Fresh Kills, the largest landfill in the United States, closed in 2001 for lack of space.

CHAPTER

Solid, Toxic, and Hazardous Waste

We have no knowledge, so we have stuff; but stuff without knowledge is never enough.

—Greg Brown—

LEARNING OUTCOMES

After studying this chapter, you should be able to:

21.1 Identify the components of solid waste.

21.2 Describe how wastes have been—and are being—disposed of or treated.

21.3 Identify how we might shrink the waste stream.

21.4 Investigate hazardous and toxic wastes.

Case Study The New Alchemy: Creating Gold from Garbage

st people think of recycling in terms of newspapers, plastic bot-, and other household goods. Your daily household recycling is bedrock of recycling programs, but another growing and excit- area of recycling is done at commercial and industrial scales. 230 million tons of garbage the United States produces each r includes some knotty problems: old furniture and carpeting, liances and computers, painted wood, food waste. It's no won- that we've simply dumped it all in landfills as long as we could. landfill space is diminishing rapidly (fig. 21.1).

Incinerators are a common alternative, but they are expensive to d and operate, and they can produce dangerous air contaminants, uding dioxins from burned plastics, and heavy metals.

One of our largest sources of waste is construction and demolition ris—the rubble left over when a building is torn down, remodeled, uilt. Construction and demolition account for over 140 million tons vaste per year, about 1.5 kg per person per day—on top of the million tons per year of municipal solid waste. All this mixed ris is normally trucked to land- but alternatives have emerged ecent years.

A slowly growing number of s and companies are sending waste, including construction ris, to commercial recyclers. example is Taylor Recycling, ed in Montgomery, New York. ting as a tree removal ness, Taylor has expanded construction and demolition te and now operates in four es. The company recycles sells 97 percent of the mixed is it receives, well above the stry average of 30 to 50 per-. Trees are ground and con- ed to mulch for landscaping. rom stumps is screened and as clean garden soil. Mixed erials are sorted into recyclable glass, metals, and plastics. Con- tion debris is sorted and ground: broken drywall is ground to gypsum, which is sold to drywall producers; wood is oosted or burned; bricks are crushed for fill and construction erial. Organic waste that can't be separated, such as food- ed paper, is sent to a gasifier. The gasifier is like an enclosed, en-free pressure cooker, which converts biomass to natural The gas runs electric generators for the plant, and any extra can be sold. Waste heat warms the recycling facility. 3 percent of incoming waste that doesn't get recycled is mainly d plastics, which are currently landfilled.

From their base outside of New York City, recycling is clearly od idea. New York has used up most of its landfill space and ships garbage to Virginia, Ohio, Pennsylvania, and South lina. Fuel and trucking costs alone drive up disposal costs, with landfill capacity shrinking, tipping fees are climbing. According to Jim Taylor, the 1,000 garbage trucks leaving New York City each day travel an average of 300 miles round-trip, at less than 4 miles per gallon of fuel.

The story of garbage processing is changing globally. Garbage has long been one of the United States' largest exports, but increasingly the country is exporting sorted recycled materials, as well. Chinese manufacturers are finding valuable material sources in American waste. In Western Europe, where environmental regulation and landfill space are both tight, recycling, composting, and conversion of biomass to gas are booming businesses. The Swiss company Kompogas, one of many companies processing garbage, ferments organic waste in giant tanks, producing methane, compost, and fertilizer.

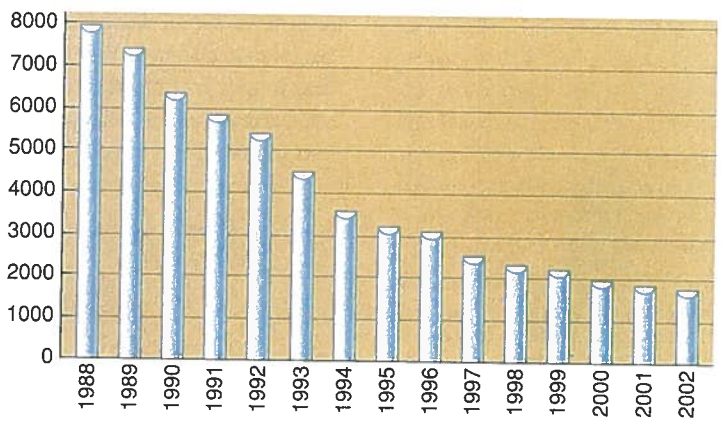


FIGURE 21.1 The number of landfills in the United States has declined steadily as space has become scarce and safety rules have increased. **Data Source:** U.S. EPA.

New technologies are providing innovative strategies for recycling waste. One method that is getting attention is Changing World Technologies' thermal depolymerization process ("thermal" means it involves heating; "depolymerization" essentially means breaking down organic molecules) that converts almost any kind of organic waste into clean, usable diesel oil. Animal by-products, sewage sludge, shredded tires, and other waste can be converted with 85 percent energy efficiency. Pilot plants have been built for specialized sources, such as a turkey processing plant in Colorado, but the technology could accommodate mixed sources as well.

