large population of many species is regarded as more diverse than a community that contains a preponderance of one species and a very small number of all of the others.

Strategies to protect genetic diversity have been established on a global scale. Some endangered species have been protected by the Convention on International Trade in Endangered Species of Wild Fauna and Flora. Examples include curtailing of logging, whaling, and taking of porpoises in tuna seines (nets).

Strategies to protect biogeographic diversity vary among countries. Luxembourg protects 44 percent of its land and Ecuador 38 percent, whereas Cambodia, Iraq, and some former Soviet Union republics have no land under conservation.

Frustrated by the inability to precisely measure environmental impacts, Millennium Ecosystem Assessment has undertaken a multiyear effort to establish systematic data sets. Heavy reliance is placed on remote sensing and satellite mapping to establish data sets, such as in Namibia where satellite imagery is used to count and map the distribution of elephants, and in Mali where farmers receive satellite updates about storms on hand-wound radios.

Biodiversity in the Tropics

Reduction of biodiversity through species extinction is especially important in tropical forests. Three species per hour are extinguished in the tropics, and more than 5,000 species are considered in danger of extinction.

Tropical forests occupy only 7 percent of Earth's land area but contain more than one-half of the world's species, including two-thirds of vascular plant species and one-third of avian species. The characteristics of the tropical forest biome contribute to the presence of more species than in temperate or polar biomes. Higher temperatures, greater climate predictability, and longer growing seasons all create a more inviting habitat for a greater diversity of species.

At a small scale, a single stand of 19 trees in Panama examined in 1980 yielded 1,200 beetle species, 80 percent previously unknown. One gram of tropical soil can hold 90 million bacteria and other microbes.

The principal cause of the high rate of extinction is cutting down forests. Rapid deforestation results from changing economic activities in the tropics, especially a decline in shifting cultivation (see Chapter 10). Under shifting cultivation, a small portion of the forest is cleared to plant for a couple of years then left to regenerate over a couple of decades. Shifting cultivation is being replaced by logging, cattle ranching, and cultivation of cash crops. These alternatives require cutting down vast expanses of forest.

Governments in developing countries support the destruction of rain forests, because they view activities such as selling timber to builders or raising cattle for fast-food restaurants as more effective strategies for promoting economic development than shifting cultivation. Until recently, the World Bank has provided loans to finance development proposals that require clearing forests.

Shifting cultivation is also regarded as a relatively inefficient approach to growing food in a hungry world. The problem with shifting cultivation compared to other forms of agriculture is that it can support only a low level of population in an area without causing environmental damage.

Tropical rain forests are disappearing at the rate of 10 to 20 million hectares (25 to 50 million acres) per year. The amount of Earth's surface allocated to tropical rain forests has been reduced to less than one-half of its original area during the past quarter century, and unless drastic measures are taken, the area will be reduced by another one-fifth within a decade. Only 6 percent of Earth's forests are protected, leaving the remaining 33 million square kilometers (13 million square miles) vulnerable.

SUMMARY

We have examined problems of depletion and degradation of Earth's resources. The distribution of resources, as well as patterns of use and abuse, vary locally. But actions with regard to resources in one region can affect people everywhere.

Some scientists believe that further depletion and destruction of Earth's resources will lead to disaster in the near future. A quarter century ago a group of scientists known as the Club of Rome presented a particularly influential statement of this position in a report titled *The Limits to Growth*. According to these scientists, many of whom were professors at the Massachusetts Institute of Technology, the combination of population growth, resource depletion, and unrestricted use of industrial technology will disrupt the world's ecology and economy and lead to mass starvation, widespread suffering, and destruction of the physical environment.

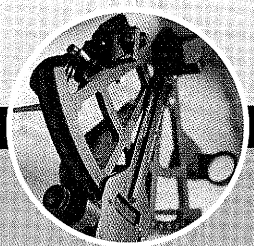
In a recent update, the authors argued that environmental destruction is proceeding at a more rapid rate than they had originally thought. If new sets of attitudes and policies toward environmental protection are not in place within 20 years, the environment will be permanently damaged, and people's standards of living will fall.

