15

Mineral Resources

Aerial view of the Summitville, Colorado, mine.

The **General Mining Law of 1872** was intended to encourage settlement in the sparsely populated western states. It allows companies or individuals, whether U.S. citizens or foreigners, to stake mining claims on federal land. They then purchase the land for a fraction of its value, extract the valuable hardrock minerals such as gold, silver, copper, lead, or zinc, and keep all the profits. In return, a percentage of profits on lumber, coal, oil, and natural gas obtained from federal land is paid to the government.

The General Mining Law contains no provisions for environmental protection, such as the replacement of topsoil and vegetation or the reestablishment of biological habitat. As a result, hardrock mining has left a legacy of ravaged land, poisoned water, and lifeless ecosystems throughout the West. Acid draining from loose rocks produced during the mining process has made many streams and rivers totally lifeless.

More than 50 of the estimated 500,000 abandoned mines in the United States are designated Superfund sites. The U.S. government—that is, taxpayers—must finance the cleanup of these sites (see Chapter 23 for more on Superfund sites). For example, after a mining company extracted $105 million of gold from a mine in Summitville, Colorado (**see photograph**), it declared bankruptcy, leaving behind an environmental disaster. The EPA designated the Summitville mine as a Superfund site and has provided more than $210 million in cleanup efforts there, focusing on decontaminating polluted soil, preventing further contamination of creeks and streams, and protecting local farmland. Cleanup of all Superfund mining sites will cost billions of dollars.

In 1872, the same year that President Ulysses S. Grant signed the General Mining Law, Yellowstone was designated the first U.S. national park. During the 1990s, a proposed mine in Montana less than 5 km (3 mi) from the Yellowstone border threatened its pristine condition. A Canadian company (Noranda, Inc.) had the rights to this land, which was surrounded by federal wilderness lands, and the company planned to establish a gold, silver, and copper mine there. Opponents of the mine, including the superintendent of Yellowstone, worried that pollution from the mine would contaminate the Yellowstone River and the park. President Clinton stopped the mine by presidential order and negotiated with the Canadian company. In 1997 Noranda agreed to sell the property to the U.S. government.

During the early 2000s, mining reform was a contentious issue in Congress. A 2005 bill proposed that U.S. and foreign mining companies could purchase claims within national parks, national wilderness areas, and other federal lands. Public outcry led to this bill's failure. Legislative efforts in 2007 and 2009 to impose royalties on mining companies that would be used for site cleanup failed to pass through Congress.

In this chapter you will consider the distribution and abundance of minerals as well as the environmental damage from obtaining and processing them. You will also examine options for the future, when mineral deposits become depleted.

In Your Own Backyard...

Select a mineral that you use in your everyday life (for example, steel, aluminum, nickel, or gold) and research how and where it is mined.

Introduction to Minerals

LEARNING OBJECTIVES

- Define *minerals* and explain the difference between high-grade and low-grade ores, as well as between metallic and nonmetallic minerals.
- Describe several natural processes that concentrate minerals in Earth's crust.
- Distinguish between surface mining and subsurface mining.
- Briefly describe how mineral deposits are discovered, extracted, and processed.

mineral An inorganic solid, occurring naturally in or on Earth's crust, with characteristic chemical and physical properties.

Minerals are such an integral part of our lives that we often take them for granted. Steel, an essential building material, is a blend of iron and other metals. Beverage cans, aircraft, automobiles, and buildings all contain aluminum. Electrical and communications wiring contain copper, which readily conducts electricity. The concrete used in buildings and roads is made from sand and gravel as well as cement, which contains crushed limestone. Sulfur, a component of sulfuric acid, is an indispensable industrial mineral with many applications in the chemical industry. It is used to make plastics and fertilizers and to refine oil. Tantalum, a rare, hard metal that is resistant to corrosion, has become important to the production of capacitors in a range of electronic devices. Other important minerals include platinum, mercury, manganese, and titanium.

The human need and desire for minerals have influenced the course of history. Phoenicians and Romans explored Britain in a search for tin. One of the first metals that humans used, tin came into its own during the Bronze Age (3500 to 1000 B.C.E.), when tin and copper were combined to produce the tougher and more durable alloy, bronze. The desire for gold and silver was directly responsible for the Spanish conquest of the New World. In 1849, a gold rush in California led to the arrival of a large number of settlers from the eastern United States. More recently, the lure of gold in Amazonian and Indonesian rain forests has contributed to the destruction of indigenous homelands and ecosystems.

Earth's minerals are elements or (usually) compounds of elements that have precise chemical compositions. For example, **sulfides** are mineral compounds in which certain elements are combined chemically with sulfur, and **oxides** are mineral compounds in which elements are combined chemically with oxygen.

Rocks, which are aggregates, or mixtures, of one or more minerals, fall into three categories, based on how they formed: igneous, sedimentary, and metamorphic. **Igneous rocks** form when magma rises from the mantle and cools. **Sedimentary rocks** form when small fragments of weathered, eroded rocks (or marine organisms) are deposited, compacted, and cemented together. **Metamorphic rocks** form when intense heat and pressure alter igneous, sedimentary, or other metamorphic rocks.

rock cycle The cycle of rock transformation that involves all parts of Earth's crust.

In the **rock cycle**, rock moves from one physical state or location to another (**Figure 15.1**). The rock cycle continually forms, modifies, transports, and destroys igneous, sedimentary, and metamorphic rocks. For example, igneous rocks form deep in Earth's crust and are uplifted to the surface. Weathering and erosion wear these rocks down to sediments, which eventually solidify into sedimentary rock. The rock cycle is similar to other cycles of matter, such as the carbon and hydrologic cycles (see Chapter 4). However, rocks are formed and move through the environment much more slowly than the elements of other cycles.

Rocks have varied chemical compositions. An **ore** is rock that contains a large enough concentration of a particular mineral to be profitably mined and extracted. **High-grade ores** contain relatively large amounts of particular minerals, whereas **low-grade ores** contain lesser amounts.

Minerals are metallic or nonmetallic (**Table 15.1**). **Metals** are minerals such as iron, aluminum, and copper, which are malleable, lustrous, and good conductors of heat and electricity. **Nonmetallic minerals**, such as sand, stone, salt, and phosphates, lack these characteristics.

MINERAL DISTRIBUTION AND FORMATION

Certain minerals, such as aluminum and iron, are relatively abundant in Earth's crust. Others, including copper, chromium, and molybdenum, are relatively scarce. Abundance does not necessarily mean that the mineral is easily accessible or profitable to extract. It is possible that you have gold and other expensive minerals in your own backyard. However, unless the concentrations are large enough to make them profitable to mine, they will remain there.

Like other natural resources, mineral deposits in Earth's crust are distributed unevenly. Some countries have extremely rich mineral deposits, whereas others have few or none. Although iron is widely distributed, Africa has less iron than the other continents. Many copper deposits are concentrated in North and South America, particularly in Chile and the United States, whereas most of Asia (other than Indonesia) has a relatively small amount of copper. Much of the world's tin is in China and Indonesia, and most chromium reserves are in South Africa. We discuss the international implications of the unequal distribution of important minerals later in the chapter.

Formation of Mineral Deposits Concentrations of minerals within Earth's crust are the result of several natural processes, including magmatic concentration, hydrothermal processes, sedimentation, and evaporation. As magma (molten rock) cools and solidifies deep in Earth's crust, it often separates into layers, with the heavier iron-containing rock settling on the bottom and the lighter silicates (rocks containing silicon) rising to the top. Varying concentrations of minerals are often found in the different rock layers. This layering, called **magmatic concentration**, is responsible for some deposits of iron, copper, nickel, chromium, and other metals.

Hydrothermal processes involve water that was heated deep in Earth's crust. This water seeps through cracks and fissures and dissolves certain minerals in the rocks. The minerals are then carried along in the hot water solution. The dissolving ability of the water is greater if chlorine or fluorine is present because these elements react with many metals (such as copper) to form water-soluble salts (e.g., copper chloride). When the hot solution encounters sulfur, a common element in Earth's crust, a chemical reaction between the metal salts and the sulfur produces metal sulfides. Because metal sulfides are not soluble in water, they

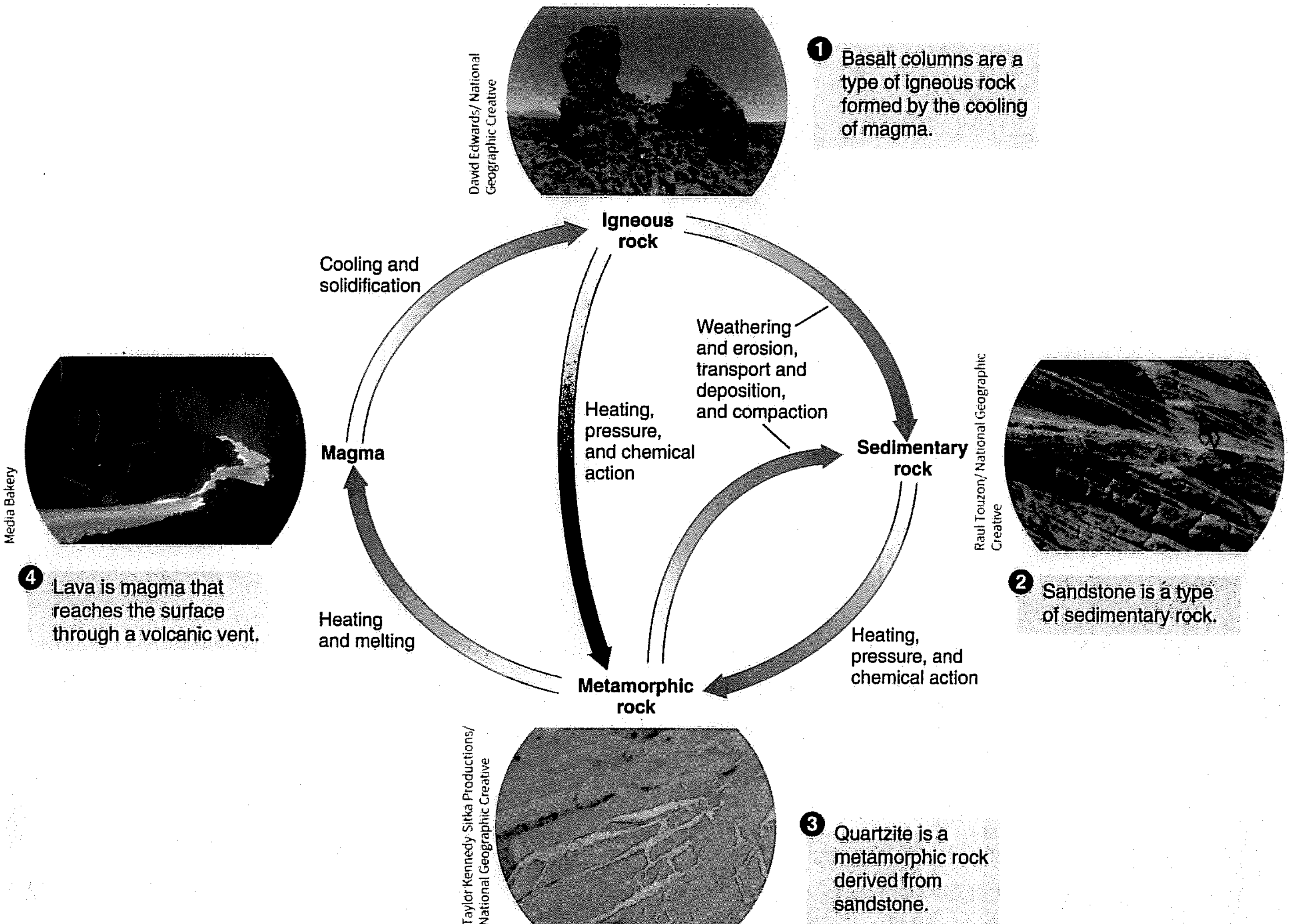


Figure 15.1 The rock cycle. Rocks do not remain in their original form forever. This highly simplified diagram shows how rocks cycle from one form to another.

form deposits by settling out of the solution. Hydrothermal processes are responsible for deposits of minerals such as gold, silver, copper, lead, and zinc.