Recycling is a rapidly growing industry because it makes money coming and going. Recyclers are paid to haul away waste, which they turn into marketable products. The business is also exciting because these companies, like Taylor Recycling, see the huge social and economic benefits of environmental solutions. Often when we discuss environmental problems, businesses are part of the problem. But these examples show that business owners can be just as excited as anybody about environmental quality. With a good business model, being green can be very rewarding.

Garbage disposal may be one of the most exciting stories in environmental science, because it shows so much promise and innovation. So far, the examples discussed here make up a minority of our waste management strategies, but they are expanding. In this chapter we'll look at our other waste management methods, the composition of our waste, and some of the differences between solid waste and hazardous waste.

21.1 Solid Waste

Waste is everyone's business. We all produce wastes in nearly everything we do. According to the Environmental Protection Agency, the United States produces 11 billion tons of solid waste each year. About half of that amount consists of agricultural waste, such as crop residues and animal manure, which are generally recycled into the soil on the farms where they are produced. They represent a valuable resource as ground cover to reduce erosion and fertilizer to nourish new crops, but they also constitute the single largest source of nonpoint air and water pollution in the country. More than one-third of all solid wastes are mine tailings, overburden from strip mines, smelter slag, and other residues produced by mining and primary metal processing. Road and building construction debris is another major component of solid waste. Much of this material is stored in or near its source of production and isn't mixed with other kinds of wastes. Improper disposal practices, however, can result in serious and widespread pollution.

Industrial waste—other than mining and mineral production—amounts to some 400 million metric tons per year in the United States. Most of this material is recycled, converted to other forms, destroyed, or disposed of in private landfills or deep injection wells. About 60 million metric tons of industrial waste falls in a special category of hazardous and toxic waste, which we will discuss later in this chapter.

Municipal waste—a combination of household and commercial refuse—amounts to more than 200 million metric tons per year in the United States (fig. 21.2). That's approximately two-thirds of a ton for each man, woman, and child every year—twice as much per capita as Europe or Japan, and five to ten times as much as most developing countries.

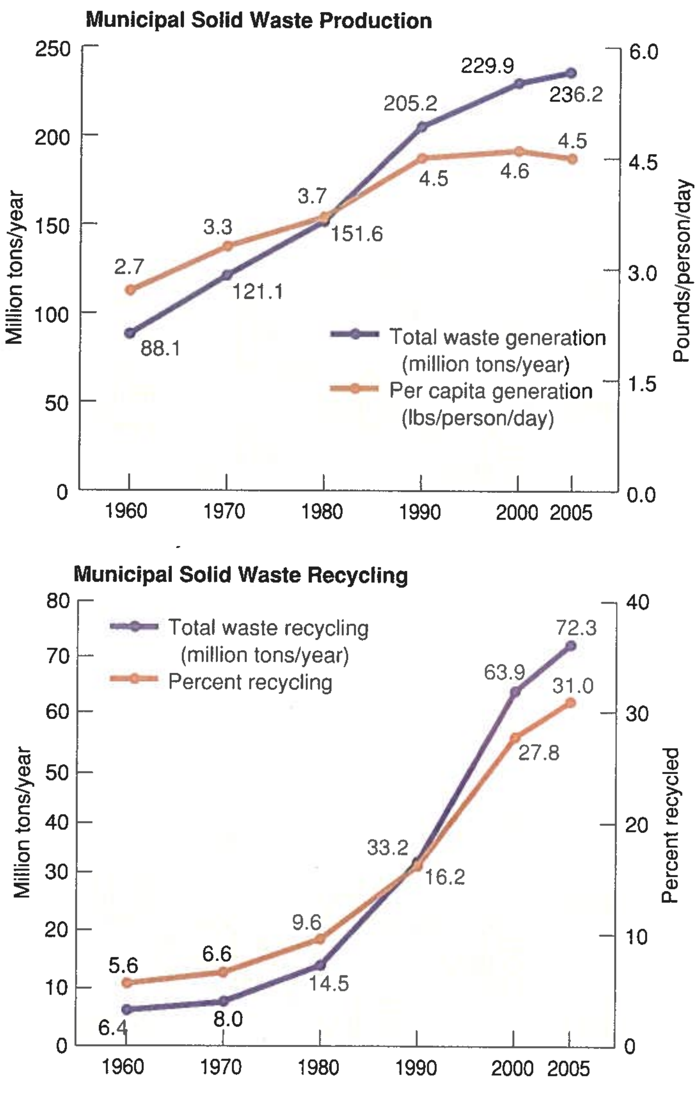


FIGURE 21.2 Bad news and good news in solid waste production. Per capita waste has risen steadily to more than 2 kg per person per day. Recycling rates are also rising, however. Recycling data include composting.
Source: Data from Environmental Protection Agency, 2006.