The threat of irreparable global environmental damage is heightened by confrontation between more developed and less developed regions. The MDCs have achieved wealth in part by using large percentages of the world's resources and discharging large percentages of the world's pollutants. Now LDCs are being asked to promote economic development with greater sensitivity to the environment than today's MDCs showed in the past. People in MDCs are increasingly willing to allocate some of their wealth to clean up the environment. Subsistence farmers in LDCs cannot afford to invest in environmental protection.

Most geographers recognize that unrestricted industrial and demographic growth will have negative consequences, but they do not believe that the dire predictions of *The Limits to Growth* are inevitable. Human actions have depleted some resources, but substitutes may be available. Although pollution degrades the physical environment, industrial growth can be compatible with environmental protection. Demand for food is increasing, but human actions are also expanding the capacity of Earth to provide food.

Here again are the key issues in Chapter 14:

1. **Why are resources being depleted?** As we consume resources, we are depleting Earth's supply. Fossil fuels and minerals are distributed unevenly across Earth, and supplies are not found in places where demand is highest.
2. **Why are resources being polluted?** Human beings are damaging and destroying Earth's resources through pollution. Pollution is the discharge of waste at a rate that exceeds the environment's capacity to absorb it. Pollutants are discharged into the atmosphere, water, and onto land.
3. **Why are resources reusable?** Depletion and destruction of scarce resources can be minimized by converting from nonrenewable to renewable sources of energy and by recycling more unwanted waste.
4. **Why can resources be conserved?** Sustainable development promotes economic development while not reducing the world's current resource base. Especially important in conserving natural resources is to maintain biodiversity through minimizing species extinction in the development process.



CASE STUDY REVISITED

Future Directions

Mexico City has taken steps to reduce air pollution. The government closed a major employer, the PEMEX oil refinery, located in the northwestern region of Mexico City, because it was responsible for 7 percent of the city's air pollution. Cars have been banned from a 50-square-block central area, and motorists are not allowed to use their cars one day each week, depending on the last digit of the license plate. Cars must now have catalytic converters and use unleaded fuel, and older buses and taxicabs have been removed from service.

However, Mexico must pay a price for implementing these pollution controls. Closing the oil refinery hurt Mexico's economy, because not only were jobs lost but the country also had to import some fuel to replace the loss of the refinery's production. Motor vehicles are essential to economic development, because they allow people to get to work and businesses to deliver goods. And the number of vehicles in Mexico City has expanded because of the rapid population growth.

Rapid population growth means that rapidly growing cities in LDCs face pressure to expand economic opportunities and material benefits for the people, regardless of environmental impact. Stricter enforcement of pollution controls would require shutting down many businesses and eliminating jobs.

Geographers emphasize that each resource in the physical environment has a distinctive capacity for accommodating human activities. Just as a good farmer knows how many animals can be fed on a parcel of land, a scientist can pinpoint the constraints that resources place on population density or economic development in a particular region. With knowledge of these constraints, we will be able to maintain agricultural and industrial development in the future.

A generation ago environmentalists coined the phrase "Think global, act local" so that we would recognize that our actions in our own communities—and even in our own backyards—could affect the entire planet. Now geographers urge us to "think global *and* think local." In an age of globalization, we cannot lose sight of the importance and pleasure of the diversity of local physical conditions and human behavior. Think both global and local, and act wherever you can do some good.