The chemical and physical weathering processes that break rock into finer and finer particles are important not only in soil formation (see Chapter 14) but also in the production of mineral deposits. Weathered particles are transported by water and deposited as sediment on riverbanks, deltas, and the seafloor in a process called **sedimentation**. During their transport, certain minerals in the weathered particles dissolve in the water. They later settle out of solution. When the warm water of a river meets the cold water of the ocean, for example, settling occurs because less material dissolves in cold water than in warm water. Sedimentation has formed important deposits of iron, manganese, phosphorus, sulfur, copper, and other minerals.

Significant amounts of dissolved materials accumulate in inland lakes and in seas that have no outlet or only a small outlet to the ocean. If these bodies of water dry up by **evaporation**, a large amount of salt is left behind. Over time, it may be covered with sediment and incorporated into rock layers. Evaporation has formed significant deposits of common table salt, borax, potassium salts, and gypsum.

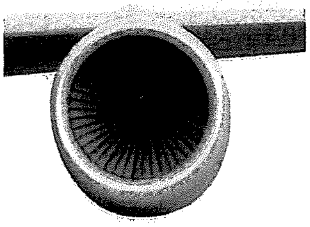
HOW MINERALS ARE FOUND, EXTRACTED, AND PROCESSED

The process of making mineral deposits available for human consumption occurs in several steps. First, a particular mineral deposit is located. Second, mining extracts the mineral from the ground. Third, the mineral is processed, or refined, by concentrating it and removing impurities. During the fourth and final step, the purified mineral is used to make a product. As you will see, each of these steps has environmental implications.

Discovering Mineral Deposits Geologists employ a variety of instruments and measurements to help locate valuable mineral deposits. Aerial or satellite photography sometimes discloses geologic formations associated with certain types of mineral deposits. Instruments that measure Earth's magnetic field and gravity reveal

Table 15.1 Some Important Minerals and Their Uses.*

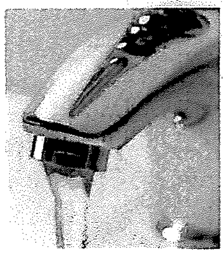
Aluminum



© mikapp/iStockphoto

Aircraft, motor vehicles, packaging (cans, foil), water treatment

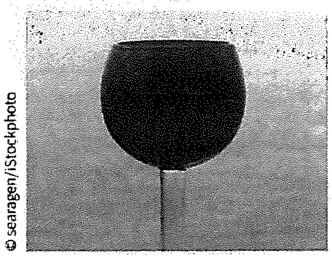
Chromium



© Dominik Pabis/iStockphoto

Chrome plate, dyes and paints, steel alloys (cutlery)

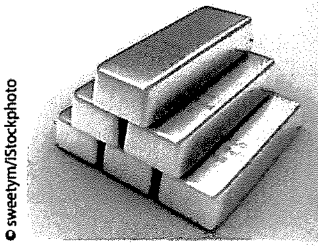
Cobalt



© searagen/iStockphoto

Corrosion and wear-resistant alloys, pigments (cobalt blue)

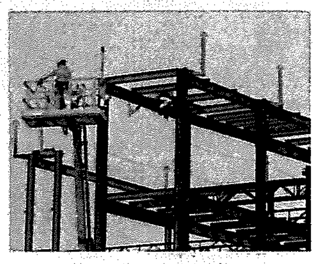
Gold



© sweetym/iStockphoto

Jewelry, money, restorative dentistry

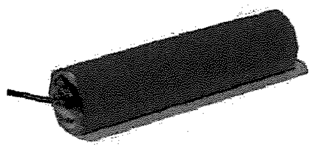
Iron



© kozmoat98/iStockphoto

Steel (alloy of iron) buildings and machinery

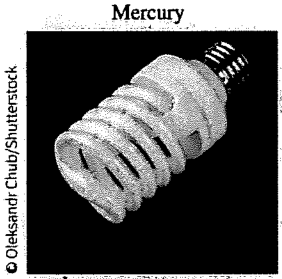
Magnesium



© kickers/iStockphoto

Beverage cans, electronic devices, firecrackers, flares

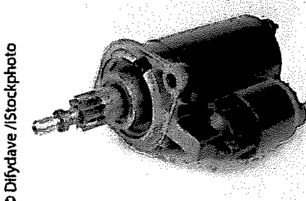
Mercury



© Oleksandr Chub/Shutterstock

Industrial chemicals, electric and electronic applications, batteries

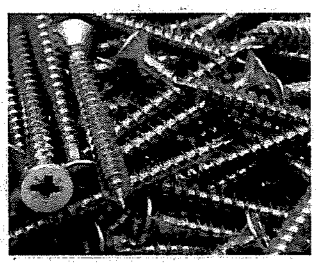
Molybdenum



© Difydave /iStockphoto

High-temperature alloys for aircraft, industrial motors

Nickel



© canon_jack/iStockphoto

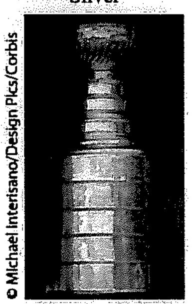
Coins, metal plating, alloys with various uses

Potassium

Martyn F. Chillmaid / Science Source

Fertilizers, photography

Silver



© Michael Interisano/Design Pics/Corbis

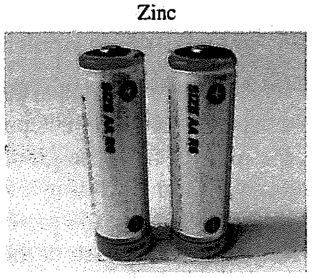
Jewelry, silverware, photography, electronics

Titanium

© Wesley VanDinter/iStockphoto

Alloy in steel and other industrial alloys; pigment in paints, plastics

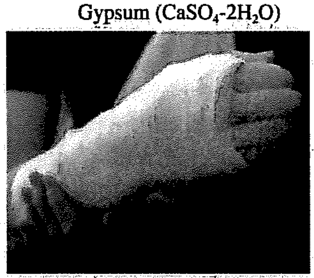
Zinc



© Djapeman/iStockphoto

Galvanizing steel, alloys (brass), anode in alkaline batteries

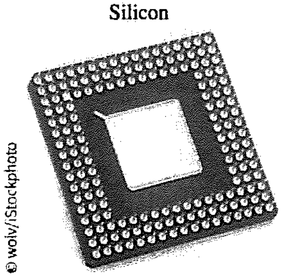
Gypsum ($CaSO_4$-$2H_2O$)



© Lowryn/iStockphoto

Drywall, plaster of Paris, Soil conditioner

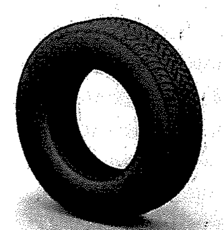
Silicon



© wolv/iStockphoto

Electronic devices, semiconductors, natural stone, glass, concrete

Sulfur



© Icefront/iStockphoto

Industrial chemicals, insecticides, gunpowder, vulcanized tires

*Gypsum, silicon, and sulfur are nonmetals. All other minerals shown are metals.

certain deposits. Seismographs, used to detect earthquakes, also provide clues about mineral deposits. Geologists analyze these data, along with their knowledge of Earth's crust and how minerals are formed, to estimate locations of possible mineral deposits. Once these sites are identified, mining companies drill or tunnel for mineral samples and analyze their composition.

Geologists use data from depth-measuring devices to produce detailed three-dimensional maps of the seafloor. From sophisticated computer analysis of these maps, geologists can estimate the types and amounts of deposits on the ocean floor.

Extracting Minerals The depth of a particular deposit determines whether surface or subsurface mining will be used. In **surface mining**, minerals are extracted near the surface, whereas in **subsurface mining**, minerals too deep to be removed by surface mining are extracted. Surface mining is more common because it is less expensive than subsurface mining. Because even surface mineral deposits occur in rock layers beneath Earth's surface, the overlying soil and rock layers, called **overburden**, must first be removed, along with the vegetation growing in the soil. Then giant power shovels scoop the minerals out.

ırface mining The traction of mineral d energy resources r Earth's surface by : removing the soil, ısoil, and overlying rock strata.

ırface mining The traction of mineral d energy resources deep underground deposits.

ırburden Soil and ; overlying a useful mineral deposit.

Mining companies have two options for surface mining—open-pit surface mining and strip mining. Iron, copper, stone, and gravel are usually extracted by **open-pit surface mining**, in which a giant hole is dug (**Figure 15.2a**). Large holes formed by open-pit surface mining are called quarries. In **strip mining**, a trench is dug to extract the minerals (**Figure 15.2b**). Then a new trench is dug parallel to the old one; the overburden from the new trench is put into the old trench, creating a hill of loose rock called a **spoil bank**.

Subsurface mining, which is underground, may be done with a shaft mine or a slope mine. A **shaft mine** is a direct vertical shaft to the vein of ore (**Figure 15.2c**). The ore is broken up underground and then hoisted through the shaft to the surface in buckets. A **slope mine** has a slanting passage that makes it possible to haul the broken ore out of the mine in carts rather than hoisting it up in buckets (**Figure 15.2d**). Sump pumps keep the subsurface mine dry, and a second shaft is usually installed for ventilation.

ank A hill of loose : created when the ›urden from a new ·nch is put into the / excavated trench uring strip mining.

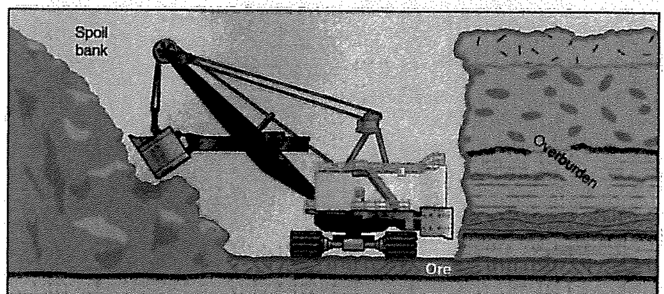
Subsurface mining disturbs the land less than surface mining, but it is more expensive and more hazardous. Miners face risk of death or injury from explosions or collapsing walls, and prolonged breathing of dust in subsurface mines can result in lung disease. (Chapter 11 discusses coal mining and its hazards.)

