CHAPTER 23

Materials Management

College student on campus texting on a smartphone. These phones are e-waste when disposed of, but the plastic and metals in them can be recycled for a profit.

LEARNING OBJECTIVES

The waste-management concept of "dilute and disperse" (for example, dumping waste into a river) is a holdover from our frontier days, when we mistakenly believed that land and water were limitless resources. We next attempted to "concentrate and contain" waste in disposal sites—which also proved to pollute land, air, and water. We are now focusing on *managing materials* to reduce environmental degradation associated with resource use and eventually eliminate waste entirely. Finally, we are getting it right! After reading this chapter, you should understand . . .

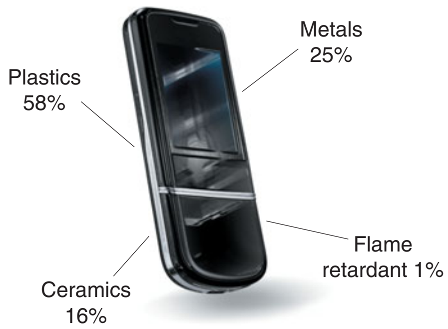
- That the standard of living in modern society is related in part to the availability of natural resources;
- The importance of resources to society;
- The differences between mineral resources and reserves;
- The factors that control the environmental impact of mineral exploitation;
- How wastes generated from the use of mineral resources affect the environment;
- The social impacts of mineral exploitation;
- How sustainability may be linked to the way we use nonrenewable minerals.
- The emerging concept of *materials management* and how to achieve it;
- The advantages and disadvantages of each of the major methods that constitute integrated waste management;
- The various methods of managing hazardous chemical waste;
- The problems related to ocean dumping and why they will likely persist for some time.

CASE STUDY

Treasures of the Cell Phone

The number of people who use cell phones in the United States has risen from about 5 million in 1990 to nearly 200 million today. In 2009 more than 1 billion cell phones were sold worldwide, about half of them in Asia and Japan. Along with calls, text messaging, and video, cell phones have connected us as never before (see opening photograph). Cell phones are commonly replaced every two to three years as new features and services become available—witness the iPhone's popularity in 2008 when the new phones came out. Each cell phone is small, but the millions of phones retired each year in the United States collectively contain a treasure chest of valuable metals worth over $300 million, not counting the cost of recycling (Table 23.1). Worldwide, their value probably exceeds a billion dollars, but although the money potentially available is attractive, a very small percentage of discarded cell phones are recycled. Most end up stored in our closets or disposed of at municipal solid-waste facilities.

The life cycle of a cell phone is shown in Figure 23.1 and is typical of most electronic waste (e-waste).[1] The primary reason more e-waste is not recycled is that we lack a simple, effective, small-scale, inexpensive way to do it. We also need to better educate people about the environmental value of recycling and to offer more attractive financial incentives to do it. Some states (California,



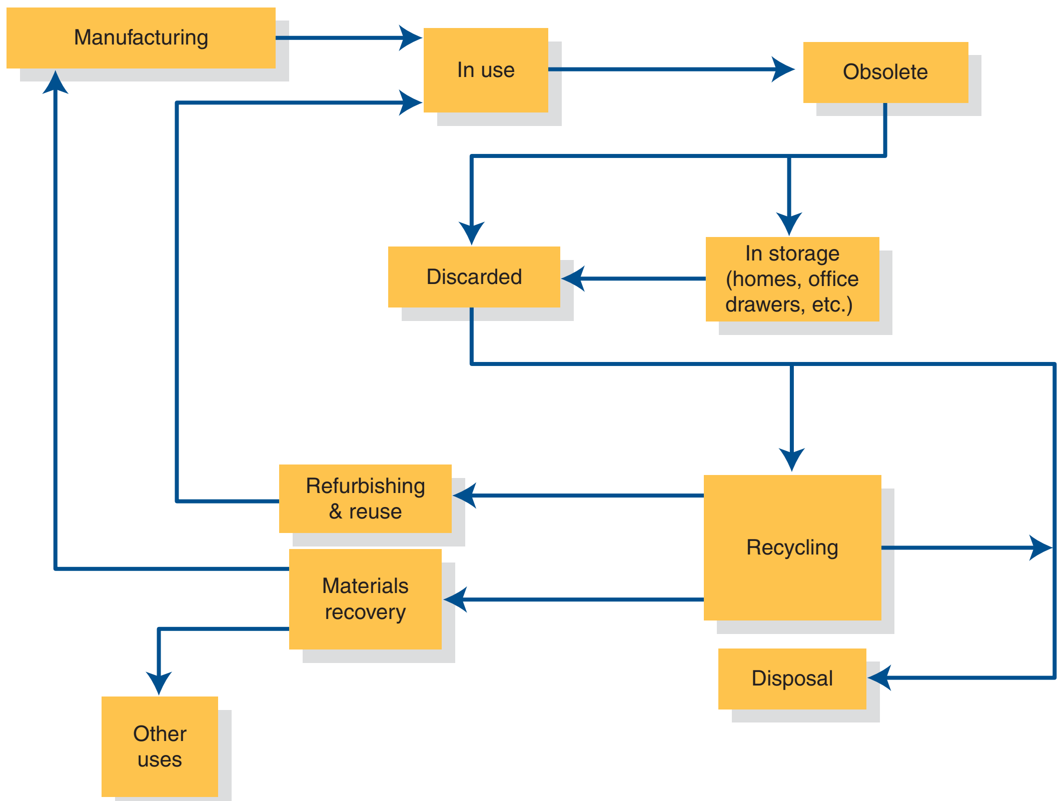


FIGURE 23.1 Composition and life cycle of a cell phone. (*Source*: Modified from D.E. Sullivan, 2006, "Recycled Cell Phones—A Treasure Trove of Valuable Metals," U.S. Geological Survey Fact Sheet 2006–3097.)

Table 23.1 METAL CONTENT AND VALUE OF U.S. CELL PHONES, NOT COUNTING COST TO RECYCLE

	METAL CONTENT AND VALUE ESTIMATED FOR A TYPICAL CELL PHONE		METAL CONTENT AND VALUE FOR 500 MILLION OBSOLETE CELL PHONES IN STORAGE IN 2005	
METAL	WT (g)	VALUE	WT (t)	VALUE
Copper	16	$0.03	7,900	$17 million
Silver	0.35	$0.06	178	$31 million
Gold	0.034	$0.40	17	$199 million
Palladium	0.015	$0.13	7.4	$63 million
Platinum	0.00034	$0.01	0.18	$3.9 million
Total		$0.63	8,102	$314 million

Source: Modified from Sullivan, D.E., 2006. Recycled cell phones—A treasure trove of valuable metals. U.S. Geological Survey Fast Sheet 2006–3097.

for example) have laws that require building the recycling costs into the prices of products.

Our failure to manage cell phones and other e-waste reminds us that we have failed in the past 50 years to move from a throwaway, waste-oriented society to a society that sustains natural resources through improved materials management. In some cases we are moving in that direction by producing less waste and recycling more discarded products. With this in mind, in this chapter we introduce concepts of waste management applied to urban waste, hazardous chemical waste, and waste in the marine environment.

23.1 The Importance of Resources to Society

Modern society depends on the availability of both **renewable resources** (air, surface water, some groundwater, plants, animals, and some energy sources) and **nonrenewable** resources (soil, some groundwater, oil, coal, and most minerals).[2-4] What partially differentiates renewable from nonrenewable resources is their availability in a human time framework. Air and water, along with biological resources such as fish and crops, are regularly replenished as long as the processes that renew them continue to operate at an adequate rate. Nonrenewable resources, such as oil and minerals, even those that are being replenished by Earth processes today, are not being replenished in a time frame useful to people. Thus, strategies to use resources sustainably are linked to specific resources. We can sustain water resources by careful water management (see Chapter 18), but sustaining minerals or oil requires strategies linked more to conservation, recycling, reuse, and substitution than to management of next year's supply delivered by Earth processes.

Many products made from both renewable and nonrenewable resources are found and consumed in a typical American home (see Figure 23.2 for nonrenewable minerals used in a home office). Consider this morning's breakfast (food is a renewable resource). You probably drank from a glass made primarily of sand; ate from dishes made of clay; flavored your food with salt mined from Earth; ate fruit grown with the aid of fertilizers, such as potassium carbonate (potash) and phosphorus; and used utensils made of stainless steel, which comes from processing iron ore and other minerals. While eating your tasty renewable resources, you may have viewed the news on a television or computer screen, listened to music on your iPod, or made appointments using your cell phone. All these electronic items are made from metals and petroleum.

Resources are vital to people, and the standard of living increases with their availability in useful forms. Indeed, the availability of resources is one measure of a society's wealth. Those who have been most successful in locating and extracting or importing and using resources have grown and prospered. Without resources to grow food, construct buildings and roads, and manufacture everything from computers to televisions to automobiles, modern technological civilization as we know it would not be possible. For example, to maintain our standard of living in the United States, each person requires about 10 tons of nonfuel minerals per year.[5] We use other resources, such as food and water, in much greater amounts.

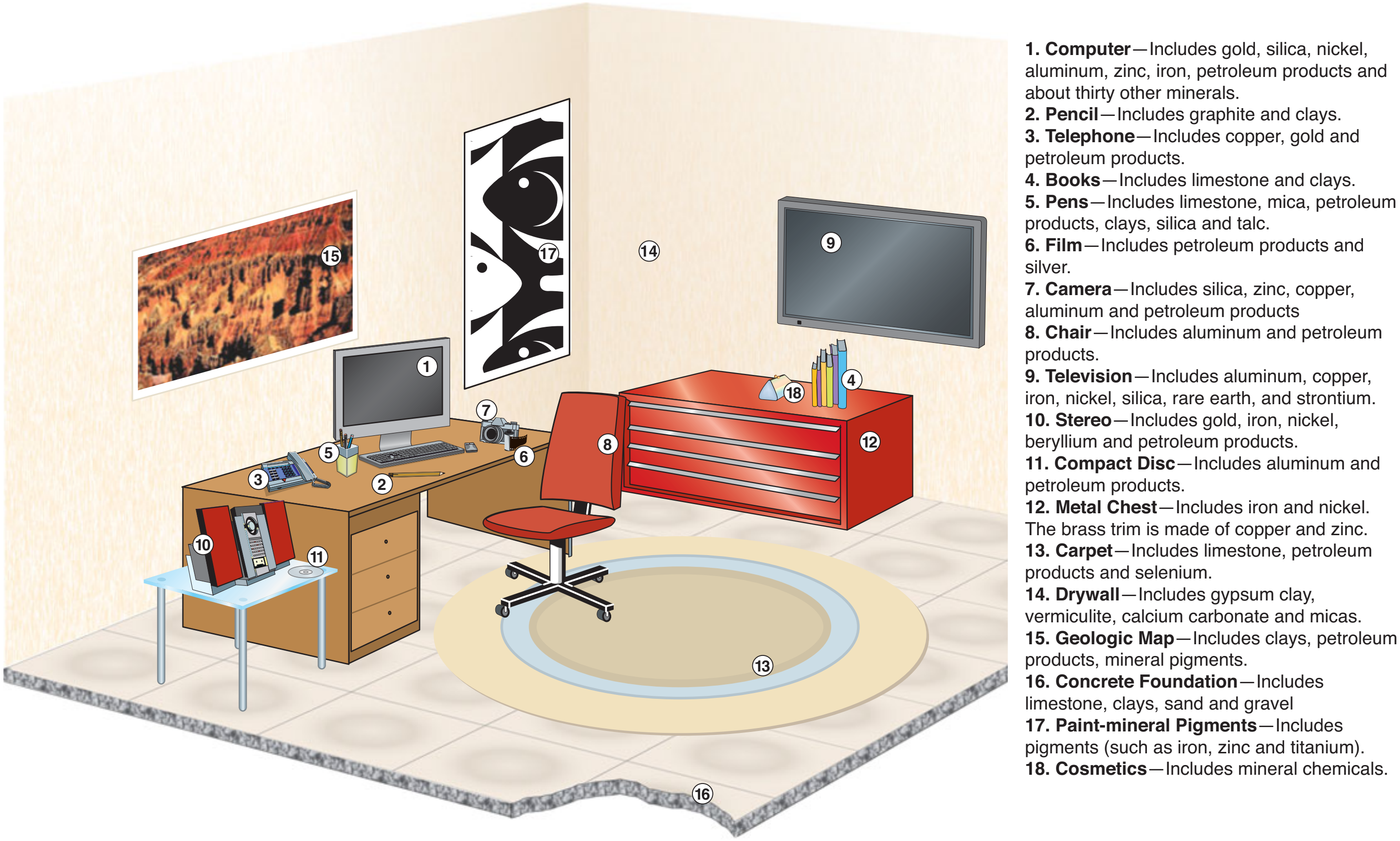


FIGURE 23.2 Mineral products used in a home office. (*Source*: Modified from S.J. Kropschot and K.M. Johnson, 2006. U.S. 65. Mineral Resources Program. USGS Circular 1289. Menlo Park, CA)

23.2 Materials Management: What It Is

Materials management has the visionary environmental goal of sustainably obtaining and using renewable and nonrenewable resources. This goal can be pursued in the following ways:[6]

- Eliminate subsidies for extracting virgin materials such as minerals, oil, and timber.
- Establish "green building" incentives that encourage the use of recycled-content materials and products in new construction.
- Assess financial penalties for production that uses poor materials-management practices.
- Provide financial incentives for industrial practices and products that benefit the environment by enhancing sustainability (for example, by reducing waste production and using recycled materials).
- Provide more incentives for people, industry, and agriculture to develop materials-management programs that eliminate or reduce waste by using it as raw material for other products.

Materials management in the United States today is beginning to influence where industries are located. For example, because approximately 50% of the steel produced in the nation now comes from scrap, new steel mills are no longer located near resources such as coal and iron ore. New steel mills are now found in a variety of places, from California to North Carolina and Nebraska; their resource is the local supply of scrap steel. Because they are starting with scrap metal, the new industrial facilities use far less energy and cause much less pollution than older steel mills that must start with virgin iron ore.[7]

Similarly, the recycling of paper is changing where new paper mills are constructed. In the past, mills were built near forested areas where the timber for paper production was being logged. Today, they are being built near cities that have large supplies of recycled paper. New Jersey, for example, has 13 paper mills using recycled paper and 8 steel "mini-mills" producing steel from scrap metal. What is remarkable is that New Jersey has little forested land and no iron mines. Resources for the paper and steel mills come from materials already in use, exemplifying the power of materials management.[7]

We have focused on renewable resources in previous parts of this book (Chapter 11, agriculture; Chapter 12, forests; Chapter 13, wildlife; Chapter 18, water; and Chapter 21, air). We discussed nonrenewable resources with respect to fossil fuels in Chapter 15. The remainder of this chapter will discuss other nonrenewable mineral resources and how to sustain them as long as possible by intelligent waste management.