KEY TERMS

Acid deposition (p. 491)
Acid precipitation (p. 491)
Active solar energy systems (p. 498)
Air pollution (p. 490)
Animate power (p. 475)
Biochemical oxygen demand (BOD) (p. 496)
Biodiversity (p. 504)
Biomass fuel (p. 475)
Breeder reactor (p. 485)
Chlorofluorocarbon (CFC) (p. 491)
Conservation (p. 503)
Ferrous (p. 487)
Fission (p. 483)
Fossil fuel (p. 476)
Fusion (p. 499)
Geothermal energy (p. 499)
Greenhouse effect (p. 490)
Hydroelectric power (p. 499)
Inanimate power (p. 475)
Nonferrous (p. 487)
Nonrenewable energy (p. 476)
Ozone (p. 491)
Passive solar energy systems (p. 498)

Photochemical smog (p. 493)
Photovoltaic cell (p. 498)
Pollution (p. 489)
Potential reserve (p. 477)
Preservation (p. 503)
Proven reserve (p. 476)
Radioactive waste (p. 483)
Recycling (p. 500)
Renewable energy (p. 476)
Resource (p. 475)
Sanitary landfill (p. 497)
Sustainable development (p. 503)

THINKING GEOGRAPHICALLY

1. What steps has your community taken to recycle solid waste and to conserve energy?
2. U.S. automakers must meet a standard for Corporate Average Fuel Efficiency (CAFE). This means that the average miles per gallon achieved by all models of a company's American-made cars must meet a government-mandated level. If they do not, the company must pay a stiff fine. Should the United States raise the CAFE standard to conserve fuel and reduce air pollution, even if the result is a loss of American jobs? Explain.
3. A recent study compared paper and polystyrene foam drinking cups. Conventional wisdom is that foam cups are bad for the environment, because they are made from petroleum and do not degrade in landfills. However, the manufacture of a paper cup consumes 36 times as much electricity and generates 580 times as much wastewater. Further, as they degrade in landfills, paper cups release methane gas, a contributor to the greenhouse effect. Which types of cups should companies such as McDonald's be encouraged to use? Why?
4. Pollution is a byproduct of producing almost anything. How can MDCs, which historically have been responsible for generating the most pollution, encourage LDCs to seek to minimize the adverse effects of pollution as they improve their levels of development?
5. Malthus argued 200 years ago that overpopulation was inevitable, because population increased geometrically while food supply increased arithmetically. Was Malthus correct? Why or why not?

ON THE INTERNET

The Internet exercises for our resource problems chapter (**www.prenhall.com/rubenstein**) revolve around the issues of fossil fuel use and depletion, alternative energy sources, and environmental pollution. Through our study exercises, we speculate on the African food resource base, and we provide a large number of maps dealing with resource problems in the world. Our **GeoSearch** page allows you to explore key terms in depth, and our **Destinations** page offers Web sites where additional information can be found regarding resource problems.

Statistics on production, consumption, and reserves of different energy sources can be found at the website of the U.S. Department of Energy's Energy Information Administration (**www.eia.doe.gov**). The U.S. Geological Survey provides information on air quality and minerals at **www.usgs.gov**. Maps of hazardous waste sites can be found through the Centers for Disease Control (**gis.cdc.gov/atsdr**).

FURTHER READINGS

Balling, Robert C., Jr. "The Geographer's Niche in the Greenhouse Millenium." *Annals of the Association of American Geographers* 90 (2000): 114–22.

Bickerstaff, K., and G. Walker. "The Place(s) of Matter: Matter Out of Place—Public Understandings of Air Pollution." *Progress in Human Geography* 27 (2003): 45–68.

Brown, Lester R., et al. *State of the World*. New York and London: W. W. Norton & Co., annually since 1984.

Buckingham, Hatfield, S. "Gender Equality: A Pre-Requisite for Sustainable Development." *Geography* 87 (2002): 227–33.

Bulkeley, Harriet. "Governing Climate Change: The Politics of Risk Society?" *Transactions of the Institute of British Geographers*, New Series 26 (2001): 430–47.

Buttimer, Anne, ed. *Sustainable Landscapes and Lifeways: Scale and Appropriateness*. Cork, Ireland: Cork University Press, 2001.

Commoner, Barry. *Making Peace with the Planet*. New York: New Press, 1990.