Processing Minerals Processing metallic minerals often involves **smelting**. Purified copper, tin, lead, iron, manganese, cobalt, or nickel smelting is done in a chimney-like *blast furnace*. **Figure 15.3** shows a blast furnace used to smelt iron. Iron ore, limestone rock, and coke (modified coal used as an industrial fuel) are added at the top of the furnace, while heated air or oxygen is added at the bottom. Chemical

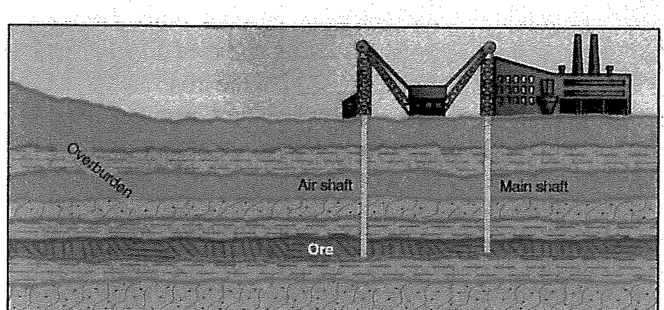
lting The process ·hich ore is melted h temperatures to te impurities from the molten metal.

James L. Amos/ National Geographic Creative

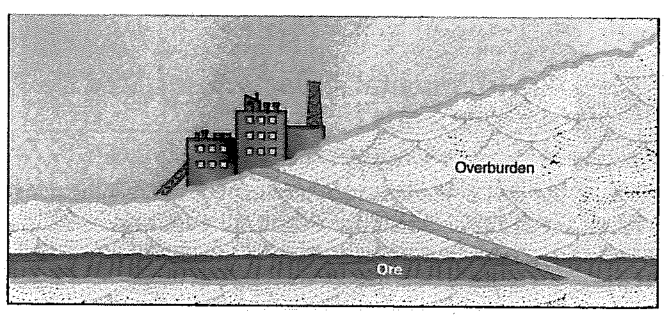
(a) This open-pit copper mine in Utah is the largest human-made excavation in the world.



(b) Strip mining removes overburden along narrow strips to reach the ore beneath.



(c) In a shaft mine, a hole is dug straight through the overburden to the ore, which is removed up through the shaft in buckets.



(d) In a slope mine, an entry to the ore is dug at an angle so that the ore can be hauled out in carts.

Figure 15.2 Types of mining operations.

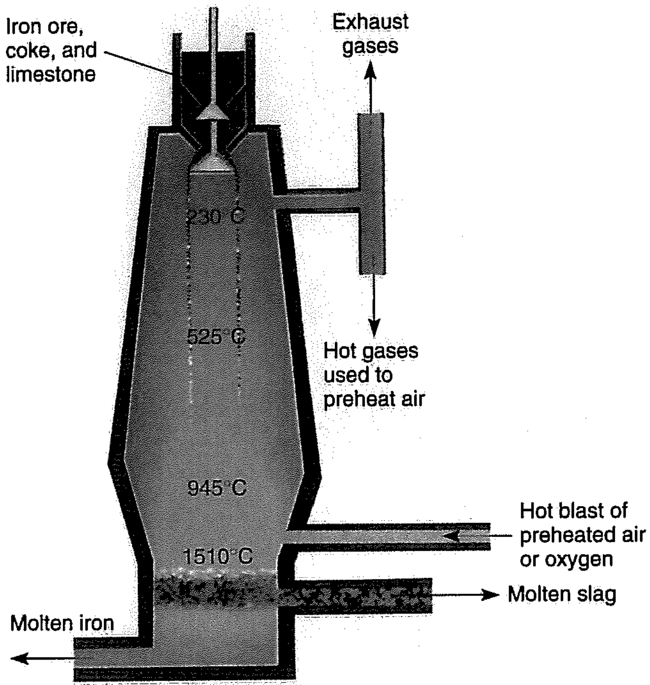


Figure 15.3 Blast furnace. Such towerlike furnaces are used to separate metal from impurities in the ore. The energy for smelting comes from a blast of heated air.

reactions take place throughout the furnace as the ore moves downward: The iron ore reacts with coke to form molten iron and carbon dioxide, whereas the limestone reacts with impurities in the ore to form a molten mixture called slag. Both molten iron and slag collect at the bottom, but slag floats on molten iron because it is less dense than iron. The slag is cooled and then disposed of. Note the vent for exhaust gases near the top of the iron smelter in Figure 15.3. If air pollution–control devices are not installed, toxic gases such as sulfur oxides are emitted during smelting.

REVIEW

1. What is the difference between high-grade and low-grade ores?
2. Which type of mining—surface mining or subsurface mining—is more harmful to the environment? Which type is more expensive to do?
3. How does magmatic concentration form mineral deposits?
4. How are mineral deposits discovered?

Environmental Impacts Associated with Minerals

LEARNING OBJECTIVES

- Explain the environmental impacts of mining and refining minerals, including a brief description of acid mine drainage.
- Explain how mining lands can be restored.

There is no question that the extraction, processing, and disposal of minerals harm the environment. Mining disturbs and damages the land, and processing and disposal of minerals pollute the air, soil, and water. As noted in the discussion of coal in Chapter 11, pollution can be controlled and damaged lands can be fully or partially restored, but these remedies are costly. Historically, the environmental cost of extracting, processing, and disposing of minerals has not been incorporated into the actual price of mineral products to consumers.

Most highly developed countries have regulatory mechanisms to minimize environmental damage from mineral consumption, and many developing countries are in the process of putting regulations in place. Such mechanisms include policies to prevent or reduce pollution, restore mining sites, and exclude certain recreational and wilderness sites from mineral development.

MINING AND THE ENVIRONMENT

Mining, particularly surface mining, disturbs large areas of land. In the United States, current and abandoned metal and coal mines occupy an estimated 9 million hectares (22 million acres). Because mining destroys existing vegetation, this land is particularly prone to erosion, with wind erosion causing air pollution and water erosion polluting nearby waterways and damaging aquatic habitats.

Open-pit mining of gold and other minerals uses huge quantities of water. As miners dig deeper into the ground to obtain the ore, they eventually hit the water table and have to pump out the water to keep the pit dry. In northern Nevada, scientists from the U.S. Geological Survey surveyed several wells and measured a drop in the water table of as much as 305 m (1000 ft). This drop, which took place during the 1990s, was linked to gold mining in the region. (Nevada has numerous gold mines that provide the United States with half of its gold.) At the same time, the Western Shoshone tribe living in the area noticed that springs important to their culture began to dry up. The region's farmers and ranchers are concerned that gold mining is depleting the groundwater they need for irrigation. The lowering of the water table in the desert ecosystem can also affect fishes and other organisms that rely on the rare pools of water formed where this groundwater reaches the surface. Ranchers, farmers, environmentalists, and others want the mining companies to reinject the water into the ground after they have pumped it out.

Mining affects water quality. According to the Worldwatch Institute, mining has contributed to the contamination of at least 19,000 km (11,800 mi) of streams and rivers in the United States. Rocks rich in minerals often contain high concentrations of heavy metals such as arsenic and lead. When rainwater seeps through sulfide minerals exposed in mine wastes, sulfuric acid is produced that in turn dissolves other toxic substances, such as lead, arsenic, and cadmium, in the spoil banks of coal and metal ore mines. These acids and highly toxic substances, called **acid mine drainage**, are washed into soil and water, including groundwater, by precipitation runoff (**Figure 15.4**). When such acids and toxic compounds make their way into nearby lakes and streams, they adversely affect the numbers and kinds of aquatic life. Rapid drainage during thunderstorms or a spring snowmelt produces "toxic pulses" of poisonous water that are particularly harmful to waterfowl, fish, and other wildlife in the watershed. Two examples of the many acid mine drainage sites in North America are the Berkeley Pit Superfund site near Butte, Montana, and Britannia Beach in British Columbia, Canada.

acid mine drainage Pollution caused when sulfuric acid and toxic dissolved materials, such as lead, arsenic, and cadmium, wash from mines into nearby lakes and streams.

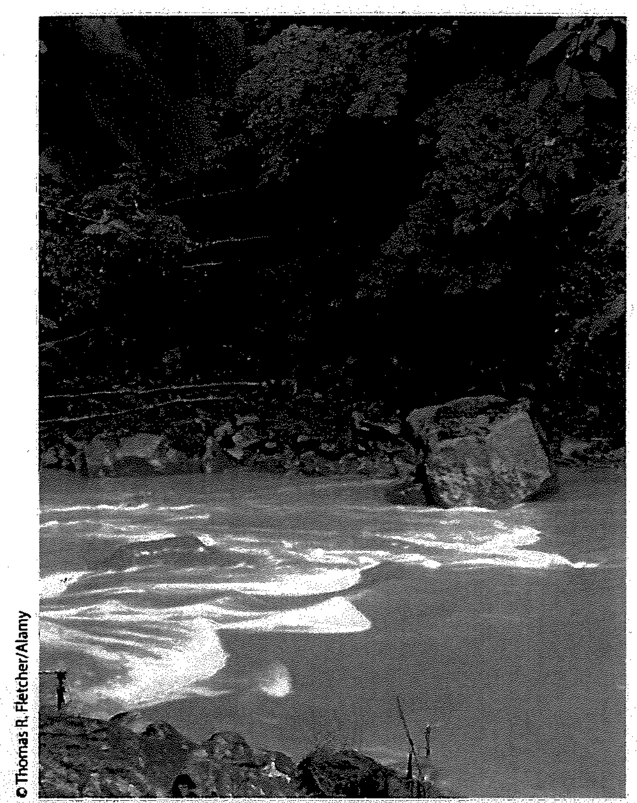


Figure 15.4 Acid mine drainage contaminating a stream. Shown is the characteristic orange acid runoff that contains sulfuric acid contaminated with lead, arsenic, cadmium, silver, and zinc. Photographed in Preston County, West Virginia

Cost–Benefit Analysis of Mine Development Environmental economists suggest that before a decision is made to develop a mine, a cost–benefit analysis should be performed that includes the benefits of the mine in dollar terms versus the benefits in dollar terms of preserving the land intact for wildlife habitat, ranchers, farmers, indigenous people, watershed protection, and recreation. This economic analysis should include the cost of damage to the environment caused by extracting and processing mineral resources. The evaluation should take into account the fact that, over time, the benefits of the mine will decline as the mineral ore is exhausted, whereas the benefits of the natural environment will likely increase, in part because natural areas are becoming rarer as the number of developed areas increases. When a cost–benefit analysis of this type is performed, it may indicate that present and future benefits of preserving the land are greater than present and future benefits of developing a mine.

ENVIRONMENTAL IMPACTS OF REFINING MINERALS

On average, approximately 80% or more of mined ore consists of impurities that become wastes after processing (**Table 15.2**). These wastes, called **tailings**, are usually left in giant piles on the ground or in ponds near the processing plants (**Figure 15.5a**). The tailings contain toxic materials such as cyanide, mercury, uranium, and sulfuric acid. Left exposed in this way, these toxic substances contaminate the air, soil, and water (**Figure 15.5b**). Heavy metals

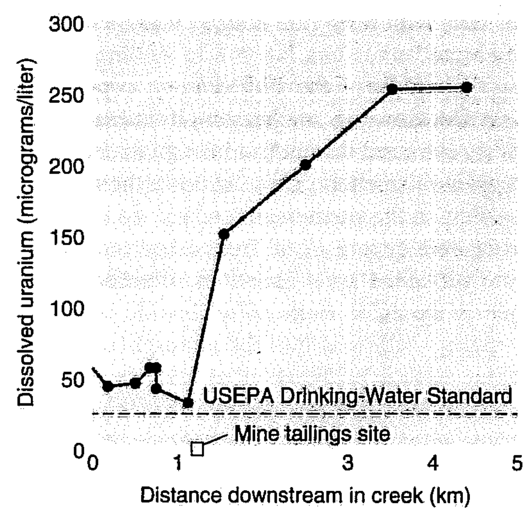
Table 15.2 Ore and Waste Production for Selected Minerals

Mineral	*Amount of Mined Ore (Million Tons)*	*Percentage of Ore That Becomes Waste During Refining**
Iron ore	2958	60
Copper	1663	99
Gold	745	99.99
Lead	267	97.5
Aluminum	128	81

*Data do not include the overburden of rock and soil that originally covered the ore deposits.