23.3 Mineral Resources

Minerals can be considered a very valuable, nonrenewable heritage from the geologic past. Although new deposits are still forming from Earth processes, these processes are producing new deposits too slowly to be of use to us today or anytime soon. Also, because mineral deposits are generally in small, hidden areas, they must be discovered, and unfortunately most of the easy-to-find deposits have already been discovered and exploited. Thus, if modern civilization were to vanish, our descendants would have a harder time finding rich mineral deposits than we did. It is interesting to speculate that they might mine landfills for metals thrown away by our civilization. Unlike biological resources, minerals cannot be easily managed to produce a sustained yield; the supply is finite. Recycling and conservation will help, but, eventually, the supply will be exhausted.

How Mineral Deposits Are Formed

Metals in mineral form are generally extracted from naturally occurring, unusually high concentrations of Earth materials. When metals are concentrated in such high amounts by geologic processes, **ore deposits** are formed. The discovery of natural ore deposits allowed early peoples to exploit copper, tin, gold, silver, and other metals while slowly developing skills in working with metals.

The origin and distribution of mineral resources is intimately related to the history of the biosphere and to the entire geologic cycle (see Chapter 6). Nearly all aspects and processes of the geologic cycle are involved to some extent in producing local concentrations of useful materials. Earth's outer layer, or crust, is silica-rich, made up mostly of rock-forming minerals containing silica, oxygen, and a few other elements. The elements are not evenly distributed in the crust: Nine elements account for about 99% of the crust by weight (oxygen, 45.2%; silicon, 27.2%; aluminum, 8.0%; iron, 5.8%; calcium, 5.1%; magnesium, 2.8%; sodium, 2.3%; potassium, 1.7%; and titanium, 0.9%). In general, the remaining elements are found in trace concentrations.

The ocean, covering nearly 71% of Earth, is another reservoir for many chemicals other than water. Most elements in the ocean have been weathered from crustal rocks on the land and transported to the oceans by rivers. Others are transported to the ocean by wind or glaciers. Ocean water contains about 3.5% dissolved solids, mostly chlorine (55.1% of the dissolved solids by weight). Each cubic kilometer of ocean water contains about 2.0 metric tons of zinc, 2.0 metric tons of copper, 0.8 metric ton of tin, 0.3 metric ton of silver, and 0.01 metric ton of gold. These concentrations are low compared with those in the crust, where corresponding values (in metric tons/km^3) are zinc, 170,000; copper, 86,000; tin, 5,700; silver, 160; and gold, 5. After rich crustal ore deposits are depleted, we will be more likely to extract metals from lower-grade deposits or even from common rock than from ocean water, unless mineral-extraction technology becomes more efficient.

Why do the minerals we mine occur in deposits—with anomalously high local concentrations? Planetary scientists now believe that all the planets in our solar system were formed by the gravitational attraction of the forming sun, which brought together the matter dispersed around it. As the mass of the proto-Earth increased, the material condensed and was heated by the process. The heat was sufficient to produce a molten liquid core, consisting primarily of iron and other heavy metals, which sank toward the center of the planet. When molten rock material known as *magma* cools, heavier minerals that crystallize (solidify) early may slowly sink toward the bottom of the magma, whereas lighter minerals that crystallize later are left at the top. Deposits of an ore of chromium, called chromite, are thought to be formed in this way. When magma containing small amounts of carbon is deeply buried and subjected to very high pressure during slow cooling (crystallization), diamonds (which are pure carbon) may be produced (Figure 23.3).[8, 9]

Earth's crust formed from generally lighter elements and is a mixture of many different kinds. The elements in the crust are not uniformly distributed because geologic processes (such as volcanic activity, plate tectonics, and sedimentary processes), as well as some biological processes, selectively dissolve, transport, and deposit elements and minerals.

FIGURE 23.3 Diamond mine near Kimberley, South Africa. This is the largest hand-dug excavation in the world.

Sedimentary processes related to the transport of sediments by wind, water, and glaciers often concentrate materials in amounts sufficient for extraction. As sediments are transported, running water and wind help segregate them by size, shape, and density. This sorting is useful to people. The best sand or sand and gravel deposits for construction, for example, are those in which the finer materials have been removed by water or wind. Sand dunes, beach deposits, and deposits in stream channels are good examples. The sand and gravel industry amounts to several billion dollars annually and, in terms of the total volume of materials mined, is one of the largest nonfuel mineral industries in the United States.[5]

Rivers and streams that empty into oceans and lakes carry tremendous quantities of dissolved material from the weathering of rocks. Over geologic time, a shallow marine basin may be isolated by tectonic activity that uplifts its boundaries, or climate variations, such as the ice ages, may produce large inland lakes with no outlets. As these basins and lakes eventually dry up, the dissolved materials drop out of solution and form a wide variety of compounds, minerals, and rocks that have important commercial value.[10]

Biological processes form some mineral deposits, such as phosphates and iron ore deposits. The major iron ore deposits exist in sedimentary rocks that were formed more than 2 billion years ago.[10] Although the processes are not fully understood, it appears that major deposits of iron stopped forming when the atmospheric concentration of oxygen reached its present level.[11]

Organisms, too, form many kinds of minerals, such as the calcium minerals in shells and bones. Some of these minerals cannot be formed inorganically in the biosphere. Thirty-one biologically produced minerals have been identified.[12]

Weathering, the chemical and mechanical decomposition of rock, concentrates some minerals in the soil, such as native gold and oxides of aluminum and iron. (The more soluble elements, such as silica, calcium, and sodium, are selectively removed by soil and biological processes.) If sufficiently concentrated, residual aluminum oxide forms an ore of aluminum known as bauxite. Important nickel and cobalt deposits are also found in soils developed from iron- and magnesium-rich igneous rocks.

23.4 Figuring Out How Much Is Left

Estimating how much is left of our valuable and nonrenewable mineral resources will help us estimate how long they are likely to last at our present rate of use and motivate us to do everything we can to sustain them as long as possible for future generations. We can begin by looking at the classification of minerals as *resources* and *reserves*.

Mineral Resources and Reserves

Mineral **resources** are broadly defined as known concentrations of elements, chemical compounds, minerals, or rocks. Mineral **reserves** are concentrations that at the time of evaluation can be legally and economically extracted as a commodity that can be sold at a profit (Figure 23.4).

The main point here is that *resources are not reserves*. An analogy from a student's personal finances may help clarify this point. A student's reserves are liquid assets, such as money in the bank, whereas the student's resources include the total income the student can expect to earn during his or her lifetime. This distinction is often critical to the student in school because resources that may become available in the future cannot be used to pay this month's bills.[6] For planning purposes, it is important to continually reassess all components of a total resource, considering new technology, the probability of geologic discovery, and shifts in economic and political conditions.[13]

Availability and Use of Our Mineral Resources

Earth's mineral resources can be divided into broad categories according to their use: elements for metal production and technology, building materials, minerals for the chemical industry, and minerals for agriculture. Metallic minerals can be further classified by their abundance. Abundant metals include iron, aluminum, chromium, manganese, titanium, and magnesium. Scarce metals include copper, lead, zinc, tin, gold, silver, platinum, uranium, mercury, and molybdenum.

Some minerals, such as salt (sodium chloride), are necessary for life. Primitive peoples traveled long distances

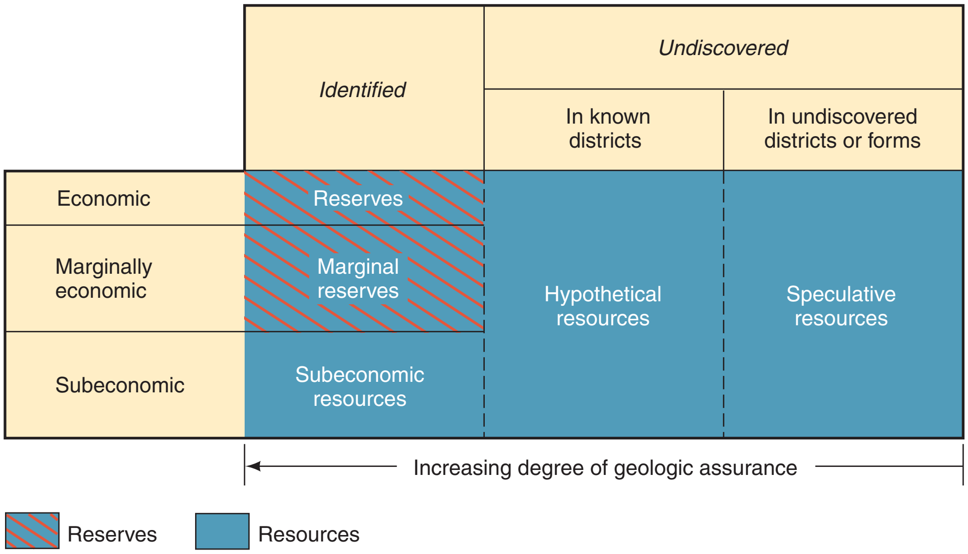


FIGURE 23.4 Classification of mineral resources used by the U.S. Geological Survey and the U.S. Bureau of Mines. (*Source: Principles of a Resource Preserve Classification for Minerals*, U.S. Geological Survey Circular 831, 1980.)

to obtain salt when it was not locally available. Other minerals are desired or considered necessary to maintain a particular level of technology.

When we think about minerals, we usually think of metals; but with the exception of iron, the predominant minerals are not metallic. Consider the annual world consumption of a few selected elements. Sodium and iron are used at a rate of approximately 100–1,000 million metric tons per year; and nitrogen, sulfur, potassium, and calcium at a rate of approximately 10–100 million metric tons per year, primarily as soil conditioners or fertilizers. Elements such as zinc, copper, aluminum, and lead have annual world consumption rates of about 3–10 million metric tons, and gold and silver are consumed at annual rates of 10,000 metric tons or less. Of the metallic minerals, iron makes up 95% of all the metals consumed; and nickel, chromium, cobalt, and manganese are used mainly in alloys of iron (as in stainless steel).

The basic issue associated with mineral resources is not actual exhaustion or extinction but the cost of maintaining an adequate stock by mining and recycling. At some point, the costs of mining exceed the worth of material. When the availability of a particular mineral becomes limited, there are four possible solutions:

1. Find more sources.
2. Recycle and reuse what has already been obtained.
3. Reduce consumption.
4. Find a substitute.

Which choice or combination of choices is made depends on social, economic, and environmental factors.

U.S. Supply of Mineral Resources

Domestic supplies of many mineral resources in the United States are insufficient for current use and must be supplemented by imports from other nations. For example, the United States imports many of the minerals needed for its complex military and industrial system, called strategic minerals (such as bauxite, manganese, graphite, cobalt, strontium, and asbestos). Of particular concern is the possibility that the supply of a much-desired or much-needed mineral will be interrupted by political, economic, or military instability in the supplying nation.

That the United States—along with many other countries—depends on a steady supply of imports to meet its domestic demand for them does not necessarily mean that sufficient kinds and amounts can't be mined domestically. Rather, it suggests economic, political, or environmental reasons that make it easier, more practical, or more desirable to import the material. This has resulted in political alliances that otherwise would be unlikely. Industrial countries often need minerals from countries whose policies they don't necessarily agree with; as a result they make political concessions, on human rights and other issues, that they would not otherwise make.[3]

Moreover, the fact remains that mineral resources are limited, and this raises important questions. How long will a particular resource last? How much short-term or long-term environmental deterioration are we willing to accept to ensure that resources are developed in a particular area? How can we make the best use of available resources?

23.5 Impacts of Mineral Development

The impact of mineral exploitation depends on ore quality, mining procedures, local hydrologic conditions, climate, rock types, size of operation, topography, and many more interrelated factors. In addition, our use of mineral resources has a significant social impact.

Environmental Impacts

Exploration for mineral deposits generally has a minimal impact on the environment if care is taken in sensitive areas, such as arid lands, marshes, and areas underlain by permafrost. Mineral mining and processing, however, generally have a considerable impact on land, water, air, and living things. Furthermore, as it becomes necessary to use ores of lower and lower grades, the environmental effects tend to worsen. One example is the asbestos fibers in the drinking water of Duluth, Minnesota, from the disposal of waste from mining low-grade iron ore.

A major practical issue is whether open-pit or underground mines should be developed in an area. As you saw in our earlier discussion of coal mining in Chapter 15, there are important differences between the two kinds of mining.[2] The trend in recent years has been away from subsurface mining and toward large, open-pit mines, such as the Bingham Canyon copper mine in Utah (Figure 23.5). The Bingham Canyon mine is one of the world's largest man-made excavations, covering nearly 8 km^2 (3 mi^2) to a maximum depth of nearly 800 m (2,600 ft).

Surface mines and quarries today cover less than 0.5% of the total area of the United States, but even though their impacts are local, numerous local occurrences will eventually constitute a larger problem. Environmental degradation tends to extend beyond the immediate vicinity of a mine. Large mining operations remove material in some areas and dump waste in others, changing topography. At the very least, severe aesthetic degradation is the result. In addition, dust may affect the air quality, even though care is taken to reduce it by sprinkling water on roads and on other sites that generate dust.

A potential problem with mineral resource development is the possible release of harmful trace elements into the environment. Water resources are particularly vulnerable even if drainage is controlled and sediment pollution is reduced (see Chapter 15 for more about this, including a discussion of acid mine drainage). The white streaks in Figure 23.6 are mineral deposits apparently leached from tailings from a zinc mine in Colorado. Similar-looking deposits may cover rocks in rivers for many kilometers downstream from some mining areas.

FIGURE 23.5 Aerial photograph of Bingham Canyon Copper Pit, Utah. It is one of the largest artificial excavations in the world.