Cutter, Susan L., and William H. Renwick. *Exploitation, Conservation, Preservation: A Geographic Perspective on Natural Resource Use*. 4th ed. Dunvers, Mass.: John Wiley, 2004.

Ehrlich, Paul R., and Anne H. Ehrlich. *Betrayal of Science and Reason: How Anti-environmental Rhetoric Threatens Our Future*. Washington: Island Press, 1998.

Meadows, Donnela H., Dennis L. Meadows, Jorgen Randers, and William W. Behrens III. *The Limits to Growth*. 2d ed. New York: Universe Books, 1973.

National Geographic. *Energy: Special Report*. Washington, D.C.: National Geographic Society, 1981.

Turner, B. L., II, Robert W. Kates, and William C. Clark. *The Earth as Transformed by Human Action*. Cambridge: Cambridge University Press, 1990.

Also consult these journals: *Ecological Economics; Ecologist; Energy Journal; Energy Policy; Environment; Environmental Management; Environmental Pollution; Journal of Environmental Management; World Watch*.

Careers in Geography

CONCLUSION

An increasing number of students recognize that geographic education is practical as well as stimulating. Employment opportunities are expanding for students trained in geography, especially in teaching, government service, and business.

Teaching. A doctorate in geography was offered at 69 U.S. and 24 Canadian universities in 2000, and the master's was the highest available degree at 80 U.S. and four Canadian universities. Traditionally, most trained geographers became teachers in high schools, colleges, or universities.

A career as a geography teacher is promising, because schools throughout North America are expanding the amount of geography in the curriculum. Educators increasingly recognize geography's role in teaching students about global diversity.

Some university geography departments have emphasized good teaching over research; others are increasingly concerned with research. The Association of American Geographers includes several dozen specialty groups organized around research themes, including agricultural, industrial, medical, and transportation geography.

Government. Geographers contribute their knowledge of the location of activities, the patterns underlying the distribution of various activities, and the interpretation of data from maps and satellite imagery.

Some geographers find employment with cities, states, provinces, and other units of local government. Typically, these opportunities are found in departments of planning, transportation, parks and recreation, economic development, housing, zoning, or other similarly titled government agencies. Geographers may be hired to conduct studies of local economic, social, and physical patterns; to prepare information through maps and reports; and to help to plan the community's future.

Many national government agencies also employ geographers:

- The Department of Agriculture hires geographers in the Forest Service and Natural Resources Conservation Service to enhance environmental quality.
- The Department of Commerce hires geographers in the Bureau of the Census to study changing population trends and in the Economic Development Administration to promote rural development.
- The Department of Defense hires geographers in the Defense Intelligence Agency and the National Imagery and Mapping Agency to analyze satellite imagery.
- The Department of Energy hires geographers in the Office of Environmental Policy and Assistance to administer environmental protection programs.
- The Department of Housing and Urban Development hires geographers to help revitalize American cities.
- The Department of Interior hires geographers in the U.S. Geological Survey to study land use and create topographic maps.
- The Department of State hires geographers for foreign service.
- The Department of Transportation hires geographers to plan new transportation projects.

Business. An increasing number of American geographers are finding jobs with private companies. The list of possibilities is long, but here are some common examples.

- Developers hire geographers to find the best locations for new shopping centers.
- Real estate firms hire geographers to assess the value of properties.
- Supermarket chains, department stores, and other retailers hire geographers to determine the potential market for new stores.
- Banks hire geographers to assess the probability that a loan applicant has planned a successful development.
- Distributors and wholesalers hire geographers to find ways to minimize transportation costs.
- Transnational corporations hire geographers to predict the behavior of consumers and officials in other countries.
- Manufacturers hire geographers to identify new sources of raw materials and markets.
- Utility companies hire geographers to determine future demand at different locations for gas, electricity, and other services.

For more information on careers in geography, contact the Association of American Geographers in Washington, D.C., or the National Council for Geographic Education at Indiana University of Pennsylvania.