Source: Adapted from Table 6.4 on page 117 in G. Gardner, et al. *State of the World*, 2003. New York: W.W. Norton & Company (2003) and based on data from U.S. Geological Survey and *Worldwatch*.

(a) This aerial view shows tailing ponds for mineral wastes, located in Utah.



(b) Dissolved uranium from tailings contaminates a creek downstream of a former uranium and copper mine in southeastern Utah.

Figure 15.5 Environmental impact of disposed tailings.
Otton, J.K., Zielinski, R.A., and Horton, R.J. 2010. Geology, Geochemistry, and Geophysics of the Fry Canyon Uranium/Copper Projects Site, Southeastern Utah—Indications of Contaminant Migration. U.S. Geological Survey Scientific Investigations Report 2010-5075.

in mine tailings at the Bunker Hill Superfund site in northern Idaho, for example, have leached (washed) into the south fork of the Coeur d' Alene River, killing fishes and waterfowl.

Smelting plants have the potential to emit large quantities of air pollutants during mineral processing. One impurity in many mineral ores is sulfur. Unless expensive pollution-control devices are added to smelters, the sulfur escapes into the atmosphere, where it forms sulfuric acid. The environmental implications of the resulting acid precipitation are discussed in Chapter 19. Pollution-control devices for smelters are the same as those used when sulfur-containing coal is burned—scrubbers and electrostatic precipitators (see Figure 19.9).

Other contaminants found in many ores include the heavy metals lead, cadmium, arsenic, and zinc. These elements have the potential to pollute the atmosphere during the smelting process. Cadmium, for example, is found in zinc ores, and emissions from zinc smelters are a major source of environmental cadmium contamination. In humans, cadmium is linked to high blood pressure; diseases of the liver, kidneys, and heart; and certain types of cancer. In addition to airborne pollutants, smelters emit hazardous liquid and solid wastes that can cause soil and water pollution. Pollution-control devices prevent such hazardous emissions, although the toxic materials captured must be safely disposed of or they will still cause environmental pollution.

CASE IN POINT

COPPER BASIN, TENNESSEE

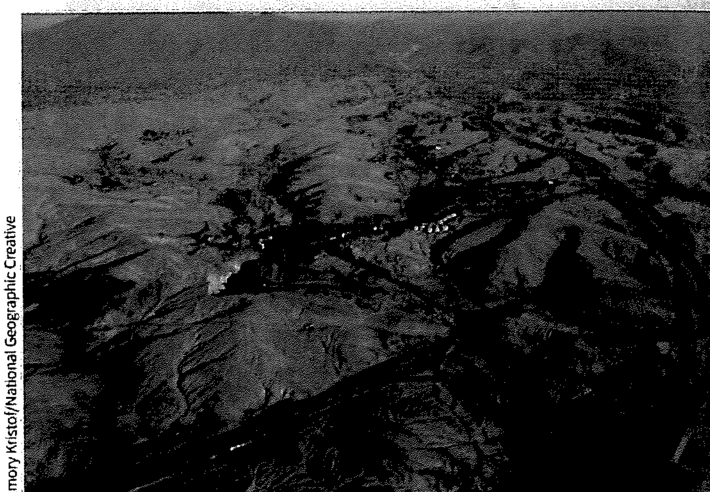
Copper Basin, Tennessee, in the southeast corner of Tennessee, near its borders with Georgia and North Carolina, is a historic example of environmental degradation caused by smelting. Until relatively recently, the Copper Basin area progressed from lush forests to a panorama of red, barren hills baking in the sun (**Figure 15.6a**). Few plant or animal species could be found—just 130 km^2 (50 mi^2) of hills with deep ruts gouged into them. How did this degradation occur?

During the middle of the 19th century, copper ore was discovered near Ducktown in southeastern Tennessee. Copper mining companies extracted the ore from the ground and dug vast pits to serve as open-air smelters. They cut down the surrounding trees and burned them in the smelters to produce the high temperatures needed to separate copper metal from other contaminants in the ore. The ore contained great quantities of sulfur, which reacted with oxygen in the air to form sulfur dioxide. As sulfur dioxide from the smelters billowed into the atmosphere, it reacted with water, forming sulfuric acid that fell as acid precipitation.

The deforestation and acid precipitation triggered ecological ruin of the area within a few short years. Acid precipitation quickly killed any plants attempting a comeback after removal of the forests. Because plants no longer covered the soil and held it in place, soil erosion cut massive gullies into the gently rolling hills. Of course, the forest animals disappeared with the plants, which had provided their shelter and food. The damage did not stop there. Soil eroding from the Copper Basin, along with acid precipitation, ended up in the Ocoee River, killing its entire aquatic community.

Beginning in the 1920s and 1930s, several government agencies, including the Tennessee Valley Authority and the U.S. Soil Conservation Service, tried to replant a portion of the area. They planted millions of loblolly pine and black locust trees as well as shorter ground-cover grasses and legume plants that tolerate acid conditions, but most of the plants died. The success of such efforts was marginal until the 1970s, when land reclamation specialists began using new techniques such as application of seed and time-released fertilizer by helicopter. These plants had a greater survival rate, and as they became established, their roots held the soil in place. Leaves dropping to the ground contributed organic material to the soil. The plants provided shade and food for animals such as birds and field mice, which slowly began to return.

Today, reclamation of Copper Basin continues under a 2001 agreement between the state of Tennessee and the U.S. Environmental Protection Agency, with the goal of having the entire area under plant cover (**Figure 15.6b**). (Of course, the forest ecosystem's full recovery will take at least a century or two.) Water treatment efforts are also restoring the Ocoee River, where fish and invertebrates are returning.



Emory Kristof/National Geographic Creative

(a) Air pollution from a copper smelter in Tennessee killed the vegetation, and then water erosion carved gullies into the hillsides. This unrestored section of Copper Basin was photographed in 1973.

© Andre Jenny/Alamy

(b) A section of Copper Basin that has been reforested.

Figure 15.6 Environmental devastation near Ducktown, Tennessee.

RESTORATION OF MINING LANDS

When a mine is no longer profitable, the land can be reclaimed, or restored to a seminatural condition, as has been done to most of the Copper Basin in Tennessee. The goals of reclamation include preventing further degradation and erosion of the land, eliminating or neutralizing local sources of toxic pollutants, and making the land productive for purposes other than mining. Restoration also makes such areas visually attractive (**Figure 15.7**).

A great deal of research is available on techniques of restoring lands degraded by mining, called **derelict lands**. Restoration involves filling in and grading the derelict land to its natural contours, then planting vegetation to hold the soil in place. The establishment of plant cover is not as simple as throwing a few seeds on the ground. Often the topsoil is completely gone or contains toxic levels of metals, so special types of plants that tolerate such a challenging environment must be used. According to experts, the main limitation on the restoration of derelict lands is not a lack of knowledge but a lack of funding.

The **Surface Mining Control and Reclamation Act** of 1977 requires reclamation of areas that were surface-mined for coal (see Chapter 11). However, no federal law is in place to require restoration of derelict lands produced by other kinds of mines. Recall from the chapter introduction that the General Mining Law makes no provision for reclamation.

Creative Approaches to Cleaning Up Mining Areas Although wetlands are widely known to provide beneficial wildlife habitats, few people realize the potential of wetlands to help clean up former mining lands. Wetlands tend to trap sediments and pollutants that enter them from upstream areas, so the quality of water resources located downstream from wetlands is improved. Although a single wetland provides these benefits, a series of wetlands constructed in the affected drainage basin is much more effective.

Figure 15.7 Reclaimed coal-mined land. Prior to reclamation, this 68-acre site in Kentucky contained refuse and barren land associated with coal mining there.

Consider the area around Butte, Montana, where copper was mined for 100 years. This area is the largest Superfund site in the United States. Its soil and water are contaminated with copper, zinc, nickel, cadmium, and arsenic. Many cleanup technologies are being developed and tested in Butte, including the design and construction of artificial wetlands. As contaminated water seeps into the wetland, bacteria consume the sulfur draining from the mines, making the water less acidic. As the water becomes less acidic, zinc and copper precipitate (settle out of solution) and enter the sediments. Constructed wetlands typically take 50 to 100 years to neutralize the acid enough for aquatic life to return to rivers and streams downstream from acid mine drainage. This time estimate is based on observations of more than 800 wetland systems constructed at coal mining sites in Appalachia, the region in the eastern United States that encompasses the central and southern Appalachian Mountains.

Creating and maintaining wetlands is expensive, although it is cost effective when compared to using lime to reduce the water's acidity. Recently, scientists at Butte have tried an inexpensive approach that involves cow manure, a "resource" readily available in Montana. Dumping cow manure onto mining lands causes the pH of the mine drainage water to increase as bacteria consume the manure. Toxic materials precipitate out of the basic water, just as they do in the artificial wetlands, improving the water quality.

Scientists are also using plants to remove heavy metals from former mining lands. **Phytoremediation** is the use of specific plants to absorb and accumulate toxic materials such as nickel from the soil. Although most plants do not tolerate soils rich in nickel, some plants, such as twist flower (*Streptanthus polygaloides*), thrive on it. This species is a hyperaccumulator, a plant that absorbs high quantities of a metal and stores it in its cells. The plants can be grown on nickel-contaminated land, harvested, and hauled to a hazardous waste site for disposal. Alternatively, the plants are burned, and nickel is obtained from the ashes. Phytoremediation has great potential to decontaminate mining and other hazardous waste sites and to extract valuable metals from soil in an environmentally benign way. (See Chapter 23 for further discussion of phytoremediation.)

REVIEW

1. What are three harmful environmental effects of mining and processing minerals?
2. Are mining lands usually restored when the mine is no longer profitable to operate? Why or why not?

Minerals: An International Perspective

LEARNING OBJECTIVES

- Describe the relationship between a country's level of industrialization and its mineral consumption.
- Distinguish between mineral reserves and mineral resources.

The economies of industrialized countries require the extraction and processing of large amounts of minerals to make products. Most of these highly developed countries rely on the mineral deposits in developing countries, having long since exhausted their own supplies. As developing countries become more industrialized, their own mineral requirements increase correspondingly, adding further pressure to a nonrenewable resource. In fact, humans have consumed more minerals since World War II than were consumed in the previous 5000 years, from the beginning of the Bronze Age to the middle of the 20th century (**Figure 15.8**).