FIGURE 23.6 Tailings from a lead, zinc, and silver mine in Colorado. White streaks on the slope are mineral deposits apparently leached from the tailings.

Mining-related physical changes in the land, soil, water, and air indirectly affect the biological environment. Plants and animals killed by mining activity or by contact with toxic soil or water are some of the direct impacts. Indirect impacts include changes in nutrient cycling, total biomass, species diversity, and ecosystem stability. Periodic or accidental discharge of low-grade pollutants through failure of barriers, ponds, or water diversions, or through the breaching of barriers during floods, earthquakes, or volcanic eruptions, also may damage local ecological systems to some extent.

Social Impacts

The social impacts of large-scale mining result from the rapid influx of workers into areas unprepared for growth. This places stress on local services, such as water supplies, sewage and solid-waste disposal systems, and also on schools, housing, and nearby recreation and wilderness areas. Land use shifts from open range, forest, and agriculture to urban patterns. Construction and urbanization affect local streams through sediment pollution, reduced water quality, and increased runoff. Air quality suffers as a result of more vehicles, construction dust, and power generation.

Perversely, closing down mines also has adverse social impacts. Nearby towns that have come to depend on the income of employed miners can come to resemble the well-known "ghost towns" of the old American West. The price of coal and other minerals also directly affects the livelihood of many small towns. This is especially evident in the Appalachian Mountain region of the United States, where coal mines have closed partly because of lower prices for coal and partly because of rising mining costs. One of the reasons mining costs are rising is the increased level of environmental regulation of the mining industry. Of course, regulations have also helped make mining safer and have facilitated land reclamation. Some miners, however, believe the regulations are not flexible enough, and there is some truth to their arguments. For example, some mined areas might be reclaimed for use as farmland now that the original hills have been leveled. Regulations, however, may require the restoration of the land to its original hilly state, even though hills make inferior farmland.

Minimizing the Environmental Impact of Mineral Development

Minimizing the environmental impacts of mineral development requires consideration of the entire cycle of mineral resources shown in Figure 23.7. This diagram reveals that waste is produced by many components of the cycle. In fact, the major environmental impacts of mineral use are related to waste products. Waste produces pollution that may be toxic to people, may harm natural ecosystems and the biosphere, and may be aesthetically displeasing. Waste may attack and degrade air, water, soil, and living things. Waste also depletes nonrenewable mineral resources and, when simply disposed of, provides no offsetting benefits for human society.

Environmental regulations at the federal, state, and local levels address pollution of air and water by all aspects of the mineral cycle, and may also address reclamation of land used for mining minerals. Today, in the United States, approximately 50% of the land used by the mining industry has been reclaimed.

Minimizing the environmental effects of mining takes several interrelated paths:[3]

- *Reclaiming* areas disturbed by mining (see A Closer Look 23.1).
- *Stabilizing soils* that contain metals to minimize their release into the environment. Often this requires placing contaminated soils in a waste facility.
- *Controlling air emissions* of metals and other materials from mining areas.
- *Treating contaminated water before it can leave a mining site or treating contaminated water that has left a mining site.*
- *Treating waste onsite and offsite.* Minimizing onsite and offsite problems by controlling sediment, water, and air pollution through good engineering and conservation practices is an important goal. Of particular interest is the development of biotechnological processes such as biooxidation, bioleaching, and biosorption, the bonding of waste to microbes, as well as genetic engineering of microbes. These practices have enormous potential for both extracting metals and minimizing environmental degradation. At several sites, for example, constructed wetlands use acid-tolerant plants to remove metals from mine wastewaters and neutralize acids by biological activity.[14] The Homestake Gold Mine in South Dakota uses biooxidation to convert contaminated water from the mining operation into substances that are environmentally safe; the process uses bacteria that have a natural ability to oxidize cyanide to harmless nitrates.[15]
- *Practicing the three R's of waste management.* That is, **R**educe the amount of waste produced, **R**euse waste as much as possible, and maximize **R**ecycling opportunities. Wastes from some parts of the mineral cycle, for example, may themselves be considered ores because they contain materials that might be recycled to provide energy or other products.[16–18]

We will look at the three R's in greater detail in Section 23.7, Integrated Waste Management.

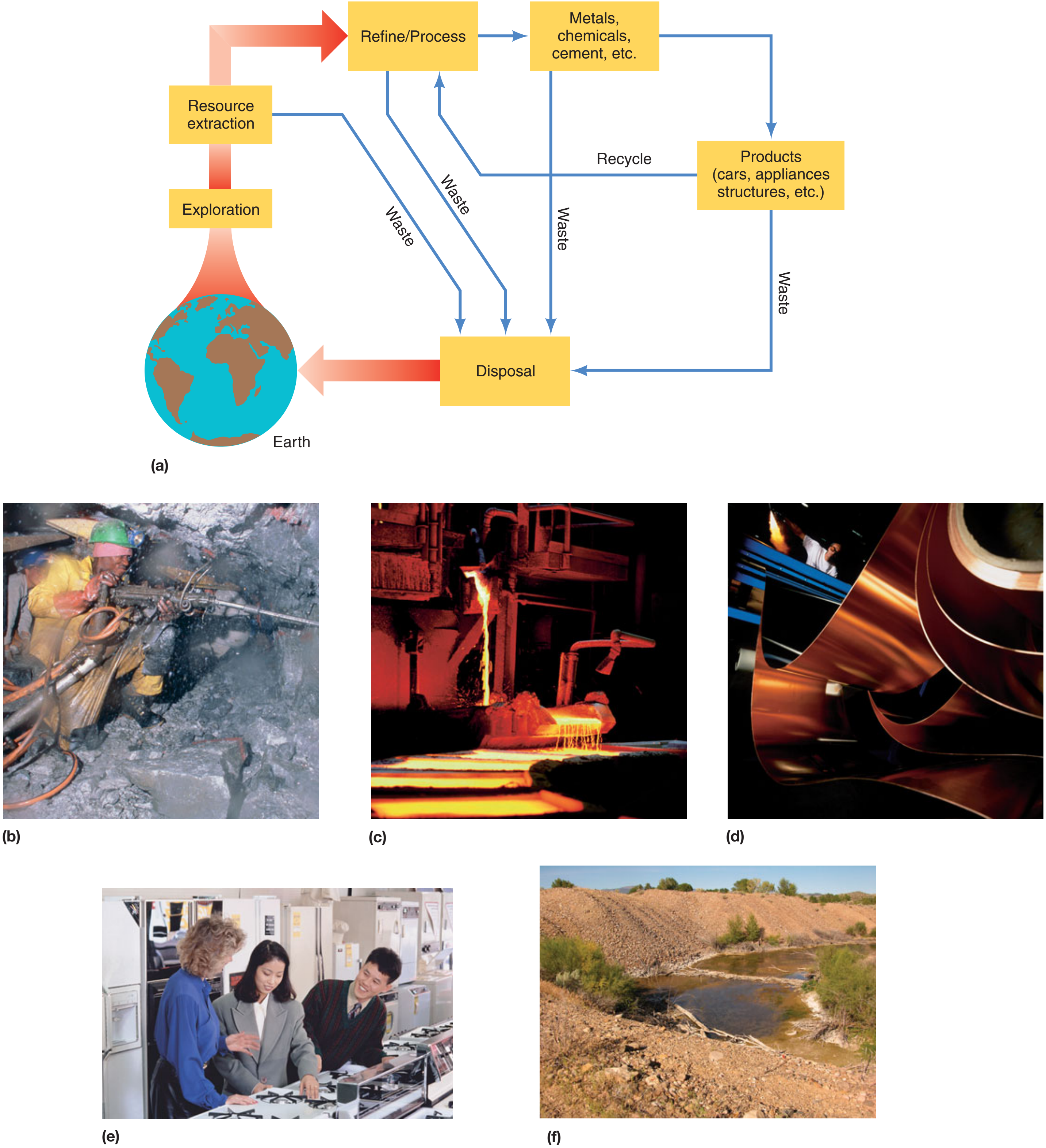


FIGURE 23.7 **(a)** Simplified flowchart of the resource cycle: **(b)** mining gold in South Africa; **(c)** copper smelter, Montana; **(d)** sheets of copper for industrial use; **(e)** appliances made in part from metals; and **(f)** disposal of mining waste from a Montana gold mine into a tailings pond.

A CLOSER LOOK 23.1

Golden, Colorado: Open-Pit Mine Becomes a Golf Course

The city of Golden, Colorado, has an award-winning golf course on land that, for about 100 years, was an open-pit mine (quarry) excavated in limestone rock (Figure 23.8). The mine produced clay for making bricks from clay layers between limestone beds. Over the life of the mine, the clay was used as a building material at many sites, including prominent buildings in the Denver area, such as the Colorado Governor's Mansion. The mine site included unsightly pits with vertical limestone walls as well as a landfill for waste disposal. However, it had spectacular views of the Rocky Mountain foothills. Today the limestone cliffs with their exposed plant and dinosaur fossils have been transformed into golf greens, fairways, and a driving range. The name Fossil Trace Golf Club reflects its geologic heritage. The course includes trails to fossil locations and also has channels, constructed wetlands, and three lakes that store floodwater runoff, helping to protect Golden from flash floods. The reclamation project started with a grassroots movement by the people of Golden to have a public golf course. The reclamation is now a moneymaker for the city and demonstrates that mining sites can not only be reclaimed, but also be transformed into valuable property.

FIGURE 23.8 This award-winning golf course in Golden, Colorado, was for a century an open-pit mine (quarry) for clay to produce bricks.

23.6 Materials Management and Our Waste

History of Waste Disposal

During the first century of the Industrial Revolution, the volume of waste produced in the United States was relatively small and could be managed using the concept of "dilute and disperse." Factories were located near rivers because the water provided a number of benefits, including easy transport of materials by boat, enough water for processing and cooling, and easy disposal of waste into the river. With few factories and a sparse population, dilute and disperse was sufficient to remove the waste from the immediate environment.[19]

As industrial and urban areas expanded, the concept of dilute and disperse became inadequate, and a new concept, "concentrate and contain," came into use. It has become apparent, however, that containment was, and is, not always achieved. Containers, whether simple trenches excavated in the ground or metal drums and tanks, may leak or break and allow waste to escape. Health hazards resulting from past waste-disposal practices have led to the present situation, in which many people have little confidence in government or industry to preserve and protect public health.[20]

In the United States and many other parts of the world, people are facing a serious solid-waste disposal problem. Basically, we are producing a great deal of waste and don't have enough acceptable space for disposing of it. It has been estimated that within the next few years approximately half the cities in the United States may run out of landfill space. Philadelphia, for example, is essentially out of landfill space now and is bargaining with other states on a monthly or yearly basis to dispose of its trash. The Los Angeles area has landfill space for only about ten more years.

To say we are actually running out of space for landfills isn't altogether accurate—land used for landfills is minute compared to the land area of the United States. Rather, existing sites are being filled, and it is difficult to site new landfills. After all, no one wants to live near a waste-disposal site, be it a sanitary landfill for municipal waste, an incinerator that burns urban waste, or a hazardous-waste disposal operation for chemical materials.

This attitude is widely known as NIMBY ("not in my backyard").

The environmentally correct concept with respect to waste management is to consider wastes as resources out of place. Although we may not soon be able to reuse and recycle all waste, it seems apparent that the increasing cost of raw materials, energy, transportation, and land will make it financially feasible to reuse and recycle more resources and products. Moving toward this objective is moving toward an environmental view that there is no such thing as waste. Under this concept, waste would not exist because it would not be produced—or, if produced, would be a resource to be used again. This is referred to as the "zero waste" movement.

Zero waste is the essence of what is known as **industrial ecology**, the study of relationships among industrial systems and their links to natural systems. Under the principles of industrial ecology, our industrial society would function much as a natural ecosystem functions. Waste from one part of the system would be a resource for another part.[21]

Until recently, zero waste production was considered unreasonable in the waste-management arena. However, it is catching on. The city of Canberra, Australia, may be the first community to propose a zero waste plan. Thousands of kilometers away, in the Netherlands, a national waste-reduction goal of 70 to 90% has been set. How this goal is to be met is not entirely clear, but a large part of the planning involves taxing waste in all its various forms, from smokestack emissions to solids delivered to landfills. Already, in the Netherlands, pollution taxes have nearly eliminated discharges of heavy metals into waterways. At the household level, the government is considering programs—known as "pay as you throw"—that would charge people by the volume of waste they produce. Taxing waste, including household waste, motivates people to produce less of it.[22]

Of particular importance to waste management is the growing awareness that many of our waste-management programs involve moving waste from one site to another, not really managing it. For example, waste from urban areas may be placed in landfills; but eventually these landfills may cause new problems by producing methane gas or noxious liquids that leak from the site and contaminate the surrounding areas. Managed properly, however, methane produced from landfills is a resource that can be burned as a fuel (an example of industrial ecology).

In sum, previous notions of waste disposal are no longer acceptable, and we are rethinking how we deal with materials, with the objective of eliminating the concept of waste entirely. In this way, we can reduce the consumption of minerals and other virgin materials, which depletes our environment, and live within our environment more sustainably.[21]

23.7 Integrated Waste Management

The dominant concept today in managing waste is known as **integrated waste management (IWM)**, which is best defined as a set of management alternatives that includes *reuse, source reduction, recycling, composting, landfill,* and *incineration*.[20]

Reduce, Reuse, Recycle

The ultimate objective of the three R's of IWM is to reduce the amount of urban and other waste that must be disposed of in landfills, incinerators, and other waste-management facilities. Study of the *waste stream* (the waste produced) in areas that use IWM technology suggests that the amount (by weight) of urban refuse disposed of in landfills or incinerated can be reduced by at least 50% and perhaps as much as 70%. A 50% reduction by weight could be achieved by (1) source reduction, such as packaging better designed to reduce waste (10% reduction); (2) large-scale composting programs (10% reduction); and (3) recycling programs (30% reduction).[20]

As this list indicates, recycling is a major player in reducing the urban waste stream. Metals such as iron, aluminum, copper, and lead have been recycled for many years and are still being recycled today. The metal from almost all of the millions of automobiles discarded annually in the United States is recycled.[16, 17] The total value of recycled metals is about $50 billion. Iron and steel account for approximately 90% by weight and 40% by total value of recycled metals. Iron and steel are recycled in such large volumes for two reasons. First, the market for iron and steel is huge, and as a result there is a large scrap-collection and scrap-processing industry. Second, an enormous economic and environmental burden would result from failure to recycle because over 50 million tons of scrap iron and steel would have to be disposed of annually.[17, 18]

Today in the United States we recycle over 30% of our total municipal solid waste, up 10% from 25 years ago. This amounts to 99% of automobile batteries, 63% of steel cans, 71% office type papers, 48% of aluminum cans, 35% of tires, 28% of glass containers, and about 30% of various plastic containers (Figure 23.9).[23] This is encouraging news. Can recycling actually reduce the waste stream by 50%? Recent work suggests that the 50% goal is reasonable. In fact, it has been reached in some parts of the United States, and the potential upper limit for recycling is considerably higher. It is estimated that as much as 80 to 90% of the U.S. waste stream might be recovered through what is known as "intensive recycling."[24] A pilot study involving 100 families in East Hampton, New York,

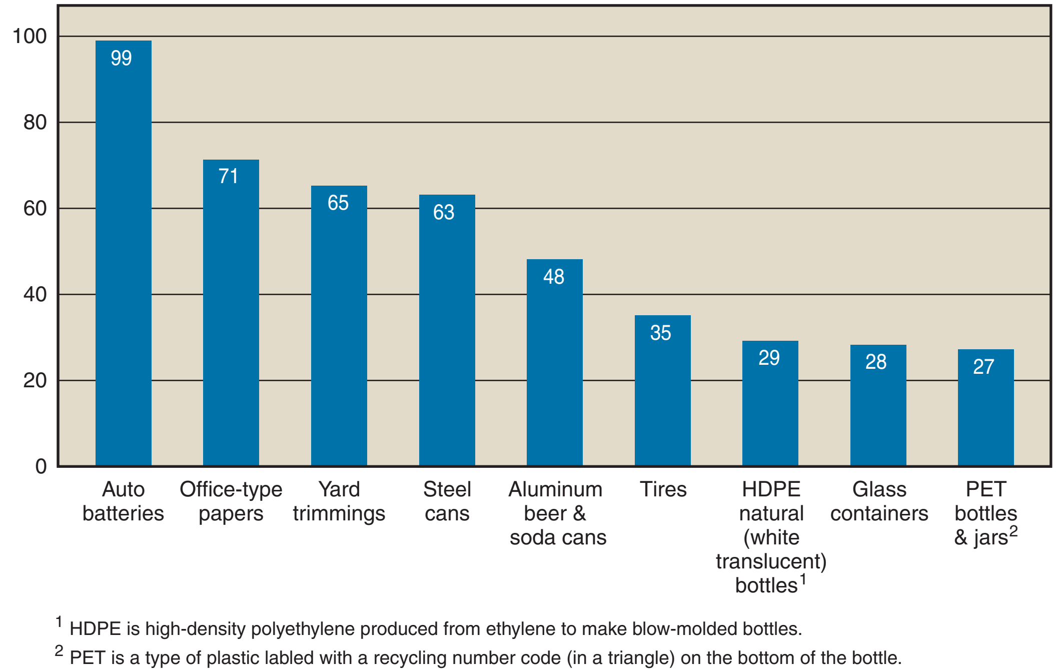


FIGURE 23.9 Recycling rates of selected materials from municipal solid waste in 2008 for the United States. (*Source*: Municipal solid-waste generation, recycling, and disposal in the United States: facts and figures 2008. Basic Information 2009. www.epa.gov.)

achieved a level of 84%. More realistic for many communities is partial recycling, which targets specific materials, such as glass, aluminum cans, plastic, organic material, and newsprint. Partial recycling can provide a significant reduction, and in many places it is approaching or even exceeding 50%.[25, 26]

Recycling is simplified with **single-stream recycling,** in which paper, plastic, glass, and metals are not separated before collection; the waste is commingled in one container and separated later at recycling centers. This is more convenient for homeowners, reduces the cost of collection, and increases the rate of recycling. Thus, single-stream recycling is growing rapidly.

Public Support for Recycling

An encouraging sign of public support for the environment is the increased willingness of industry and business to support recycling on a variety of scales. For example, fast-food restaurants are using less packaging and providing onsite bins for recycling paper and plastic. Groceries and supermarkets are encouraging the recycling of plastic and paper bags by providing bins for their collection, and some offer inexpensive reusable canvas shopping bags instead of disposables. Companies are redesigning products so that they can be more easily disassembled after use and the various parts recycled. As this idea catches on, small appliances, such as electric frying pans and toasters, may be recycled rather than ending up in landfills. The automobile industry is also responding by designing automobiles with coded parts so that they can be more easily disassembled (by professional recyclers) and recycled, rather than left to become rusting eyesores in junkyards.

On the consumer front, people are now more likely to purchase products that can be recycled or that come in containers that are more easily recycled or composted. Many consumers have purchased small home appliances that crush bottles and aluminum cans, reducing their volume and facilitating recycling. The entire arena is rapidly changing, and innovations and opportunities will undoubtedly continue.

As with many other environmental solutions, implementing the IWM concept successfully can be a complex undertaking. In some communities where recycling has been successful, it has resulted in glutted markets for recycled products, which has sometimes required temporarily stockpiling or suspending the recycling of some items. It is apparent that if recycling is to be successful, markets and processing facilities will also have to be developed to ensure that recycling is a sound financial venture as well as an important part of IWM.

Recycling of Human Waste

The use of human waste, or "night soil," on croplands is an ancient practice. In Asia, recycling of human waste has a long history. Chinese agriculture was sustained for thousands of years through collection of human waste, which was spread over agricultural fields. The practice grew, and by the early 20th century the land application of sewage was a primary disposal method in many metropolitan areas in countries including Mexico, Australia, and the United States.[27] Early uses of human waste for agriculture occasionally spread infectious diseases through bacteria, viruses, and parasites in waste applied to crops. Today, with the globalization of agriculture, we still see occasional warnings and outbreaks of disease from contaminated vegetables (see Chapter 19).

A major problem with recycling human waste is that, along with human waste, thousands of chemicals and metals flow through our modern waste stream. Even garden waste that is composted may contain harmful chemicals, such as pesticides.[27]

23.8 Municipal Solid-Waste Management

Municipal solid-waste management continues to be a problem in the United States and other parts of the world. In many areas, particularly in developing countries, waste-management practices are inadequate. These practices, which include poorly controlled open dumps and illegal roadside dumping, can spoil scenic resources, pollute soil and water, and pose health hazards.

Illegal dumping is a social problem as much as a physical one because many people are simply disposing of waste as inexpensively and as quickly as possible, perhaps not seeing their garbage as an environmental problem. If nothing else, this is a tremendous waste of resources, since much of what is dumped could be recycled or reused. In areas where illegal dumping has been reduced, the keys have been awareness, education, and alternatives. Education programs teach people about the environmental problems of unsafe, unsanitary dumping of waste, and funds are provided for cleanup and for inexpensive collection and recycling of trash at sites of origin.

We look next at the composition of solid waste in the United States and then go on to describe specific disposal methods: onsite disposal, composting, incineration, open dumps, and sanitary landfills.

Composition of Solid Waste

The average content of unrecycled solid waste likely to end up at a disposal site in the United States is shown in Figure 23.10. It is no surprise that paper is by far the most abundant component. However, considerable variation can be expected, based on factors such as land use, economic base, industrial activity, climate, and time of year.

People have many misconceptions about our waste stream.[28] With all the negative publicity about fast-food packaging, polystyrene foam, and disposable diapers, many people assume that these make up a large percentage of the waste stream and are responsible for the rapid filling of landfills. However, excavations into modern landfills using archaeological tools have cleared up some misconceptions. We now know that fast-food packaging accounts for only about 0.25% of the average landfill; disposable diapers, approximately 0.8%; and polystyrene products about 0.9%.[29] Paper is a major constituent in landfills, perhaps as much as 50% by volume and 40% by weight. The largest single item is newsprint, which accounts for as much as 18% by volume.[29] Newsprint is one of the major items targeted for recycling because big environmental dividends can be expected. However (and this is a value judgment), the need to deal with the major waste products doesn't mean that we need not cut down on our use of disposable diapers, polystyrene, and other paper products. In addition to creating a need for disposal, these products are made from resources that might be better managed.

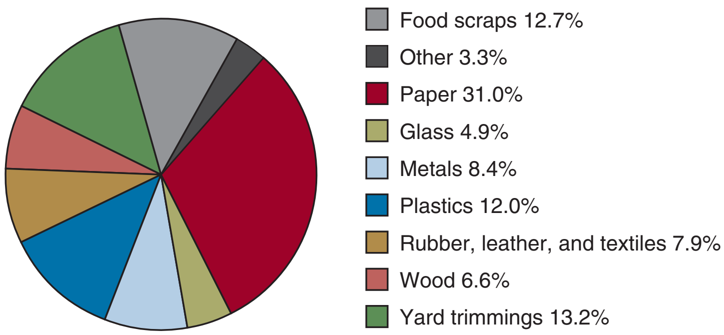


FIGURE 23.10 U.S. municipal solid-waste generation before recycling in 2008 was about 250 million tons, or about 4.6 lbs (2 kg) per person. (*Source*: Municipal solid waste generation, recycling, and disposal in the United States: facts and figures 2008_Basic Information 2009.www.epa.gov.)

Onsite Disposal

A common onsite disposal method in urban areas is the garbage-disposal device installed in the wastewater pipe under the kitchen sink to grind garbage and flush it into the sewer system. This effectively reduces the amount of handling and quickly removes food waste. What's left of it is transferred to sewage-treatment plants, where solids remaining as sewage sludge still must be disposed of.[30, 31]

Composting

Composting is a biochemical process in which organic materials, such as lawn clippings and kitchen scraps, decompose to a rich, soil-like material. The process involves rapid partial decomposition of moist solid organic waste by aerobic organisms. Although simple backyard compost piles may come to mind, large-scale composting as a waste-management option is generally carried out in the controlled environment of mechanical digesters. This technique is popular in Europe and Asia, where intense farming creates a demand for compost. However, a major drawback of composting is the necessity of separating organic material from other waste. Therefore, it is probably economically advantageous only where organic material is collected separately from other waste. Another negative is that composting plant debris previously treated with herbicides may produce a compost toxic to some plants. Nevertheless, composting is an important component of IWM, and its contribution continues to grow.[30, 31]

Incineration

Incineration burns combustible waste at temperatures high enough (900°–1,000°C, or 1,650°–1,830°F) to consume all combustible material, leaving only ash and noncombustibles to dispose of in a landfill. Under ideal conditions, incineration may reduce the volume of waste by 75–95%.[31] In practice, however, the actual decrease in volume is closer to 50% because of maintenance problems as well as waste-supply problems. Besides reducing a large volume of combustible waste to a much smaller volume of ash, incineration has another advantage: It can be used to supplement other fuels and generate electrical power.

Incineration of urban waste is not necessarily a clean process; it may produce air pollution and toxic ash. In the United States, for example, incineration is apparently a significant source of environmental dioxin, a carcinogenic toxin (see Chapter 10).[32] Smokestacks from incinerators also may emit oxides of nitrogen and sulfur, which lead to acid rain; heavy metals, such as lead, cadmium, and mercury; and carbon dioxide, which is related to global warming.

In modern incineration facilities, smokestacks fitted with special devices trap pollutants, but the process of pollutant abatement is expensive. The plants themselves are expensive, and government subsidization may be needed to aid in their establishment. Evaluation of the urban waste stream suggests that an investment of $8 billion could build enough incinerators in the United States to burn approximately 25% of the solid waste that is generated. However, a similar investment in source reduction, recycling, and composting could divert as much as 75% of the nation's urban waste stream away from landfills.[24]

The economic viability of incinerators depends on revenue from the sale of the energy produced by burning the waste. As recycling and composting increase, they will compete with incineration for their portion of the waste stream, and sufficient waste (fuel) to generate a profit from incineration may not be available. The main conclusion that can be drawn based on IWM principles is that a combination of reusing, recycling, and composting could reduce the volume of waste requiring disposal at a landfill by at least as much as incineration.[24]

Open Dumps (Poorly Controlled Landfills)

In the past, solid waste was often disposed of in open dumps (now called landfills), where refuse was piled up and left uncovered. Thousands of open dumps have been closed in recent years, and new open dumps are banned in the United States and many other countries. Nevertheless, many are still being used worldwide (Figure 23.11).[31]

Sanitary Landfills

A **sanitary landfill** (also called a municipal solid-waste landfill) is designed to concentrate and contain refuse without creating a nuisance or hazard to public health or safety. The idea is to confine the waste to the smallest practical area, reduce it to the smallest practical volume, and cover it with a layer of compacted soil at the end of each day of operation, or more frequently if necessary. Covering the waste is what makes the landfill sanitary. The compacted layer restricts (but does not eliminate) continued access to the waste by insects, rodents, and other animals, such as seagulls. It also isolates the refuse, minimizing the amount of surface water seeping into it and the amount of gas escaping from it.[33]

Leachate

The most significant hazard from a sanitary landfill is pollution of groundwater or surface water. If waste buried in a landfill comes into contact with water percolating down from the surface or with groundwater moving laterally through the refuse, **leachate**—noxious, mineralized liquid capable of transporting bacterial pollutants—is

FIGURE 23.11 Urban garbage dump in Rio de Janeiro, Brazil. At this site, people are going through the waste and recycling materials that can be reused or resold. This activity is all too common in dumps for large cities in the developing world. In some cases several thousand scavengers, including children, sift through tons of burning garbage to collect cans and bottles.

produced.[34] For example, two landfills dating from the 1930s and 1940s on Long Island, New York, have produced subsurface leachate trails (plumes) several hundred meters wide that have migrated kilometers from the disposal site. The nature and strength of the leachate produced at a disposal site depend on the composition of the waste, the amount of water that infiltrates or moves through the waste, and the length of time that infiltrated water is in contact with the refuse.[31]

Site Selection

The siting of a sanitary landfill is very important and must take into consideration a number of factors, including topography, location of the groundwater table, amount of precipitation, type of soil and rock, and location of the disposal zone in the surface water and groundwater flow system. A favorable combination of climatic, hydrologic, and geologic conditions helps to ensure reasonable safety in containing the waste and its leachate.[35] The best sites are in arid regions, where disposal conditions are relatively safe because little leachate is produced. In a humid environment, some leachate is always produced; therefore, an acceptable level of leachate production must be established to determine the most favorable sites in such environments. What is acceptable varies with local water use, regulations, and the ability of the natural hydrologic system to disperse, dilute, and otherwise degrade the leachate to harmless levels.