Mining in the United States has clearly caused many serious environmental problems. The problems in developing countries that rely on mining for a significant part of their economies are as great as or greater than those faced by highly developed countries. The governments in developing countries lack the financial resources and infrastructure to deal with acid mine drainage and other serious environmental problems caused by hardrock mining. To complicate the issue, foreign companies often have significant mining interests in developing countries. For example, France, Germany, Great Britain, Japan, Russia, Spain, and the United States have been involved at various times during the past two centuries in mining (some would say exploiting) ores containing tin, zinc, copper, and lead in Bolivia. The mining district of Bolivia currently faces a catastrophic environmental nightmare from decades of mining abuse. Yet the Bolivian government does not address the issue because mining is the predominant industry in Bolivia.

WORLDWIDE MINERAL PRODUCTION AND CONSUMPTION

At one time, most of the highly developed countries had rich resource bases, including abundant mineral deposits that enabled them to industrialize. In the process of industrialization, they largely depleted their domestic reserves of minerals and as a result must increasingly turn to developing countries. This is particularly true for European countries, Japan, and, to a lesser extent, the United States.

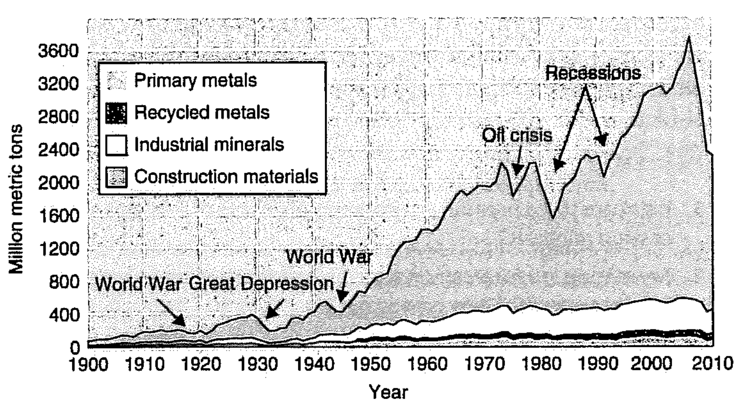


Figure 15.8 Annual U.S. use of raw nonfuel minerals, 1900–2010.
Source: USGS National Minerals Information Center 2012

The level of mineral consumption varies widely between highly developed and developing countries. The United States and Canada, which have not quite 5% of the world's population, consume about 25% of many of the world's metals. It is too simplistic, however, to divide the world into two groups, the mineral consumers (highly developed countries) and the mineral producers (developing countries). Although many developing countries do lack any significant mineral deposits, the world's 10 most resource-rich nations—in terms of value of metal and ore reserves—are not all the wealthiest: South Africa, Russia, Australia, Canada, Brazil, China, Chile, the United States, Ukraine, and Peru.

Mineral production and consumption in China are increasing dramatically as China industrializes. For example, in 2013 China produced 44% of the world's primary aluminum (aluminum obtained from ores, not from recycling). China also consumed almost all of this aluminum, making it both the world's largest producer and biggest consumer of primary aluminum.

Because industrialization increases the demand for minerals, developing countries that at one time met their mineral needs with domestic supplies become increasingly reliant on foreign supplies as economic development occurs. South Korea is one such nation. During the 1950s it exported iron, copper, and other minerals. South Korea has experienced dramatic economic growth from the 1960s to the present and, as a result, must now import iron and copper to meet its needs.

MINERAL DISTRIBUTION VERSUS CONSUMPTION

The metallic element chromium provides a useful example of global versus national distribution and consumption. Chromium is used to make vivid red, orange, yellow, and green pigments for paints; chrome plate; and, combined with other metals, certain types of hard steel. Chromium has no known substitute for many of its important applications, including jet engine parts. Industrialized nations that lack significant chromium deposits, such as the United States, must import essentially all of their chromium. South Africa is one of only a few countries with significant deposits of chromium. Zimbabwe and Turkey also export chromium. Although world reserves of chromium are adequate for the immediate future, the United States and several other industrialized countries are utterly dependent on a few countries for their chromium supplies.

Many industrialized nations have stockpiled strategically important minerals to reduce their dependence on potentially unstable suppliers. The United States and others have stockpiles of strategic minerals such as titanium, tin, manganese, chromium, platinum, and cobalt, mainly because these metals are critically important to industry and defense; in the United States, stockpiles have been decreasing since 1994.

Recently, China began stockpiling *rare earth metals*, which are 17 elements such as dysprosium and terbium that are important in high-technology applications like hybrid-car batteries, wind turbines, and laser-guided missiles. China, which controls about 80% of the global supply of rare earth metals, has also reduced its exports to other countries. China's chokehold on supply triggered steep price increases in the minerals in 2010–2011, but a more recent lack of global demand and the development of new sources led to price drops. Despite their name, some rare earth metals are not rare, but the ones needed in high-technology industries are relatively rare.

EVALUATING OUR MINERAL SUPPLIES

Will we run out of supplies of important minerals? To address this question, we must first examine how large the global supply of various mineral reserves and mineral resources is. **Mineral reserves** are currently profitable to extract, whereas **mineral resources** are potential resources that may be profitable to extract in the future. The combination of a mineral's reserves and resources is its **total resources** or **world reserve base.**

mineral reserves lineral deposits that been identified and currently profitable to extract.

ɜral resources Any ıdiscovered mineral deposits or known ːposits of low-grade ·e that are currently rofitable to extract.

Estimates of mineral reserves and resources fluctuate with economic, technological, and political changes. If the price of a mineral on the world market falls, certain borderline mineral reserves may slip into the mineral resource category; increasing prices may restore them to the mineral reserve category. When new technological methods decrease the cost of extracting ores, deposits ranked in the mineral resource category are reclassified as mineral reserves. If the political situation in a country becomes so unstable that mineral reserves cannot be mined, they are reclassified as mineral resources; a later shift toward political stability may cause the minerals to be placed on the mineral reserve list again.

It is extremely difficult to forecast future mineral supplies. In the 1970s, projections of escalating demand and impending shortages of many important minerals were commonplace. There are three reasons that none of these shortages actually materialized. First, new discoveries of major deposits occurred in recent decades—iron and aluminum deposits in Brazil and Australia, for example. Second, plastics, synthetic polymers, ceramics, and other materials replaced metals in many products. Third, a global economic slump resulted in a lower consumption of minerals. However, it is always possible that changes in the world economic situation—such as the rapid economic development of China—will contribute to future mineral shortages.

Economic factors aside, the prediction of future mineral needs is difficult because it is impossible to know when or if there will be new discoveries of mineral reserves or replacements for minerals (such as plastics). It is impossible to know when or if new technological developments will make it economically feasible to extract minerals from low-grade ores.

With these reservations in mind, most experts currently think mineral supplies, both metallic and nonmetallic, will be adequate during the 21st century. However, several important minerals—mercury, tungsten, and tin, for example—may become increasingly scarce during that period. Another reasonable projection is that the prices of even relatively plentiful minerals, such as iron and aluminum, will increase during your lifetime. The eventual depletion of large, rich, and easily accessible deposits of these metals means that we will have to mine and refine low-grade ores, which will be more expensive.

ENVIRONEWS

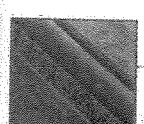
Coping with Conflict Minerals

Tantalum is a dark-gray, very hard metal able to resist heat and corrosion and conduct electricity. Prized as the source material of electronic capacitors, it is found in cell phones, computer circuits, digital cameras, gaming hardware, and even in weapon systems. In the Democratic Republic of the Congo (DRC), tantalum is mined in a form known as *coltan*, an ore containing a tantalum oxide and the mineral columbite. During the recent devastating war in the DRC, which resulted in deaths of millions, militias took over the mining and selling of coltan and other "blood" minerals, including diamonds. These groups forced DRC residents into unsafe labor and created environmental havoc. The sale of coltan supported the conflict. Although peace accords were negotiated, fighting continues, and coltan remains a black-market commodity. The prized ore is also present and controlled illegally in the border region of Venezuela and Columbia.

The world's dependence on tantalum creates dilemmas for manufacturers of high-tech goods: How do they avoid conflict sources of this metal? And how do consumers know which sources were used? In 2010, the U.S. Congress passed legislation to prevent electronics manufacturers from supporting wars by purchasing conflict minerals such as coltan. Unfortunately, legal mining operations are often near the illicit ones controlled by militia groups and sources cannot be tracked.

REVIEW

1. How does a country's mineral consumption tend to change as it becomes more industrialized?
2. How do mining experts differentiate between mineral reserves and mineral resources?



Increasing the Supply of Minerals

LEARNING OBJECTIVE

- Briefly discuss efforts to discover new mineral supplies.

As a resource becomes scarce, efforts intensify to discover new supplies, to conserve existing supplies, and to develop new substitutes for it. Although many reserves have been discovered and exploited, unknown deposits may be found. In addition, the development of advanced mining technologies may make it possible to exploit known resources that are too expensive to develop using existing techniques.

LOCATING AND MINING NEW DEPOSITS

Many known mineral reserves have not yet been exploited. Although Indonesia is known to have many rich mineral deposits, its thick forests and mosquitoes that carry the malaria parasite have made accessibility to these deposits difficult. Large deposits of iron, copper, cobalt, gold, and lithium exist in Afghanistan—enough minerals to transform the country's economy. Years of war, however, make investment in Afghanistan unlikely, at least in the short term. Both northern and southern polar regions have had little mineral development. This is due in part to a lack of technology for mining in frigid environments. Normal offshore drilling rigs cannot be used in Antarctic waters because the shifting ice formed during its harsh winter would tear the rigs apart. As new technologies become available, increasing pressure will be exerted to mine in northern Canada, Siberia, and Antarctica.

Exploitation of the rich mineral deposits in Siberia is planned, although new technologies must be developed to make this feasible. Some of the ore deposits in Siberia have unusual combinations of minerals (e.g., potassium combined with aluminum) that cannot be separated using existing technology.

Is there a possibility that currently unknown mineral deposits will be discovered at some future time? The U.S. Geological Survey thinks that undiscovered mineral deposits may exist, particularly in developing countries where detailed geologic surveys are not yet available. A detailed survey of the western portion of South America along the Andes Mountains could reveal significant mineral deposits. Geologists presume that minerals will be found in the Amazon Basin, although in many ways the rain forest and thick overlying alluvial layers of the river basin make these deposits as inaccessible as those in Antarctica. Logistic problems hamper examination of certain areas deep in the rain forest to assess the likelihood of deposits being present. As in other regions, mining in the Amazon Basin would pose a grave environmental threat.

Geologists consider it likely that deep deposits buried 10 km (6.2 mi) or more in Earth's crust will someday be discovered and exploited. The special technology required to mine deposits that deep is not yet available.

MINERALS IN ANTARCTICA

To date, no substantial mineral deposits have been found in Antarctica, although smaller amounts of valuable minerals have been discovered. Geologists think it likely that major deposits of valuable metals and oil are present and that they will be discovered in the future. Nobody owns Antarctica, and many nations are involved in negotiations on the future of this continent and its possible mineral wealth.

The **Antarctic Treaty**, an international agreement in effect since 1961, limits activity in Antarctica to peaceful uses such as scientific studies. Twenty-six nations are voting members to the Antarctic Treaty. During the 1980s, nearly a decade of delicate negotiations resulted in a pact that would have permitted exploitation of Antarctica's minerals. The pact required unanimous agreement for ratification. In 1989, several countries refused to support the pact because of concerns that any mineral exploitation would damage Antarctica's environment. As a result of these concerns, an international agreement, the **Environmental Protection Protocol to the Antarctic Treaty**, or the **Madrid Protocol**, was established. The protocol, which went into effect in 1990, includes a moratorium on mineral exploration and development for a minimum of 50 years. It designates Antarctica and its marine ecosystem as a "natural reserve dedicated to peace and society."