Elements of the most desirable site in a humid climate with moderate to abundant precipitation are shown in Figure 23.12. The waste is buried above the water table in relatively impermeable clay and silt that water cannot easily move through. Any leachate therefore remains in the vicinity of the site and degrades by natural filtering action and chemical reactions between clay and leachate.[36, 37]

Siting waste-disposal facilities also involves important social considerations. Often, planners choose sites where they expect minimal local resistance or where they perceive land to have little value. Waste-disposal facilities are frequently located in areas where residents tend to have low socioeconomic status or belong to a particular racial or ethnic group. The study of social issues in siting waste facilities, chemical plants, and other such facilities is an emerging field known as **environmental justice**.[38, 39]

Monitoring Pollution in Sanitary Landfills

Once a site is chosen for a sanitary landfill and before filling starts, monitoring the movement of groundwater should begin. Monitoring involves periodically taking samples of water and gas from specially designed monitoring wells. Monitoring the movement of leachate and gases should continue as long as there is any possibility of pollution and is particularly important after the site is completely filled and permanently covered. Continued monitoring is necessary because a certain amount of settling always occurs after a landfill is completed; and if small depressions form, surface water may collect, infiltrate, and produce leachate. Monitoring and proper maintenance of an abandoned landfill reduce its pollution potential.[33]

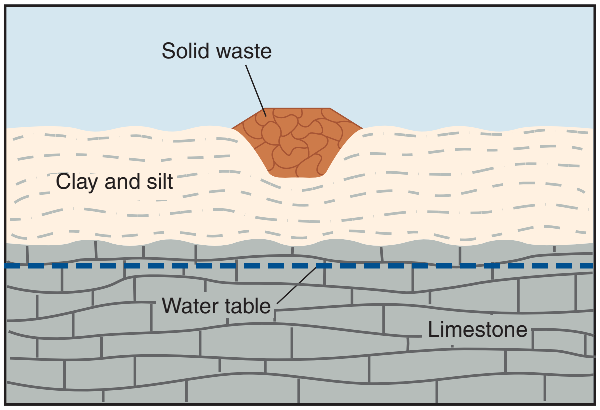


FIGURE 23.12 The most desirable landfill site in a humid environment. Waste is buried above the water table in a relatively impermeable environment. (*Source*: W.J. Schneider, *Hydraulic Implications of Solid-Waste Disposal*, U.S. Geological Survey Circular 601F, 1970.)

How Pollutants Can Enter the Environment from Sanitary Landfills

Pollutants from a solid-waste disposal site can enter the environment through as many as eight paths (Figure 23.13):[40]

1. Methane, ammonia, hydrogen sulfide, and nitrogen gases can be produced from compounds in the waste and the soil and can enter the atmosphere.
2. Heavy metals, such as lead, chromium, and iron, can be retained in the soil.
3. Soluble materials, such as chloride, nitrate, and sulfate, can readily pass through the waste and soil to the groundwater system.
4. Overland runoff can pick up leachate and transport it into streams and rivers.
5. Some plants (including crops) growing in the disposal area can selectively take up heavy metals and other toxic materials. These materials are then passed up the food chain as people and animals eat the plants.
6. If plant residue from crops left in fields contains toxic substances, these substances return to the soil.
7. Streams and rivers may become contaminated by waste from groundwater seeping into the channel (3) or by surface runoff (4).
8. Wind can transport toxic materials to other areas.

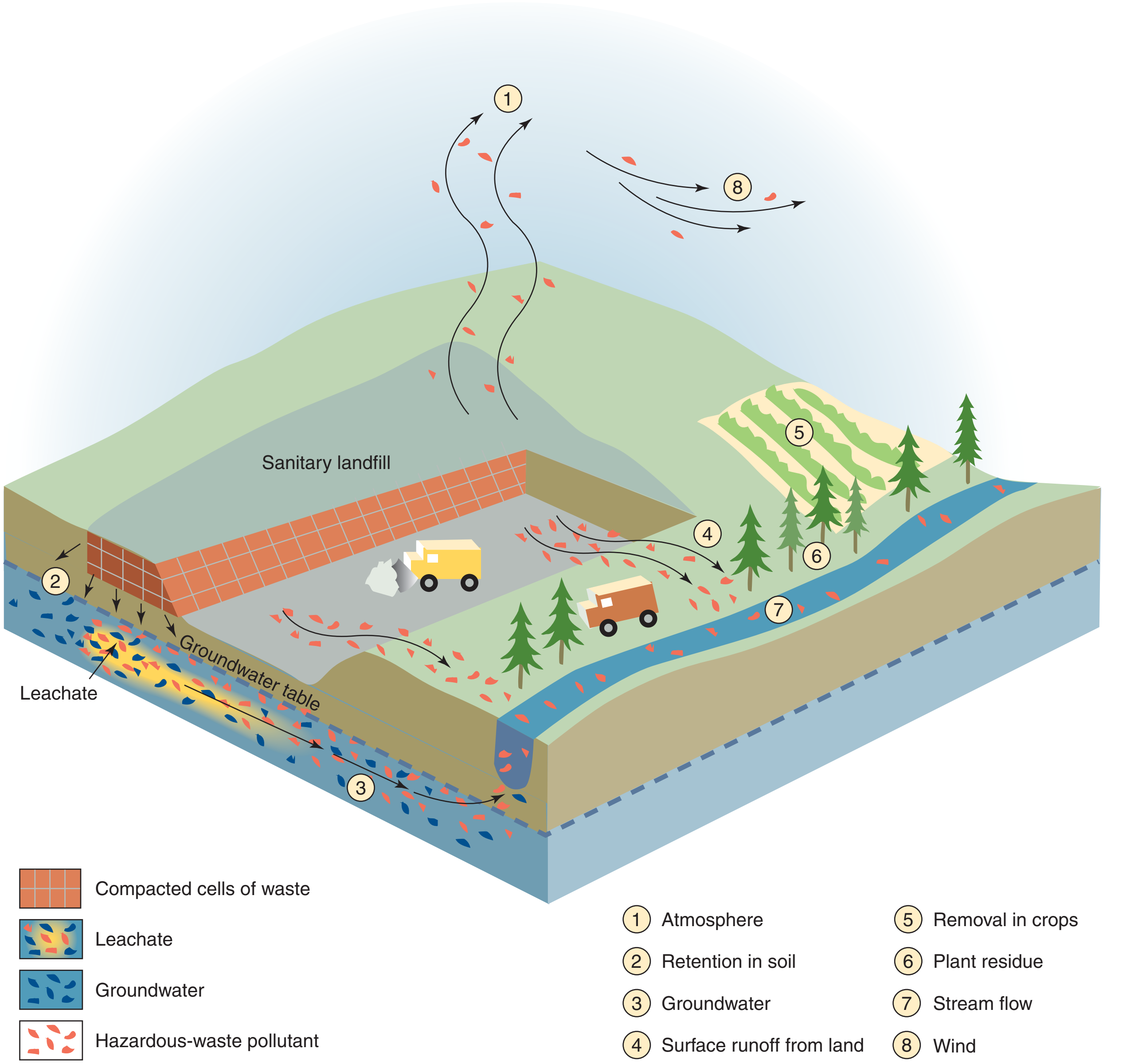


FIGURE 23.13 Idealized diagram showing eight paths that pollutants from a sanitary landfill site may follow to enter the environment.

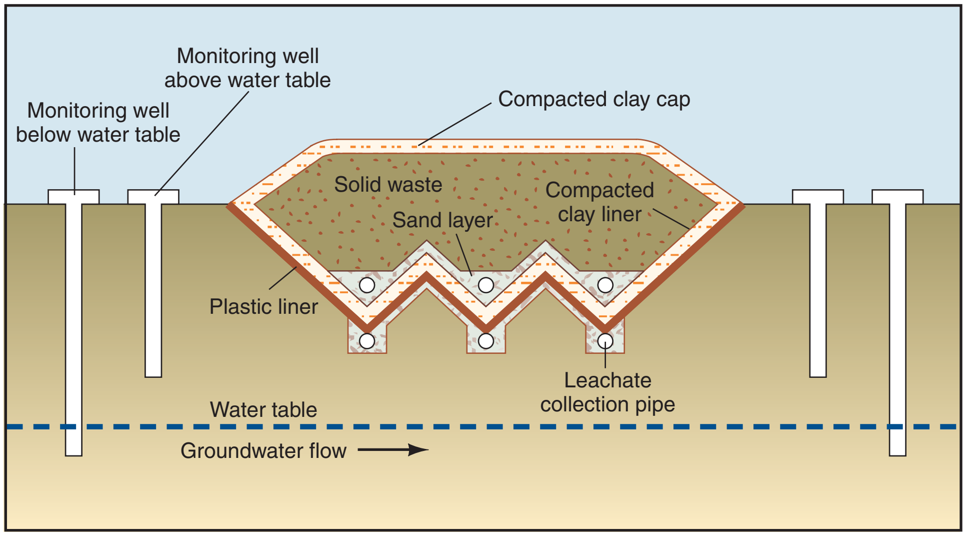
Modern sanitary landfills are engineered to include multiple barriers: clay and plastic liners to limit the movement of leachate; surface and subsurface drainage to collect leachate; systems to collect methane gas from decomposing waste; and groundwater monitoring to detect leaks of leachate below and adjacent to the landfill. A thorough monitoring program considers all eight possible paths by which pollutants enter the environment. In practice, however, monitoring seldom includes all pathways. It is particularly important to monitor the zone above the water table to identify potential pollution before it reaches and contaminates groundwater, where correction would be very expensive. Figure 23.14 shows (a) an idealized diagram of a landfill that uses the multiple-barrier approach and (b) a photograph of a landfill site under construction.

Federal Legislation for Sanitary Landfills

New landfills that opened in the United States after 1993 must comply with stricter requirements under the Resource Conservation and Recovery Act of 1980. The legislation, as its title states, is intended to strengthen and standardize the design, operation, and monitoring of sanitary landfills. Landfills that cannot comply with regulations face closure. However, states may choose between two options: (1) comply with federal standards or (2) seek EPA approval of solid-waste management plans.

The federal standards include the following:

- Landfills may not be sited on floodplains, wetlands, earthquake zones, unstable land, or near airports (birds drawn to landfill sites are a hazard to aircraft).



(a)


(b)

FIGURE 23.14 **(a)** Idealized diagram of a solid-waste facility (sanitary landfill) illustrating multiple-barrier design, monitoring system, and leachate collection system. **(b)** Rock Creek landfill under construction in Calaveras County, California. This municipal solid-waste landfill is underlain by a compacted clay liner, exposed in the center left portion of the photograph. The darker slopes, covered with gravel piles, overlie the compacted clay layer. These form a vapor barrier designed to keep moisture in the clay so it won't crack. Trenches at the bottom of the landfill are lined with plastic and are part of the leachate collection system for the landfill. The landfill is also equipped with a system to monitor the water below the leachate collection system.

- Landfills must have liners.
- Landfills must have a leachate collection system.
- Landfill operators must monitor groundwater for many specified toxic chemicals.
- Landfill operators must meet financial assurance criteria to ensure that monitoring continues for 30 years after the landfill is closed.

EPA approval of a state's landfill program allows greater flexibility:

- Groundwater monitoring may be suspended if the landfill operator can demonstrate that hazardous constituents are not migrating from the landfill.
- Alternative types of daily cover over the waste may be used.
- Alternative groundwater-protection standards are allowed.
- Alternative schedules for documentation of groundwater monitoring are allowed.
- Under certain circumstances, landfills in wetlands and fault zones are allowed.
- Alternative financial assurance mechanisms are allowed.

Given the added flexibility, it appears advantageous for states to develop EPA-approved waste-management plans.

Reducing the Waste that Ends Up in a Landfill

Most of the municipal solid waste we generate is from our homes, and over 50% of it could be diverted from the landfill by the 3 R's of waste management: reduce, reuse, and recycle. Diversion may eventually be increased to as much as 85% through improved waste management. In other words, the life of the landfill can be extended by keeping more waste out of the landfill through conservation and recycling, or by turning waste, even waste that is presently buried, into a source of clean energy. The latter involves first removing materials that can be recycled, then linking noncombustion thermal or biochemical processes with the

Table 23.2 ACTIONS YOU CAN TAKE TO REDUCE THE WASTE YOU GENERATE

Keep track of the waste you personally generate: Know how much waste you produce. This will make you conscious of how to reduce it.

Recycle as much as is possible and practical: Take your cans, glass, and paper to a recycling center or use curbside pickup. Take your hazardous materials such as batteries, cell phones, computers, paint, used oil, and solvents to a hazardous waste collection site.

Reduce packaging: Whenever possible buy your food items in bulk or concentrated form.

Use durable products: Choose automobiles, light bulbs, furniture, sports equipment, and tools that will last a longer time.

Reuse products: Some things may be used several times. For example, you can reuse boxes and shipping "bubble wrap" to ship packages.

Purchase products made from recycled material: Many bottles, cans, boxes, containers, cartons, carpets, clothing, floor tiles, and other products are made from recycled material. Select these whenever you can.

Purchase products designed for ease in recycling: Products as large as automobiles along with many other items are being designed with recycling in mind. Apply pressure to manufacturers to produce items that can be easily recycled.

Source: Modified from U.S. Environmental Protection Agency. Accessed April 21, 2006 at www.epa.gov.

remaining solid waste to produce electricity and alternative fuels (for example, biodiesel). The less waste in the landfill, the less potential for pollution of ground and surface water, along with the important fringe benefit of green energy.

The average waste per person in the United States increased from about 1 kg (2.2 lb) per day in 1960 to 2 kg (4.5 lb) per day in 2008. This is an annual growth rate of about 1.5% per year and is not sustainable because the doubling time for waste production is only a few decades. The 236 million tons we produced in 2003 would be close to 500 million tons by 2050, and we are already having big waste-management problems today. Table 23.2 lists some of the many ways you could reduce the waste you generate. What other ways can you think of?

23.9 Hazardous Waste

So far in this chapter we have discussed integrated waste management and materials management for the everyday waste stream from homes and businesses. We now consider the important topic of hazardous waste.

Creation of new chemical compounds has proliferated in recent years. In the United States, approximately 1,000 new chemicals are marketed each year, and about 70,000 chemicals are currently on the market. Although many have been beneficial to people, approximately 35,000 chemicals used in the United States are classified as definitely or potentially hazardous to people or ecosystems if they are released into the environment as waste—and unfortunately, a lot of it is.

The United States currently produces about 700 million metric tons of hazardous chemical waste per year, referred to more commonly as **hazardous waste**. About 70% of it is generated east of the Mississippi River, and about half of the total by weight is generated by chemical-products industries. The electronics industry (see A Closer Look 23.2 for discussion of e-waste) and petroleum and coal products industries each contribute about 10%.[41-43] Hazardous waste may also enter the environment when buildings are destroyed by events such as fires and hurricanes, releasing paints, solvents, pesticides, and other chemicals that were stored in them, or when debris from damaged buildings is later burned or buried. As a result, collection of such chemicals after natural disasters is an important goal in managing hazardous materials.

In the mid-20th century, as much as half the total volume of hazardous waste produced in the United States was indiscriminately dumped.[42] Some was illegally dumped on public or private lands, a practice called midnight dumping. Buried drums of illegally dumped hazardous waste have been discovered at hundreds of sites by contractors constructing buildings and roads. Cleanup has been costly and has delayed projects.[41]

The case of Love Canal is a well-known hazardous-waste horror story. In 1976, in a residential area near Niagara Falls, New York, trees and gardens began to die. Rubber on tennis shoes and bicycle tires disintegrated. Puddles of toxic substances began to ooze through the soil. A swimming pool popped from its foundation and floated in a bath of chemicals.

The story of Love Canal started in 1892 when William Love excavated a canal 8 km (5 mi) long as part of the development of an industrial park. The development didn't need the canal when inexpensive electricity arrived, so the uncompleted canal remained unused for decades

A CLOSER LOOK 23.2

"e-waste": A Growing Environmental Problem

Hundreds of millions of computers and other electronic devices—such as cell phones, iPods, televisions, and computers games—are discarded every year. The average life of a computer is about three years, and it is not manufactured with recycling in mind. That is changing in the United States. as the cost to recycle TV and computer screens is charged to their manufacturers.

When we take our electronic waste, called **e-waste**, to a location where computers are turned in, we assume that it will be handled properly, but this is too often not what happens. In the United States, which helped start the technology revolution and produces most of the e-waste, its eventual disposal may cause serious environmental problems. The plastic housing for computers, for example, may produce toxins when burned. Computer parts also have small amounts of heavy metals—including gold, tin, copper, cadmium, and mercury—that are harmful and may cause cancer if inhaled, ingested, or absorbed through the skin. At present, many millions of computers are disposed of by what is billed as recycling, but the EPA has no official process to ensure that this e-waste won't cause future problems. In fact, most of these computers are being exported under the label of "recycling" to countries such as Nigeria and China.

China's largest e-waste facility is in Guiyu, near Hong Kong. People in the Guiyu area process more than 1 million tons of e-waste each year with little thought to the potential toxicity of the material the workers are handling (Figure 23.15). In the United States, computers cannot be recycled profitably without charging the people who dump them a fee. Even with that, many U.S. firms ship their e-waste out of the country, where greater profits are possible. The revenue to the Guiyu area is about $1 million per year, so the central government is reluctant to regulate the activity. Workers at locations where computers are disassembled may be unaware that some of the materials they are handling are toxic and

FIGURE 23.15 e-waste being processed in China—a hazardous occupation.

that they thus have a hazardous occupation. Altogether, in the Guiyu area, more than 5,000 family-run facilities specialize in scavenging e-waste for raw materials. While doing this, they are exposing themselves to a variety of toxins and potential health problems.

To date, the United States has not made a proactive attempt to regulate the computer industry so that less waste is produced. In fact, the United States is the only major nation that did not ratify an international agreement that restricts and bans exports of hazardous e-waste.[43]

Our current ways of handling e-waste are not sustainable, and the value we place on a quality environment should include the safe handling and recycling of such waste. Hopefully, that is the path we will take in the future. There are positive signs. Some companies are now processing e-waste to reclaim metals such as gold and silver. Others are designing computers that use less toxic materials and are easier to recycle. The European Union is taking a leadership role in requiring more responsible management of e-waste.

and became a dump for wastes. From 1920 to 1952, some 20,000 tons of more than 80 chemicals were dumped into the canal. In 1953 the Hooker Chemical Company—which produced the insecticide DDT as well as an herbicide and chlorinated solvents, and had dumped chemicals into the canal—was pressured to donate the land to the city of Niagara Falls for $1.00. The city knew that chemical wastes were buried there, but no one expected any problems. Eventually, several hundred homes and an elementary school were built on and near the site, and for years everything seemed fine. Then, in 1976–1977, heavy rains and snows triggered a number of events, making Love Canal a household word.[41]

A study of the site identified many substances suspected of being carcinogens, including benzene, dioxin, dichlorethylene, and chloroform. Although officials admitted that little was known about the impact of these chemicals, there was grave concern for people living in the area. Eventually, concern centered on alleged high rates of miscarriages, blood and liver abnormalities, birth defects, and chromosome damage. The government had to destroy about 200 homes and a school, and about 800 families were relocated and reimbursed. After about $400 million was spent on cleaning up the site, the EPA eventually declared the area clean, and about 280 remaining homes were sold.[44] Today, the community around the canal is known as Black Creek Village, and many people live there.

Uncontrolled or poorly controlled dumping of chemical waste has polluted soil and groundwater in several ways:

- In some places, chemical waste is still stored in barrels, either stacked on the ground or buried. The barrels may eventually corrode and leak, polluting surface water, soil, and groundwater.
- When liquid chemical waste is dumped into an unlined lagoon, contaminated water may percolate through soil and rock to the groundwater table.
- Liquid chemical waste may be illegally dumped in deserted fields or even along roads.

Some sites pose particular dangers. The floodplain of a river, for example, is not an acceptable site for storing hazardous waste. Yet, that is exactly what occurred at a site on the floodplain of the River Severn near a village in one of the most scenic areas of England. Several fires at the site in 1999 were followed by a large fire of unknown origin on October 30, 2000. Approximately 200 tons of chemicals, including industrial solvents (xylene and toluene), cleaning solvents (methylene chloride), and various insecticides and pesticides, produced a fireball that rose into the night sky (Figure 23.16). Wind gusts of hurricane strength spread toxic smoke and ash to nearby farmlands and villages, which had to be evacuated. People exposed to the smoke complained of a variety of symptoms, including headaches, stomachaches and vomiting, sore throats, coughs, and difficulty breathing.

A few days later, on November 3, the site flooded (Figure 23.17). The floodwaters interfered with cleanup after the fire and increased the risk of downstream contamination by waterborne hazardous wastes. In one small village, contaminated floodwaters apparently inundated farm fields, gardens, and even homes.[45] Of course, the solution to this problem is to clean up the site and move waste storage to a safer location.

23.10 Hazardous-Waste Legislation

Recognition in the 1970s that hazardous waste was a danger to people and the environment and that the waste was not being properly managed led to important federal legislation in the United States.

Resource Conservation and Recovery Act

Management of hazardous waste in the United States began in 1976 with passage of the Resource Conservation and Recovery Act (RCRA). At the heart of the act is identification of hazardous wastes and their life cycles. The idea was to issue guidelines and assign responsibilities to those who manufacture, transport, and dispose of hazardous waste. This

FIGURE 23.16 On October 30, 2000, fire ravaged a site on the floodplain of the River Severn in England where hazardous waste was being stored. Approximately 200 tons of chemicals burned.

FIGURE 23.17 Flooding on November 3, 2000, followed the large fire at a hazardous-waste storage site on the floodplain of the River Severn in England (see Figure 23.16 at left).

is known as "cradle-to-grave" management. Regulations require stringent record keeping and reporting to verify that the wastes are not a public nuisance or a health problem.

RCRA applies to solid, semisolid, liquid, and gaseous hazardous wastes. It considers a waste hazardous if its concentration, volume, or infectious nature may contribute to serious disease or death or if it poses a significant hazard to people and the environment as a result of improper management (storage, transport, or disposal).[41] The act classifies hazardous wastes in several categories: materials highly toxic to people and other living things; wastes that may ignite when exposed to air; extremely corrosive wastes; and reactive unstable wastes that are explosive or generate toxic gases or fumes when mixed with water.

Comprehensive Environmental Response, Compensation, and Liability Act

In 1980, Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). It defined policies and procedures for release of hazardous substances into the environment (for example, landfill regulations). It also mandated development of a list of sites where hazardous substances were likely to produce or already had produced the most serious environmental problems and established a revolving fund (*Superfund*) to clean up the worst abandoned hazardous-waste sites. In 1984 and 1986, CERCLA was strengthened by amendments that made the following changes:

- Improved and tightened standards for disposal and cleanup of hazardous waste (for example, requiring double liners, monitoring landfills).
- Banned land disposal of certain hazardous chemicals, including dioxins, polychlorinated biphenyls (PCBs), and most solvents.
- Initiated a timetable for phasing out disposal of all untreated liquid hazardous waste in landfills or surface impoundments.
- Increased the Superfund. The fund was allocated about $8.5 billion in 1986; Congress approved another $5.1 billion for fiscal year 1998, which almost doubled the Superfund budget.[46]

The Superfund has had management problems, and cleanup efforts are far behind schedule. Unfortunately, the funds available are not sufficient to pay for decontaminating all targeted sites. Furthermore, present technology may not be sufficient to treat all abandoned waste-disposal sites; it may be necessary to simply try to confine waste at those sites until better disposal methods are developed. It seems apparent that abandoned disposal sites are likely to remain problems for some time to come.

Federal legislation has also changed the ways in which real estate business is conducted. For example, there are provisions by which property owners may be held liable for costly cleanup of hazardous waste on their property, even if they did not directly cause the problem. As a result, banks and other lending institutions might be held liable for release of hazardous materials by their tenants.

The Superfund Amendment and Reauthorization Act (SARA) of 1986 permits a possible defense against such liability if the property owner completed an **environmental audit** before purchasing the property. Such an audit involves studying past land use at the site, usually determined by analyzing old maps, aerial photographs, and reports. It may also involve drilling and sampling groundwater and soil to determine whether hazardous materials are present. Environmental audits are now completed routinely before purchasing property for development.[46]

In 1990 the U.S. Congress reauthorized hazardous-waste-control legislation. Priorities include:

- Establishing who is responsible (liable) for existing hazardous waste problems.
- When necessary, assisting in or providing funding for cleanup at sites identified as having a hazardous-waste problem.
- Providing measures whereby people who suffer damages from the release of hazardous materials are compensated.
- Improving the required standards for disposal and cleanup of hazardous waste.

23.11 Hazardous-Waste Management: Land Disposal

Management of hazardous chemical waste involves several options, including recycling; onsite processing to recover by-products that have commercial value; microbial breakdown; chemical stabilization; high-temperature decomposition; incineration; and disposal by **secure landfill** (Figure 23.18) or deep-well injection. A number of technological advances have been made in toxic-waste management; as land disposal becomes more expensive, the recent trend toward onsite treatment is likely to continue. However, onsite treatment will not eliminate all hazardous chemical waste; disposal of some waste will remain necessary.

Table 23.3 compares hazardous "waste" reduction technologies for treatment and disposal. Notice that all available technologies cause some environmental disruption. There is no simple solution for all waste-management issues.

Table 23.3 COMPARISON OF HAZARD REDUCTION TECHNOLOGIES

	DISPOSAL		TREATMENT			
PARAMETER COMPARED	**LANDFILLS AND IMPOUNDMENTS**	**INJECTION WELLS**	**INCINERATION AND OTHER THERMAL DESTRUCTION**	**HIGH-TEMPERATURE DECOMPOSITION[A]**	**CHEMICAL STABILIZATION**	**MICROBIAL BREAKDOWN**
Effectiveness: how well it contains or destroys hazardous characteristics	Low for volatiles, high for unsoluble solids	High, for waste compatible with the disposal environment	High	High for many chemicals	High for many metals	High for many metals and some organic waste such as oil
Reliability issues	Siting, construction, and operation Uncertainties: long-term integrity and cover	Site history and geology, well depth, construction, and operation	Monitoring uncertainties with respect to high degree of DRE: surrogate measures, PICs, incinerability[b]	Mobile units; on-site treament avoids hauling risks Operational simplicity	Some inorganics still soluble Uncertain leachate production	Monitoring uncertainties during construction and operation
Environment media most affected	Surface water and groundwater	Surface water and groundwater	Air	Air	Groundwater	Soil, groundwater
Least compatible wastes[c]	Highly toxic, persistent chemicals	Reactive; corrosive; highly toxic, mobile, and persistent	Highly toxic organics, high heavy-metal concentration	Some inorganics	Organics	Highly toxic persistent chemicals
Relative costs	Low to moderate	Low	Moderate to high	Moderate to high	Moderate	Moderate
Resource recovery potential	None	None	Energy and some acids	Energy and some metals	Possible building materials	Some metals

[a]Molten salt, high-temperature fluid well, and plasma arc treatments.

[b]DRE=destruction and removal efficiency; PIC = product of incomplete combustion.

[c]Wastes for which this method may be less effective for reducing exposure, relative to other technologies. Wastes listed do not necessarily denote common usage.

Source: Modified after Council on Environmental Quality, 1983.

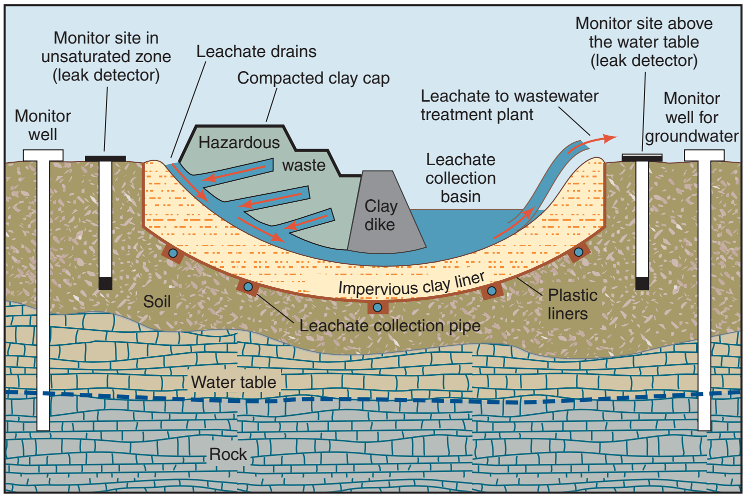


FIGURE 23.18 A secure landfill for hazardous chemical waste. The impervious liners, systems of drains, and leak detectors are integral parts of the system to ensure that leachate does not escape from the disposal site. Monitoring in the unsaturated zone is important and involves periodic collection of soil water.