Why be concerned about Antarctica's environment? For one thing, polar regions are extremely vulnerable to human activities. Even scientific investigations and tourists, with their trash, pollution, and noise, have negatively affected the wildlife, such as emperor penguins, leopard seals, and blue whales, along Antarctica's coastline. No one doubts that large-scale mining operations would wreak havoc on such a fragile environment.

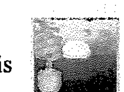
Maintaining Antarctica in a pristine state is important because this continent plays a pivotal role in regulating many aspects of the global environment, such as global changes in sea level. Studying the natural environment of Antarctica helps scientists gain valuable insights into such important environmental issues as global climate change and stratospheric ozone depletion (**Figure 15.9**).

MINERALS FROM THE OCEAN

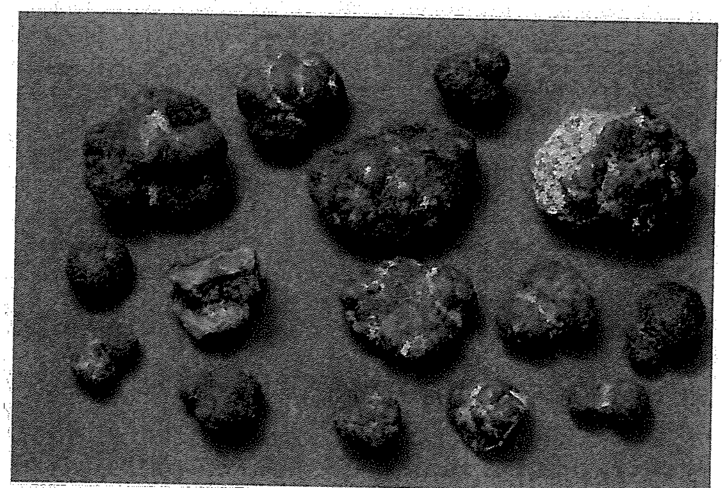
Seawater, which covers approximately three-fourths of our planet, contains many dissolved minerals. The total amount of minerals available in seawater is staggeringly high, but their concentrations are low. Currently, sodium chloride (common table salt), bromine, and magnesium are profitably extracted from seawater. It may be possible in the future to profitably extract other minerals from seawater and concentrate them, but current mineral prices and technology make this impossible now.

Large deposits of minerals lie on the ocean floor. **Manganese nodules**—small rocks the size of potatoes that contain manganese and other minerals, such as copper, cobalt, and

Figure 15.9 Research in Antarctica. Scientists set up a GPS receiver in west Antarctica as part of the west Antarctic GPS Network (WAGN) project. The WAGN project is measuring crustal movements surrounding the west Antarctic ice sheet. These movements in the lithosphere could affect the future of the ice sheet and its corresponding effect on sea level. How is this research related to global climate change?



nickel—are widespread on the ocean floor, particularly in the Pacific (**Figure 15.10**). Estimates of manganese nodules are quite large. Nodules in the Pacific Ocean may contain as much as 6 billion metric tons (6.6 billion tons) of manganese, more than the total amount found in land reserves. Dredging manganese nodules from the ocean floor would adversely affect sea life, and the current market value for these minerals would not cover the expense of obtaining them using existing technology. Despite these concerns, many experts think that deep-sea mining will be feasible in a few decades, and several industrialized nations such as the United States have staked out claims in a region of the Pacific known for its large number of nodules. To date, none have been mined.



(a) These polymetallic nodules are concretions of about 20% manganese, as well as iron, copper, cobalt, nickel, and other metals. These were taken from the Pacific Ocean at a depth of about 4 km (2.4 mi).

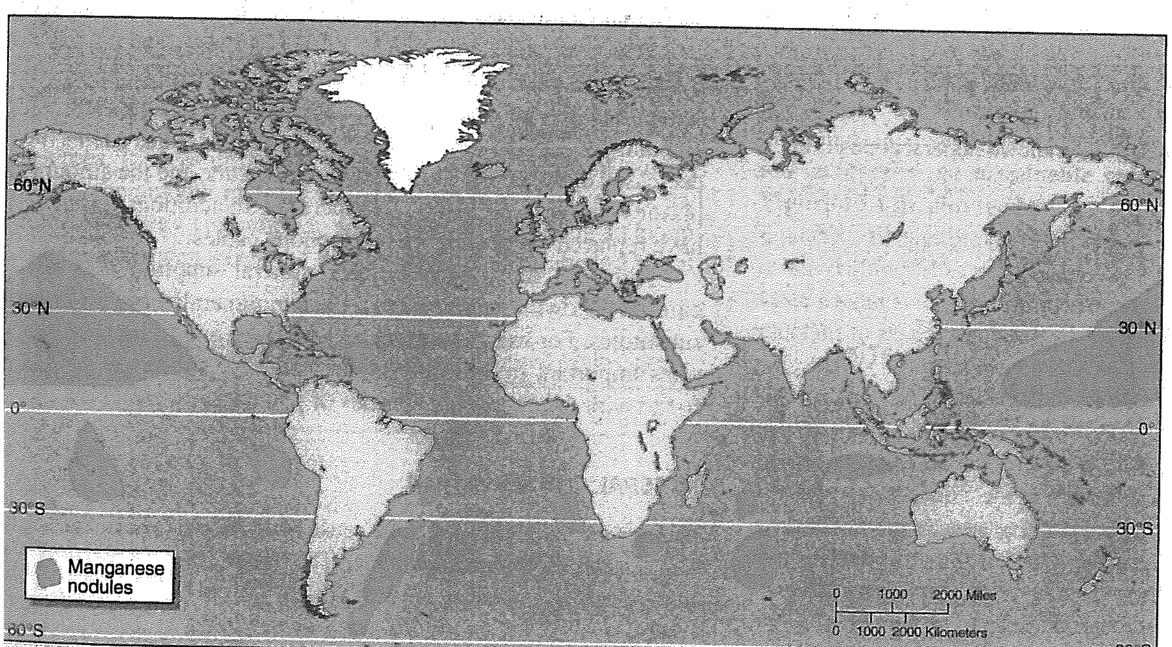
Such potential exploitations of the ocean floor are controversial. Many people think it is inevitable that minerals will be mined from the floor of the deep sea, but others think the seabed should be declared off limits because of the potential ecological havoc that mining could cause on the diverse life-forms inhabiting the ocean floor. Sea urchins, sea cucumbers, sea stars, acorn worms, sea squirts, sea lilies, and lamp shells are but a few of the animals known to inhabit the seabed environment.

These problems have been considered since the 1960s, when industrialized countries first expressed an interest in removing manganese nodules from the ocean floor. Their interest triggered the formation of an international treaty, the **U.N. Convention on the Law of the Sea (UNCLOS)**. UNCLOS, which became effective in 1994, is generally considered a "constitution for the ocean" that protects its resources. As of 2013, 166 countries had ratified this treaty. (The United States has not yet ratified UNCLOS but voluntarily observes its provisions.)

The provisions of UNCLOS are not binding for territorial waters, only for international waters, so seabed mining is not prohibited in territorial waters. For example, hydrothermal vent systems in deep territorial waters off Papua New Guinea contain gold, zinc, copper, and silver in higher concentrations than are found in land mines. It seems likely that ocean mining will become technologically feasible and profitable sometime in the next few years. Nautilus Minerals, Inc. is planning to mine one of Papua New Guinea's hydrothermal vents soon.

ADVANCED MINING AND PROCESSING TECHNOLOGIES

We have already mentioned that special technologies will be needed to mine minerals in inaccessible areas such as polar regions



(b) Location of known manganese nodules in the ocean. Although these potato-sized nodules have enticed mining companies, it is not yet commercially feasible to obtain them. (Adapted from P.A. Rona, "Resources of the Sea Floor." *Science*, Vol. 299. January 31, 2003)

Figure 15.10 Manganese nodules.

and deposits deep in the ground. Making use of large, low-grade mineral deposits throughout the world will also require the development of special techniques. As minerals grow scarcer, economic and political pressure to exploit low-grade ores will increase. Obtaining high-grade metals from low-grade ores is an expensive proposition, in part because a great deal of energy must be expended to obtain enough ore. Future technology may make such exploitation more energy-efficient, thereby reducing costs.

Even if advanced technology makes obtaining minerals from low-grade ores feasible, other factors (e.g., poor access to water needed to extract and process the minerals) might limit exploitation of this potential source. The environmental costs may be too high, because obtaining minerals from low-grade ores causes greater land disruption and produces far more pollution than does the development of high-grade ores.

Biomining Microorganisms are used to extract minerals from some low-grade ores. Microorganisms have proved efficient for copper mining, allowing the U.S. copper industry to become more competitive internationally. When mixed with sulfuric acid, a bacterium (*Thiobacillus ferrooxidans*) promotes a chemical reaction that leaches copper into an acidic solution, releasing larger quantities of the metal more efficiently than traditional methods.

Other important applications of **biomining** are emerging. Although it is still in the development stage, treating low-grade gold ores with bacteria such as *Thiobacillus* allows a 90% recovery of gold, compared to 75% recovery for the more expensive and energy-intensive conventional methods. Phosphates, used primarily for fertilizers and additives in some manufactured goods, are traditionally extracted by inefficient burning at high temperatures or by wasteful acid treatment processes. New biological processes extract phosphates at room temperature. Some researchers are developing biomining techniques to remove and recycle phosphates from wastewater.

REVIEW

1. What is a problem that limits mining known mineral deposits in Indonesia? In Siberia?

Using Substitution and Conservation to Expand Mineral Supplies

LEARNING OBJECTIVES

- Summarize the conservation of minerals by reuse, recycling, and changing our mineral requirements.
- Explain how sustainable manufacturing and dematerialization contribute to mineral conservation.

Much of our civilization's technology depends on minerals, and certain minerals may be unavailable or quite limited in the future. Therefore, we should extend existing mineral supplies as far as possible through substitution and conservation (**Figure 15.11**).

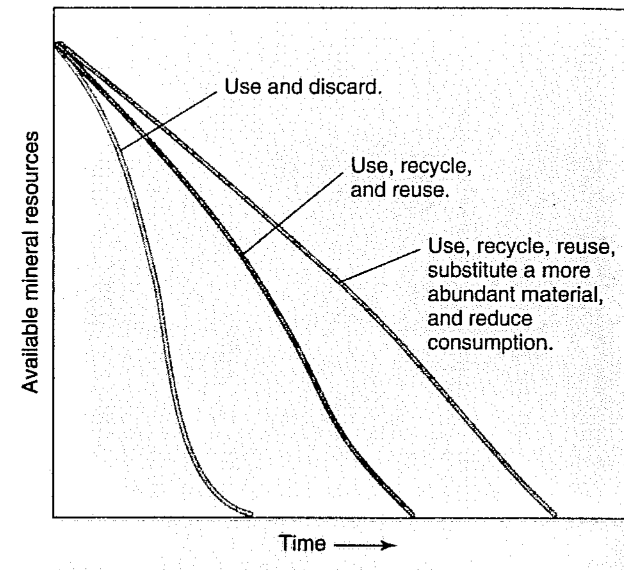


Figure 15.11 Depletion times of a nonrenewable resource such as copper. Three assumptions are made; in each case, we start with the same quantity of mineral reserves available for production. The remaining reserves level off as the resource becomes scarcer and more costly. This graph does not take into consideration the discovery of new reserves or improved mining technologies.