Direct land disposal of hazardous waste is often not the best initial alternative. The consensus is that even with extensive safeguards and state-of-the-art designs, land disposal alternatives cannot guarantee that the waste will be contained and will not cause environmental disruption in the future. This concern holds true for all land disposal facilities, including landfills, surface impoundments, land application, and injection wells. Pollution of air, land, surface water, and groundwater may result if a land disposal site fails to contain hazardous waste. Pollution of groundwater is perhaps the most significant risk because groundwater provides a convenient route for pollutants to reach people and other living things.

Some of the paths that pollutants may take from land disposal sites to contaminate the environment include leakage and runoff to surface water or groundwater from improperly designed or maintained landfills; seepage, runoff, or air emissions from unlined lagoons; percolation and seepage from failure of surface land application of waste to soils; leaks in pipes or other equipment associated with deep-well injection; and leaks from buried drums, tanks, or other containers.[47-50]

23.12 Alternatives to Land Disposal of Hazardous Waste

Our handling of hazardous chemical waste should be multifaceted. In addition to the disposal methods just discussed, chemical-waste management should include such processes as source reduction, recycling and resource recovery, treatment, and incineration. Recently, it has been argued that these alternatives to land disposal are not being used to their full potential—that is, the volume of waste could be reduced, and the remaining waste could be recycled or treated in some form prior to land disposal of the treatment residues.[51] The advantages of source reduction, recycling, treatment, and incineration include the following:

- Useful chemicals can be reclaimed and reused.
- Treatment may make wastes less toxic and therefore less likely to cause problems in landfills.
- The volume of waste that must eventually be disposed of is reduced.
- Because a reduced volume of waste is finally disposed of, there is less stress on the dwindling capacity of waste-disposal sites.

Although some of the following techniques have been discussed as part of integrated waste management, they have special implications and complications in regard to hazardous wastes.

Source Reduction

The object of source reduction in hazardous-waste management is to reduce the amount of hazardous waste generated by manufacturing or other processes. For example, changes in the chemical processes involved, equipment and raw materials used, or maintenance measures may successfully reduce the amount or toxicity of hazardous waste produced.[51]

Recycling and Resource Recovery

Hazardous chemical waste may contain materials that can be recovered for future use. For example, acids and solvents collect contaminants when they are used in manufacturing processes. These acids and solvents can be processed to remove the contaminants and then be reused in the same or different manufacturing processes.[51]

Treatment

Hazardous chemical waste can be treated by a variety of processes to change its physical or chemical composition and reduce its toxicity or other hazardous characteristics. For example, acids can be neutralized, heavy metals can be separated from liquid waste, and hazardous chemical compounds can be broken up through oxidation.[51]

Incineration

High-temperature incineration can destroy hazardous chemical waste. However, incineration is considered a waste treatment, not a disposal method, because the process produces an ash residue that must itself be disposed of in a landfill. Hazardous waste has also been incinerated offshore on ships, creating potential air pollution and ash-disposal problems in the marine environment—an environment we consider next.

23.13 Ocean Dumping

Oceans cover more than 70% of Earth. They play a part in maintaining our global environment and are of major importance in the cycling of carbon dioxide, which helps regulate the global climate. Oceans are also important in cycling many chemical elements important to life, such as nitrogen and phosphorus, and are a valuable resource because they provide us with such necessities as food and minerals.

It seems reasonable that such an important resource would receive preferential treatment, and yet oceans have long been dumping grounds for many types of waste, including industrial waste, construction debris, urban sewage, and plastics (see A Closer Look 23.3). Ocean dumping contributes to the larger problem of ocean pollution, which has seriously damaged the marine environment and caused a health hazard. Figure 23.19 shows locations in the oceans of the world that are accumulating pollution continuously, or have intermittent pollution problems, or have potential for pollution from ships in the major shipping lanes. Notice that the areas with continual or intermittent pollution are near the shore.

Unfortunately, these are also areas of high productivity and valuable fisheries. Shellfish today often contain organisms that cause diseases such as polio and hepatitis. In the United States, at least 20% of the nation's commercial shellfish beds have been closed (mostly temporarily) because of pollution. Beaches and bays have been closed (again, mostly temporarily) to recreational uses. Lifeless zones in the marine environment have been created. Heavy kills of fish and other organisms have occurred, and profound changes in marine ecosystems have taken place (see Chapter 22).[52, 53]

Marine pollution has a variety of specific effects on oceanic life, including the following:

- Death or retarded growth, vitality, and reproductivity of marine organisms.
- Reduction of dissolved oxygen necessary for marine life, due to increased biochemical oxygen demand.
- Eutrophication caused by nutrient-rich waste in shallow estuaries, bays, and parts of the continental shelf, resulting in oxygen depletion and subsequent killing of algae, which may wash up and pollute coastal areas. (See Chapter 19 for a discussion of eutrophication in the Gulf of Mexico.)
- Habitat change caused by waste-disposal practices that subtly or drastically change entire marine ecosystems.[52]

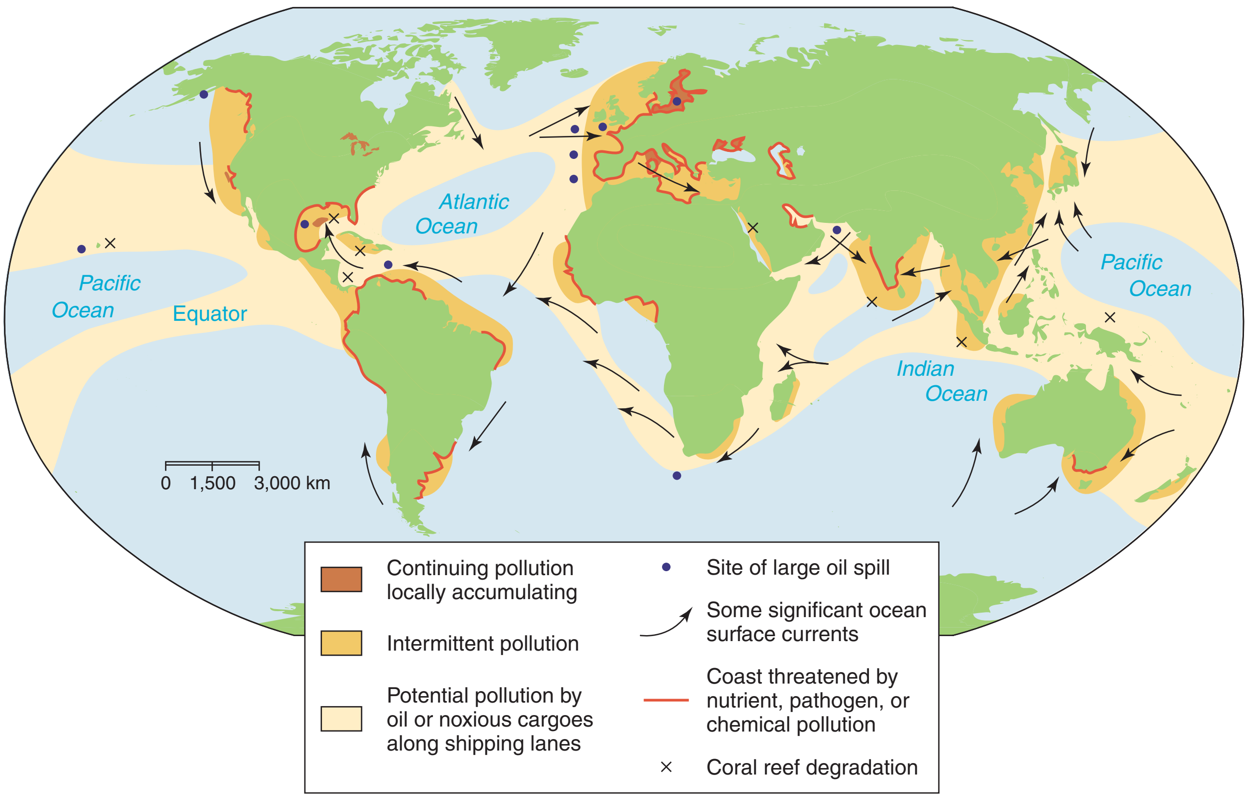


FIGURE 23.19 Ocean pollution of the world. Notice that the areas of continuing and locally accumulating pollution, as well as the areas with intermittent pollution, are in nearshore environments. (*Source*: Modified from the Council on Environmental Quality, *Environmental Trends*, 1981, with additional data from A.P. McGinn, "Safeguarding the Health of the Oceans," WorldWatch Paper 145 [Washington, DC: WorldWatch Institute, 1999], pp. 22–23.)

A CLOSER LOOK 23.3

Plastics in the Ocean

Vast quantities of plastic are used for a variety of products, ranging from beverage containers to cigarette lighters. For decades, people have been dumping plastics into the oceans. Some are dumped by passengers from passing ships; others are dropped as litter along beaches and swept into the water by the tides. Once in the ocean, plastics that float move with the currents and tend to accumulate where currents converge, concentrating the debris. Convergent currents of the Pacific (Figure 23.20) have a whirlpool-like action that concentrates debris near the center of these zones. One such zone is north of the equator, near the northwestern Hawaiian Islands. These islands are so remote that most people would expect them to be unspoiled, even pristine. In fact, however, there are literally hundreds of tons of plastics and other types of human debris on these islands. Recently, the National Oceanographic and Atmospheric Administration collected more than 80 tons of marine debris on Pearl and Hermes Atolls. Plastic debris is also widespread throughout the western North Atlantic Ocean. In the large North Atlantic subtropical gyre about 1200 km (750 mi) in diameter, centered about 1000 km (625 mi) east of Florida.[54] Most plastic is small fragments of a few mm up to about 1/2 size of a penny, and apparently is being digested by microbes.

The island ecosystems include sea turtles, monk seals, and a variety of birds, including albatross. Marine scientist Jean-Michel Cousteau and his colleagues have been studying the problem of plastics on the northwestern Hawaiian Islands, including Midway Island and Kure Atoll. They reported that the beaches of some of the islands and atolls look like a "recycling bin" of plastics. They found numerous cigarette lighters, some with fuel still in them, as well as caps from plastic bottles and all kinds of plastic toys and other debris. Birds on the islands pick up the plastic, attracted to it but not knowing what it is, and eat it. Figure 23.21 shows a dead albatross with debris in its stomach that caused its death. Plastic rings from a variety of products are also ingested by sea turtles and have been found around the snouts of seals, causing them to starve to death. In some areas, the carcasses of albatrosses litter the shorelines.

The solution to the problem is to be more careful about recycling plastic products to ensure they do not enter the marine environment. Collecting plastic items that accumulate on beaches is a step in the right direction, but it is a reactive response. Better to be proactive and reduce the source of the pollution.

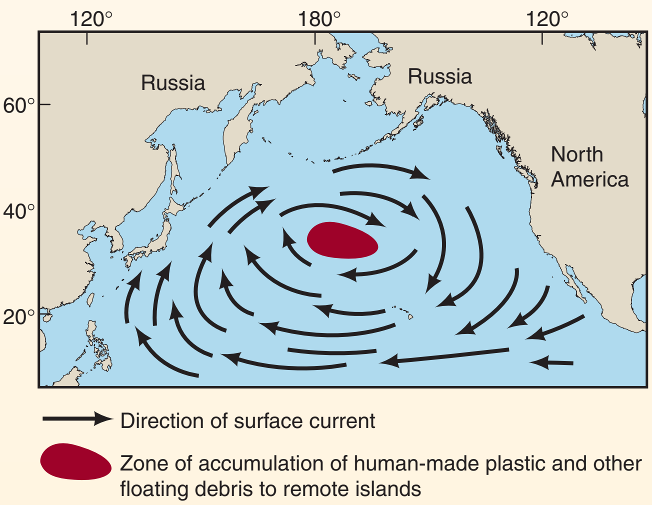


FIGURE 23.20 General circulation of the North Pacific Ocean. Arrows show the direction of the currents. Notice the tightening clockwise spiral pattern that carries floating debris to remote islands.

FIGURE 23.21 Albatross killed on a remote Pacific island by ingesting a large volume of plastic and other debris delivered by ocean currents. The photograph is not staged—the bird actually ingested all the plastic shown!

Marine waters of Europe are in particular trouble, in part because urban and agricultural pollutants have raised concentrations of nutrients in seawater. Blooms (heavy, sudden growth) of toxic algae are becoming more common. For example, in 1988 a bloom was responsible for killing nearly all marine life to a depth of about 15 m (50 ft), in the waterway connecting the North Sea to the Baltic Sea. It is believed that urban waste and agricultural runoff contributed to the toxic bloom.

Although oceans are vast, they are basically giant sinks for materials from continents, and parts of the marine environment are extremely fragile.[53] One area of concern is the *microlayer*, the upper 3 mm of ocean water. The base of the marine food chain consists of planktonic life abundant in the microlayer, and the young of certain fish and shellfish also reside there in the early stages of their life. Unfortunately, these upper few millimeters of the ocean also tend to concentrate pollutants, such as toxic chemicals and heavy metals. One study reported that concentrations of heavy metals—including zinc, lead, and copper—in the microlayer are from 10 to 1,000 times higher than in the deeper waters. It is feared that disproportionate pollution of the microlayer will have especially serious effects on marine organisms.[53] There is also concern that ocean pollution is a threat to some marine ecosystems, such as coral reefs, estuaries. salt marshes, and mangrove swamps.

Marine pollution can also have major impacts on people and society. Contaminated marine organisms, as we mentioned, may transmit toxic elements or diseases to people who eat them. In addition, beaches and harbors polluted by solid waste, oil, and other materials may not only damage marine life but also lose their visual appeal and other amenities. Economic loss is considerable as well. Loss of shellfish from pollution in the United States, for example, amounts to many millions of dollars per year. A great deal of money also is spent cleaning up solid waste, liquid waste, and other pollutants in coastal areas.[51]

23.14 Pollution Prevention

Approaches to waste management are changing. During the first several decades of environmental concern and management (the 1970s and 1980s), the United States approached the problem through government regulations and waste-control measures: chemical, physical, or biological treatment and collection (for eventual disposal), or transformation or destruction of pollutants after they had been generated. This was considered the most cost-effective approach to waste management.

With the 1990s came a growing emphasis on **pollution prevention—**ways to stop generating so much waste, rather than ways to dispose of it or manage it. This approach, which is part of materials management, includes the following:[55]

- Purchasing the proper amount of raw materials so that no excess remains to be disposed of.
- Exercising better control of materials used in manufacturing processes so that less waste is produced.
- Substituting nontoxic chemicals for hazardous or toxic materials currently used.
- Improving engineering and design of manufacturing processes so less waste is produced.

These approaches are often called P-2 approaches, for "pollution prevention." Probably the best way to illustrate the P-2 process is through a case history.[55]

A Wisconsin firm that produced cheese was faced with the disposal of about 2,000 gallons a day of a salty solution generated during the cheese-making process. Initially, the firm spread the salty solution on nearby agricultural lands—common practice for firms that could not discharge wastewater into publicly owned treatment plants. This method of waste disposal, when done incorrectly, caused the level of salts in the soil to rise so much that it damaged crops. As a result, the Department of Natural Resources in Wisconsin placed limitations on this practice.

The cheese firm decided to modify its cheese-making processes to recover salt from the solution and reuse it in production. This involved developing a recovery process that used an evaporator. The recovery process reduced the salty waste by about 75% and at the same time reduced the amount of the salt the company had to purchase by 50%. The operating and maintenance costs for recovery were approximately 3 cents per pound of salt recovered, and the extra cost of the new equipment was recovered in only two months. The firm saved thousands of dollars a year by recycling its salt.

The case history of the cheese firm suggests that rather minor changes can often result in large reductions of waste produced. And this case history is not an isolated example. Thousands of similar cases exist today as we move from the era of recognizing environmental problems, and regulating them at a national level, to providing economic incentives and new technology to better manage materials.[55]

23.15 Sustainable Resource Management

Sustaining renewable resources, such as water, wildlife, crops, and forests, though complex and sometimes difficult to achieve, is fairly easy to understand. Management of the environment must include development of goals and procedures to ensure that what makes a particular resource renewable persists over the long term (numerous generations). We have devoted several chapters in this book to sustainability with respect to renewable resources (water, air, energy, crops, forests, fish, and wildlife). However, simultaneously considering sustainable development and mineral exploitation and use is problematic. This is because, even with the most careful use, nonrenewable mineral resources will eventually be used up, and sustainability is a long-term concept that requires finding ways to assure future generations a fair share of Earth's resources. Recently, it has been argued that, given human ingenuity and sufficient lead time, we can find solutions for sustainable development that incorporate nonrenewable mineral resources.

Human ingenuity is important because often it is not the mineral we need so much as what we use the mineral for. For example, we mine copper and use it to transmit electricity in wires or electronic pulses in telephone wires. It is not the copper itself we desire but the properties of copper that allow these transmissions. We can use fiberglass cables in telephone wires, eliminating the need for copper. Digital cameras have eliminated the need for film development that uses silver. The message is that it is possible to compensate for a nonrenewable mineral by finding new ways to do things. We are also learning that we can use raw mineral materials more efficiently. For example, in the late 1800s when the Eiffel Tower was constructed, 8,000 metric tons of steel were used. Today the tower could be built with only a quarter of that amount.[56]

Finding substitutes or ways to more efficiently use nonrenewable resources generally requires several decades of research and development. A measure of how much time we have for finding solutions to the depletion of nonrenewable reserves is the ***R*-to-*C* ratio**, where *R* is the known reserves (for example, hundreds of thousands of tons of a metal) and *C* is the rate of consumption (for example, thousands of tons per year used by people). The *R*-to-*C* ratio is often misinterpreted as the time a reserve will last at the present rate of consumption. During the past 50 years, the *R*-to-*C* ratios for metals, such as zinc and copper, have fluctuated around 30 years. During that time, consumption of the metals roughly tripled, but we discovered new deposits. Although the *R*-to-*C* ratio is a *present* analysis of a dynamic system in which both the amount of reserves and consumption may change over time, it does provide a view of how scarce a particular mineral resource may be. Metals with relatively small ratios can be viewed as being in short supply, and it is those resources for which we should find substitutes through technological innovation.[56]

In sum, we may approach sustainable development and use of nonrenewable mineral resources by developing more efficient ways of mining resources and finding ways to more efficiently use available resources, recycling more and applying human ingenuity to find substitutes for a nonrenewable mineral.

CRITICAL THINKING ISSUE

Can We Make Recycling a More Financially Viable Industry?

There is enthusiastic public support for recycling in the United States today. Many people understand that managing our waste has many advantages to society as a whole and the environment in particular. People like the notion of recycling because they correctly assume they are helping to conserve resources, such as forests, that make up much of the nonurban environment of the planet. Large cities from New York to Los Angeles have initiated recycling programs, but many people are concerned that recycling is not yet "cost-effective."

To be sure, there are success stories, such as a large urban paper mill on New York's Staten Island that recycles more than 1,000 tons of paper per day. It is claimed that this paper mill saves more than 10,000 trees a day and uses only about 10% of the electricity required to make paper from virgin wood processing. On the West Coast, San Francisco has an innovative and ambitious recycling program that diverts nearly 50% of the urban waste from landfills to recycling programs. The city is even talking about the concept of zero waste, hoping to achieve total recycling of waste by 2020. In part, this is achieved by instigating a "pay-as-you-throw-away" approach; businesses and individuals are charged for disposal of garbage but not for materials that are recycled. Materials from the waste of the San Francisco urban area are shipped as far away as China and the Philippines to be recycled into usable products; organic waste is sent to agricultural areas; and metals, such as aluminum, are sent around California and to other states where they are recycled.

To understand some of the issues concerning recycling and its cost, consider the following points:

- The average cost of disposal at a landfill is about $40/ton in the United States, and even at a higher price of about $80/ton it may be cheaper than recycling.
- Landfill fees in Europe range from $200 to $300/ton.
- Europe has been more successful in recycling, in part because countries such as Germany hold manufacturers responsible for disposing of the industrial goods they produce, as well as the packaging.
- In the United States, packaging accounts for approximately one-third of all waste generated by manufacturing.
- The cost to cities such as New York, which must export their waste out of state, is steadily rising and is expected to exceed the cost of recycling within about ten years.
- Placing a 10-cent refundable deposit on all beverage containers except milk would greatly increase the number recycled. For example, states with a deposit system have an average recycling rate of about 70–95% of bottles and cans, whereas states that do not have a refundable-deposit system average less than 30%.
- When people have to pay for trash disposal at a landfill, but are not charged for materials that are recycled—such as paper, plastic, glass, and metals—the success of recycling is greatly enhanced.
- Beverage companies do not particularly favor requiring a refundable deposit for containers. They claim that the additional costs would be several billion dollars, but do agree that recovery rates would be higher, providing a steadier supply of recycled metal, such as aluminum, as well as plastic.
- Education is a big issue with recycling. Many people still don't know which items are recyclable and which are not.
- Global markets for recyclable materials, such as paper and metals, have potential for expansion, particularly for large urban areas on the seacoast, where shipping materials is economically viable. Recycling in the United States today is a $14 billion industry; and if it is done right, it generates new jobs and revenue for participating communities.
- The economic downturn since 2004 has resulted in much lower prices for recycled materials, such as paper, and even aluminum. The drop in demand for recycled materials in 2009 was global.

Critical Thinking Questions

1. What can be done about the global problem of e-waste? Could more be recycled safely?
2. What can be done to help recycling industries become more cost-effective?
3. What are some of the indirect benefits to society and the environment from recycling?
4. Defend or criticize the contention that if we really want to improve the environment by reducing our waste, we have to focus on more than the fact that recycling waste may cost more than dumping it at a landfill.
5. What are the recycling efforts in your community and university, and how could they be improved?
6. Do you think the global economic downturn since 2004 will cause a permanent problem for the recycling industry? Why? Why not?

SUMMARY

- Mineral resources are usually extracted from naturally occurring, anomalously high concentrations of Earth materials. Such natural deposits allowed early peoples to exploit minerals while slowly developing technological skills.
- Mineral resources are not mineral reserves. Unless discovered and developed, resources cannot be used to ease present shortages.
- The availability of mineral resources is one measure of the wealth of a society. Modern technological civilization would not be possible without the exploitation of mineral resources. However, it is important to recognize that mineral deposits are not infinite and that we cannot maintain exponential population growth on a finite resource base.
- The United States and many other affluent nations rely on imports for their supplies of many minerals. As other nations industrialize and develop, such imports may be more difficult to obtain, and affluent countries may have to find substitutes for some minerals or use a smaller portion of the world's annual production.

- The mining and processing of minerals greatly affect the land, water, air, and biological resources and have social impacts as well, including increased demand for housing and services in mining areas.
- Sustainable development and use of nonrenewable resources are not necessarily incompatible. Reducing consumption, reusing, recycling, and finding substitutes are environmentally preferable ways to delay or alleviate possible crises caused by the convergence of a rapidly rising population and a limited resource base.
- The history of waste-disposal practices since the Industrial Revolution has progressed from dilution and dispersion to the concept of integrated waste management (IWM), which emphasizes the three R's: reducing waste, reusing materials, and recycling.
- One goal of the emerging concept of industrial ecology is a system in which the concept of waste doesn't exist because waste from one part of the system would be a resource for another part.
- The most common way to dispose of solid waste is the sanitary landfill. However, around many large cities, space for landfills is hard to find, partly because few people wish to live near a waste-disposal site.
- Hazardous chemical waste is one of the most serious environmental problems in the United States. Hundreds or even thousands of abandoned, uncontrolled disposal sites could be time bombs that will eventually cause serious public health problems. We know that we will continue to produce some hazardous chemical waste. Therefore, it is imperative that we develop and use safe ways to dispose of it.
- Ocean dumping is a significant source of marine pollution. The most seriously affected areas are near shore, where valuable fisheries often exist.
- Pollution prevention (P-2)—identifying and using ways to prevent the generation of waste—is an important emerging area of materials management.

REEXAMINING THEMES AND ISSUES

Human Population

Materials-management strategies are inextricably linked to the human population. As the population increases, so does the waste generated. In developing countries where population increase is the most dramatic, increases in industrial output, when linked to poor environmental control, produce or aggravate waste-management problems.

Sustainability

Assuring a quality environment for future generations is closely linked to materials management. Of particular importance here are the concepts of integrated waste management, materials management, and industrial ecology. Carried to their natural conclusion, the ideas behind these concepts would lead to a system in which the issue would no longer be waste management but instead resource management. Pollution prevention (P-2) is a step in this direction.

Global Perspective

Materials management is becoming a global problem. Improper management of materials contributes to air and water pollution and can cause environmental disruption on a regional or global scale. For example, waste generated by large inland cities and disposed of in river systems may eventually enter the oceans and be dispersed by the global circulation patterns of ocean currents. Similarly, soils polluted by hazardous materials may erode, and the particles may enter the atmosphere or water system, to be dispersed widely.

Urban World

Because so much of our waste is generated in the urban environment, cities are a focus of special attention for materials management. Where population densities are high, it is easier to implement the principles behind "reduce, reuse, and recycle." There are greater financial incentives for materials management where waste is more concentrated.

People and Nature

Production of waste is a basic process of life. In nature, waste from one organism is a resource for another. Waste is recycled in ecosystems as energy flows and chemicals cycle. As a result, the concept of waste in nature is much different than that in the human waste stream. In the human system, waste may be stored in facilities such as landfills, where it may remain for long periods, far from natural cycling. Our activities to recycle waste or burn it for energy move us closer to transforming waste into resources. Converting waste into resources brings us closer to nature by causing urban systems to operate in parallel with natural ecosystems.

Science and Values

People today value a quality, pollution-free environment. The way materials have been managed continues to affect health and other environmental problems. An understanding of these problems has resulted in a considerable amount of work and research aimed at reducing or eliminating the impact of resource use. How a society manages its waste is a sign of the maturity of the society and its ethical framework. Accordingly, we have become more conscious of environmental justice issues related to materials management.

KEY TERMS

composting **532**
environmental audit **540**
environmental justice **534**
e-waste **538**
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STUDY QUESTIONS

1. What is the difference between a resource and a reserve?
2. Under what circumstances might sewage sludge be considered a mineral resource?
3. If surface mines and quarries cover less than 0.5% of the land surface of the United States, why is there so much environmental concern about them?
4. A deep-sea diver claims that the oceans can provide all our mineral resources with no negative environmental effects. Do you agree or disagree?
5. What factors determine the availability of a mineral resource?
6. Using a mineral resource involves four general phases: (a) exploration, (b) recovery, (c) consumption, and (d) disposal of waste. Which phase do you think has the greatest environmental effect?
7. Have you ever contributed to the hazardous-waste problem through disposal methods used in your home, school laboratory, or other location? How big a problem do you think such events are? For example, how bad is it to dump paint thinner down a drain?
8. Why is it so difficult to ensure safe land disposal of hazardous waste?
9. Would you approve the siting of a waste-disposal facility in your part of town? If not, why, and where do you think such facilities should be?
10. Why might there be a trend toward onsite disposal rather than land disposal of hazardous waste? Consider the physical, biological, social, legal, and economic aspects of the question.
11. Considering how much waste has been dumped in the nearshore marine environment, how safe is it to swim in bays and estuaries near large cities?

12. Do you think we should collect household waste and burn it in special incinerators to make electrical energy? What problems and what advantages do you see for this method, compared with other waste-management options?

13. Should companies that dumped hazardous waste years ago, when the problem was not understood or recognized, be held liable today for health problems to which their dumping may have contributed?

14. Suppose you found that the home you had been living in for 15 years was atop a buried waste-disposal site. What would you do? What kinds of studies should be done to evaluate potential problems?

FURTHER READING

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