FINDING MINERAL SUBSTITUTES

The substitution of more abundant materials for scarce minerals is an important goal of manufacturing. Economics partly drives the search for substitutes; one effective way to cut production costs is to substitute an inexpensive or abundant material for an expensive or scarce one. In recent years, plastics, ceramic composites, and high-strength glass fibers have been substituted for scarcer materials in many industries.

Earlier in the 20th century, tin was a critical metal for can making and packaging; since then, other materials have been substituted for tin, including plastic, glass, and aluminum. The amounts of lead and steel used in telecommunications cables have decreased dramatically during the past 35 years, and the amount of plastics has had a corresponding increase. In addition, glass fibers have replaced copper wiring in telephone cables.

Although substitution extends mineral supplies, it is not a cure-all for dwindling resources. Certain minerals have no known substitutes. For example, platinum catalyzes many chemical reactions important in industry. So far, no other substance has been found with the catalyzing abilities of platinum.

MINERAL CONSERVATION

Conservation, including both reuse and recycling, extends mineral supplies. The **reuse** of items such as beverage bottles, which are collected, washed, and refilled, is one way to extend mineral resources. In **recycling**, used items such as beverage cans and scrap iron are collected, remelted, and reprocessed into new products. In addition to promoting specific conservation

reuse Conservation of the resources in used items by using them ove and over again.

recycling Conservation of the resources in used items by convertin them into new products techniques such as reuse and recycling, public awareness and attitudes about resource conservation can be modified to encourage low waste.

Reuse When the same product is used over and over again, both mineral consumption and pollution are reduced. The benefits of reuse are greater than those of recycling (see Chapter 23). Recycling a glass bottle requires crushing it, melting the glass, and forming a new bottle. Reusing a glass bottle simply requires washing it, which typically expends less energy than recycling. Reuse is a national policy in Denmark, where nonreusable beverage containers are prohibited.

Several countries and states have adopted beverage container deposit laws, which require consumers to pay a deposit, usually a nickel or dime, for each beverage bottle or can that they purchase. The deposit is refunded when the container is returned to the retailer or to special redemption centers. Unredeemed deposits are generally used to provide revenue for environmental programs such as hazardous waste cleanups. In addition to encouraging reuse and recycling, thereby reducing mineral resource consumption, beverage container deposit laws save tax money by reducing litter and solid waste. Countries that have adopted beverage container deposit laws include the Netherlands, Germany, Norway, Sweden, and Switzerland, as well as parts of Canada and the United States.

Recycling A large percentage of the products made from minerals—such as cans, bottles, chemical products, electronic devices, and batteries—is typically discarded after use. The minerals in some of these products—batteries and electronic devices, for instance—are difficult to recycle. Minerals in other products, such as paints containing lead, zinc, or chromium, are lost through normal use. However, the technology exists to recycle many other mineral products. Recycling of certain minerals is already a common practice throughout the industrialized world, including the United States, but there is much room for improvement (**Table 15.3**).

Recycling has several advantages beyond extending mineral resources. It saves unspoiled land from the disruption of mining, reduces the amount of solid waste that must be disposed of, and decreases energy consumption and pollution. Recycling an aluminum beverage can saves the energy equivalent of about 180 mL (6 oz) of gasoline. Recycling aluminum reduces the emission of aluminum fluoride, a toxic air pollutant produced during the processing of aluminum ore.

Table 15.3 Recycling Rates for Metals in the United States, 2011

Mineral	*Percent Recycled*
Aluminum	60
Copper	34
Iron and Steel	63
Lead	73
Magnesium	53
Nickel	42
Zinc	29

Source: USGS *2011 Minerals Yearbook*.

About 67% of the aluminum cans in the United States were recycled in 2012, a large increase reported by professional and recycling organizations. The aluminum industry, local governments, and private groups have established thousands of recycling centers across the country. It takes approximately six weeks for a used can to be melted, re-formed, filled, and put back on a supermarket shelf. Clearly, even more recycling is possible. It may be that today's sanitary landfills will become tomorrow's mines, as valuable minerals and other materials are extracted from them. (In many countries, sanitary landfills are already treated as mines.)

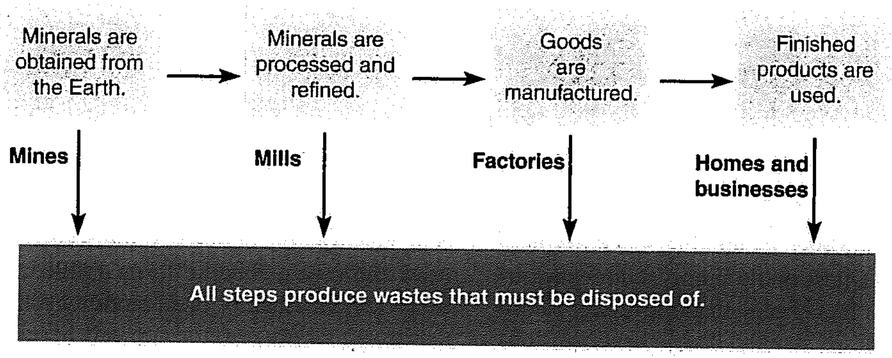
Changing Our Mineral Requirements We can reduce mineral consumption by becoming a low-waste society. U.S. citizens have developed a "throwaway" mentality wherein damaged or unneeded articles are discarded. Industries looking for short-term economic profits encourage this attitude, even though the long-term economic and environmental costs of it are high. We consume fewer resources if products are durable and repairable. Laws such as those requiring a deposit on beverage containers reduce consumption by encouraging reuse and recycling.

The throwaway mentality is also evident in manufacturing industries. Traditionally, industries consume raw materials and produce goods *and* a large amount of waste that is simply discarded (**Figure 15.12a**). Increasingly, manufacturers are finding that the waste products from one manufacturing process can become the raw materials for another industry. By selling these "wastes," industries gain additional profits and lessen the amounts of materials that must be discarded.

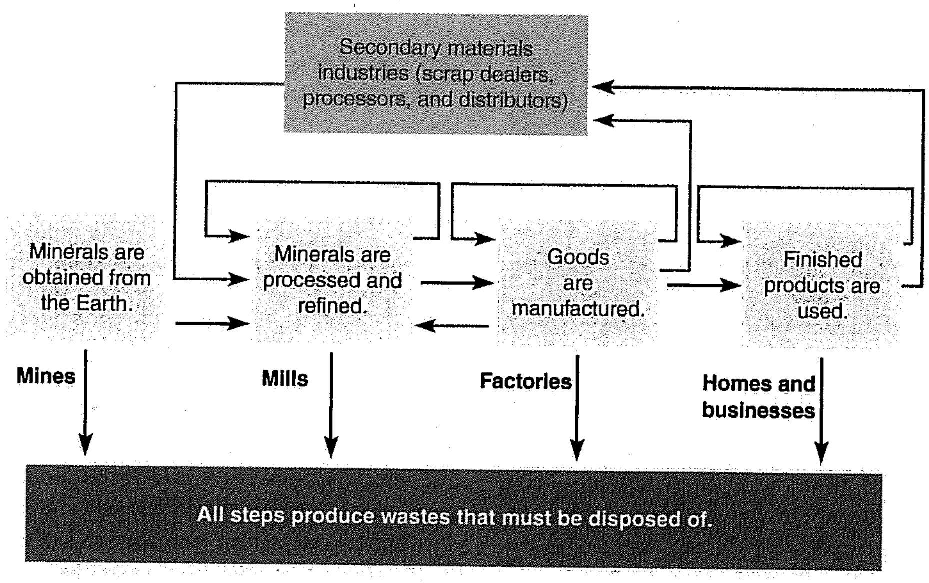
The chemical and petrochemical industries were among the first businesses to minimize wastes by converting them into useful products. For example, some chemical companies buy aluminum wastes from other companies and convert the aluminum in the wastes to aluminum sulfate, a chemical used to treat municipal water supplies. Such waste minimization is known as **sustainable manufacturing** (**Figure 15.12b**; also see Meeting the Challenge: Industrial Ecosystems). Sustainable manufacturing requires that companies provide information about their waste products to other industries. However, many companies are reluctant to reveal the kinds of wastes they produce because their competitors may deduce trade secrets from the nature of their wastes. This difficulty will have to be overcome before sustainable manufacturing is fully implemented.

sustainable manufacturing A manufacturing system based on minimizing industrial waste.

Dematerialization As products evolve, they tend to become lighter in weight and often smaller. Washing machines manufactured in the 1960s were much heavier than comparable machines manufactured today. The same is true of other household appliances, automobiles, and electronic items. This decrease in the weight of products over time is known as **dematerialization**. Ideally, dematerialization is beneficial to the environment because



(a) Massive amounts of solid waste are produced at all steps in the traditional flow of minerals, from mining the mineral to discarding the used-up product.



(b) The flow of minerals in a low-waste society is more complex, with sustainable manufacturing, consumer reuse, and consumer recycling practiced at intermediate steps.

Arrow key: —— Sustainable manufacturing
—— Consumer reuse
—— Consumer recycling

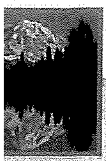
Figure 15.12 Mineral flow in an industrial society.

it reduces the quantity of waste during both production and consumption.

Although dematerialization gives the appearance of reducing consumption of minerals and other materials, it sometimes has the opposite effect. Smaller and lighter products may be of lower quality. Because repairing broken lightweight items is difficult and may cost more than the original products, retailers and manufacturers encourage consumers to replace rather than repair the items. Although the weight of materials being used to make each item has decreased, the number of such items being used in a given period may actually have increased.

REVIEW

1. Explain the difference between reuse and recycling.
2. What is sustainable manufacturing?



MEETING THE CHALLENGE

Industrial Ecosystems

litional industries operate in a one-way, ar fashion: natural resources from the envi- nent → products → wastes dumped back environment. However, natural resources n as minerals and fossil fuels are present nite amounts, and the environment has a ted capacity to absorb waste. The field of **ıstrial ecology** has emerged to address e issues. An extension of the concept of ainable manufacturing, industrial ecology ‹s to use resources efficiently and regards stes" as potential products. Industrial ecol- tries to create **industrial ecosystems** that pare in many ways to natural ecosystems.

Consider the industrial ecosystem in ndborg, Denmark, which consists of an tric power plant, an oil refinery, a pharma- ical plant, a wallboard factory, a sulfuric producer, a cement manufacturer, fish ing, horticulture (greenhouses), and area es and farms. At first glance, these enti- seem to have little in common, but they are d to one another in ways that resemble a food web in a natural ecosystem (see the figure). In this industrial ecosystem, the wastes produced by one company are sold to another company as raw materials for their processes, in a manner analogous to nutrient cycling in nature.

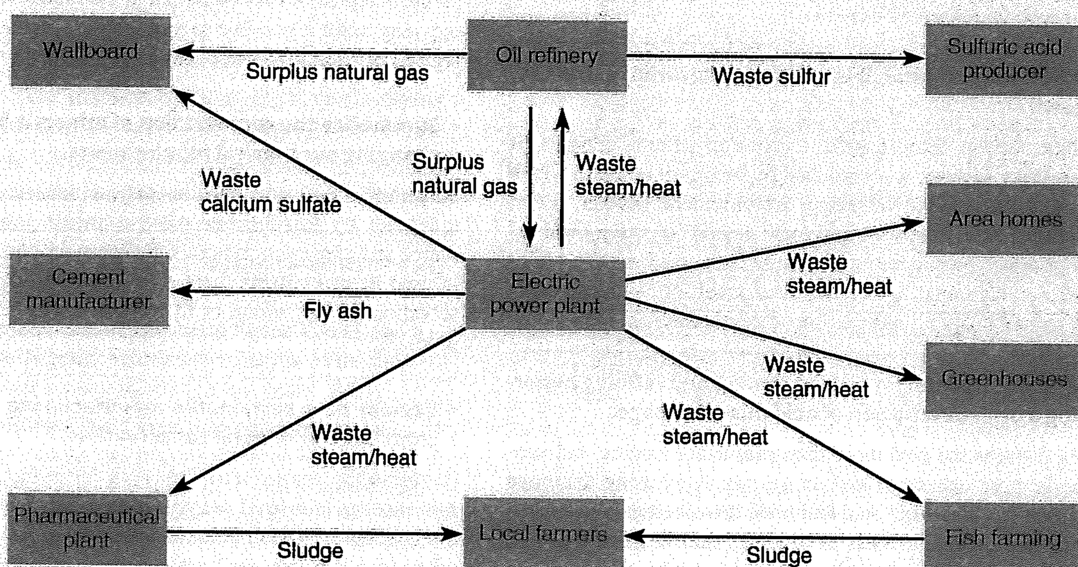
The coal-fired electric power plant originally cooled its waste steam and released it into the local fjord. The steam is now supplied to the oil refinery and the pharmaceutical plant, and additional surplus heat produced by the power plant warms greenhouses, the fish farm, and area homes. The need for 3500 oil-burning home-heating systems was eliminated as a result.

Surplus natural gas from the oil refinery is sold to the power plant and the wallboard factory. The power plant now saves tons of coal each year by burning the less expensive natural gas. Before selling the natural gas, the oil refinery removes excess sulfur from it, as required by air pollution-control laws. This sulfur is sold to a company that uses it to manufacture sulfuric acid.

To meet environmental regulations, the power plant installed pollution-control equipment to remove sulfur from its coal smoke. This sulfur, in the form of calcium sulfate, is sold to the wallboard plant and used as a substitute for gypsum, which is naturally occurring calcium sulfate. The fly ash produced by the power plant goes to the cement manufacturer for use in road building.

Local farmers use the sludge from the fish farm as a fertilizer for their fields. The fermentation vats at the pharmaceutical plant also generate a high-nutrient sludge used by local farmers. Most pharmaceutical companies discard this sludge because it contains living microorganisms, but the Kalundborg plant heats the sludge to kill the microorganisms, converting a waste material into a commodity.

These interactions did not spring into existence at the same time; each represents a separately negotiated deal. It took years to develop the entire industrial ecosystem. Although these examples of industrial cooperation were initiated for economic reasons, each has distinct environmental benefits, from energy conservation to a reduction of pollution.



Industrial ecosystem in Kalundborg, Denmark. During the production of energy, food, and other products, resource recovery is maximized and waste production is minimized.

REVIEW OF LEARNING OBJECTIVES WITH SELECTED KEY TERMS

- **Define *minerals* and explain the difference between high-grade and low-grade ores, as well as between metallic and nonmetallic minerals.**

A **mineral** is an inorganic solid, occurring naturally in or on Earth's crust, with characteristic chemical and physical properties. **High-grade ores** contain relatively large amounts of particular minerals; **low-grade ores** contain lesser amounts. Minerals may be **metals**, such as iron, aluminum, and copper, or **nonmetallic minerals**, such as phosphates, salt, and sand.

- **Describe several natural processes that concentrate minerals in Earth's crust.**

Magmatic concentration is the formation of mineral deposits as liquid magma separates into layers, cools, and solidifies. **Hydrothermal processes** form mineral deposits as hot water dissolves minerals from rock, and the solution seeps through cracks until the minerals encounter sulfur, react to produce metal sulfides, cool, and settle out of solution. In **sedimentation**, certain minerals dissolve in water and later settle out of solution on riverbanks, deltas, and the seafloor. In **evaporation**, dissolved materials in lakes with no outlet form mineral deposits when the water evaporates and the materials are left behind.

- **Distinguish between surface mining and subsurface mining.**

Surface mining is the extraction of mineral and energy resources near Earth's surface by first removing the soil, subsoil, and overlying rock strata. In **strip mining**, a type of surface mining, a trench is dug to extract the minerals. **Subsurface mining** is the extraction of mineral and energy resources from deep underground deposits.

- **Briefly describe how mineral deposits are discovered, extracted, and processed.**

Detailed geologic surveys determine the location of mineral deposits. If the deposit is near the surface, it is extracted by surface mining, in which the **overburden**, soil and rock overlying a useful mineral deposit, is first removed. A **spoil bank** is a hill of loose rock created when the overburden from a new trench is put into the already excavated trench during strip mining. Processing minerals often involves **smelting**, in which ore is melted at high temperatures to separate impurities from the molten metal.

- **Explain the environmental impacts of mining and refining minerals, including a brief description of acid mine drainage.**

Surface mining disturbs the land more than subsurface mining, but subsurface mining is more expensive and dangerous. **Acid mine drainage** is pollution caused when sulfuric acid and toxic dissolved materials such as lead, arsenic, and cadmium wash from mines into nearby lakes and streams. **Tailings**, the impurities that make up about 80% of mined ore, are often left in giant piles near mineral-processing plants. Mercury, cyanide, uranium, and sulfuric acid leach into the soil and water from tailings. Unless pollution-control devices are used, smelting plants may emit large amounts of air pollutants during mineral processing.

- **Explain how mining lands can be restored.**

Derelict lands are extensively damaged due to mining but can be restored to prevent further degradation and to make the land productive for other purposes. Land reclamation is expensive, and no federal law exists to require restoration of derelict lands other than those produced by coal mines.

- **Describe the relationship between a country's level of industrialization and its mineral consumption.**

Highly developed countries consume a disproportionate share of the world's minerals, but as developing countries industrialize, their need for minerals increases. China's mineral production and consumption are increasing rapidly.

- **Distinguish between mineral reserves and mineral resources.**

Mineral reserves are mineral deposits that have been identified and are currently profitable to extract. **Mineral resources** are any undiscovered mineral deposits or known deposits of low-grade ore that are currently unprofitable to extract.

- **Briefly discuss efforts to discover new mineral supplies.**

Mineral deposits will probably be discovered in some developing countries when they are surveyed geologically. Minerals that possibly exist in Antarctica may be mined in the future, but current international law protects Antarctica from such activities. Mineral deposits in ocean water and on the ocean floor may be mined in the future. Advanced mining technology may make it possible to profitably extract minerals from inaccessible regions or from low-grade ores.

- **Summarize the conservation of minerals by reuse, recycling, and changing our mineral requirements.**

Substitution and conservation extend mineral supplies. Manufacturing industries try to substitute more common, less expensive minerals for scarce and expensive minerals. **Reuse** is the conservation of the resources in used items by using them over and over again. **Recycling** is the conservation of the resources in used items by converting them into new products.

- **Explain how sustainable manufacturing and dematerialization contribute to mineral conservation.**

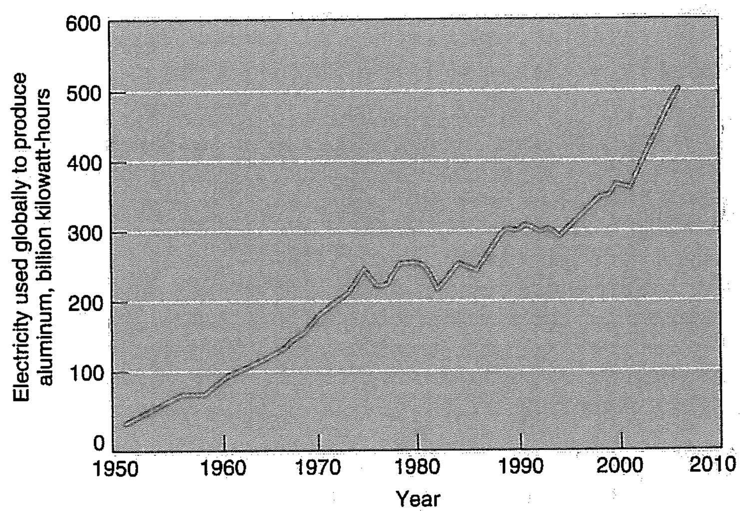
Sustainable manufacturing is a manufacturing system based on minimizing industrial waste. **Industrial ecology** is an extension of the concept of sustainable manufacturing, in which resources are used efficiently and "wastes" are regarded as potential products. **Dematerialization** is the decrease in size and weight of a product as a result of technological improvements over time. Dematerialization reduces consumption only if products are durable and easily and inexpensively repaired.

ritical Thinking and Review Questions

1. What is the difference between rocks and minerals? Between metals and nonmetallic minerals?
2. Distinguish between surface and subsurface mining, between open-pit and strip mines, and between shaft and slope mines.
3. How does the cartoon below relate to the General Mining Law of 1872? How does it reflect the environmental effects of strip mining versus subsurface mining?

ScienceCartoonsPlus.com

4. What is overburden? A spoil bank? Smelting? Tailings?
5. Explain why it is more environmentally damaging to obtain minerals from low-grade ores than to extract them from high-grade ores.
6. Historically, the cost of environmental damage arising from mining and processing minerals was not included in the price of consumer products. Do you think it should be? Why or why not?
7. How did Copper Basin, Tennessee, become an environmental disaster? What efforts have aided in its recovery?
8. Compare mineral consumption in the United States, China, and a poorer country such as Nigeria. Which has experienced the most rapid increase in mineral consumption in recent years? Why?
9. Why do we have to distinguish between mineral resources and mineral reserves when making projections about how long a specific mineral will be available? Why it is difficult to obtain an accurate appraisal of total resources for a particular mineral?
10. What are manganese nodules? Why have these known deposits not been mined?
11. Have mineral deposits been mined in Antarctica? Why or why not?
12. Sketch mineral flow in a traditional industrialized society. Make sure you include mines, mills, factories, homes, and businesses. Now sketch mineral flow in a low-waste industrialized society. Which diagram is more complex, and why?
13. Some people in industry argue that the planned obsolescence of products, which means they must be replaced often, creates jobs. Others think that the production of smaller quantities of durable, repairable products would generate jobs and stimulate the economy. Explain each viewpoint.
14. How does the industrial ecosystem at Kalundborg, Denmark, resemble a natural ecosystem? Would this approach produce more or fewer greenhouse gases than if the same energy and products were produced using traditional industrial practices? Explain.
15. Examine the graph, which shows the increase in world use of electricity for mining and refining virgin aluminum since the 1950s. Given that the production of aluminum has become more energy-efficient, how do you account for the current global increase in electricity used in aluminum production?



(Adapted from: *Vital Signs 2007-2008*. New York: W.W. Norton & Company, 2007)

Food for Thought

Mining and farming can often be linked. What are some examples of mined minerals that are important to the production of food and livestock? What environmental effects might poor mining practices have on agriculture?