The waste stream is everything we throw away

Does it surprise you to learn that you generate that much garbage? Think for a moment about how much we discard every year. There are organic materials, such as yard and garden wastes, food wastes, and sewage sludge from treatment plants; junked cars; worn out furniture; and consumer products of all types. Newspapers, magazines, advertisements, and office refuse make paper one of our major wastes (fig. 21.3). In spite of recent progress in recycling,

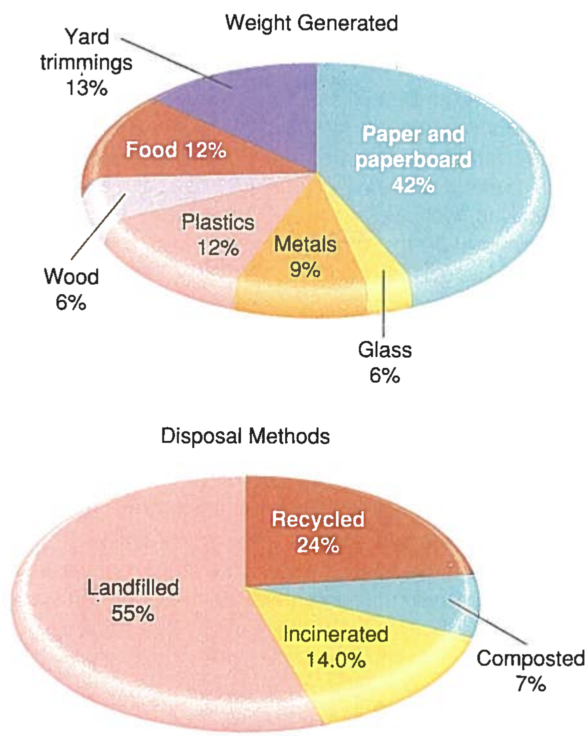


FIGURE 21.3 Composition of municipal solid waste in the United States by weight, before recycling, and disposal methods.
Source: Data from U.S. Environmental Protection Agency Office of Solid Waste Management, 2006.

any of the 200 *billion* metal, glass, and plastic food and beverage ›ntainers used every year in the United States end up in the trash. 'ood, concrete, bricks, and glass come from construction and ›molition sites, dust and rubble from landscaping and road build- g. All of this varied and voluminous waste has to arrive at a final sting place somewhere.

The **waste stream** is a term that describes the steady flow varied wastes that we all produce, from domestic garbage and ırd wastes to industrial, commercial, and construction refuse. any of the materials in our waste stream would be valuable sources if they were not mixed with other garbage. Unfortu- tely, our collecting and dumping processes mix and crush erything together, making separation an expensive and some- nes impossible task. In a dump or incinerator, much of the lue of recyclable materials is lost.

Another problem with refuse mixing is that hazardous aterials in the waste stream get dispersed through thousands tons of miscellaneous garbage. This mixing makes the sposal or burning of what might have been rather innocuous ıff a difficult, expensive, and risky business. Spray paint ns, pesticides, batteries (zinc, lead, or mercury), cleaning lvents, smoke detectors containing radioactive material, and astics that produce dioxins and PCBs when burned are mixed lly-nilly with paper, table scraps, and other nontoxic materials. e best thing to do with household toxic and hazardous mate- ls is to separate them for safe disposal or recycling, as we ll see later in this chapter.

Think About It

Figure 21.2 shows a continuing increase in waste production per capita. What is the percentage increase per capita from 1960 to 2000? (*Hint:* calculate (4.6 − 2.7) ÷ 2.7.) What might account for his increase? Is there a relationship between waste production and our quality of life?

1.2 Waste Disposal Methods

ıere are our wastes going now? In this section, we will exam- some historic methods of waste disposal as well as some ıre options. Notice that our presentation begins with the least irable—but most commonly used—measures and proceeds to cuss some preferable options. Keep in mind as you read this t modern waste management reverses this order and stresses "three R's" of reduction, reuse, and recycling before destruc- ı or, finally, secure storage of wastes.

›en dumps release hazardous ıterials into air and water

many people, the way to dispose of waste is to simply drop ›meplace. Open, unregulated dumps are still the predominant hod of waste disposal in most developing countries (fig. 21.4). giant developing-world megacities have enormous garbage problems. Mexico City, one of the largest cities in the world, generates some 10,000 tons of trash *each day.* Until recently, most of this torrent of waste was left in giant piles, exposed to the wind and rain, as well as rats, flies, and other vermin. Manila, in the Philippines, generates a similar amount of waste, half of which goes to a giant, constantly smoldering dump called "Smoky Mountain." Over 20,000 people live and work on this mountain of refuse, scavenging for recyclable items or edible food scraps. In July 2000, torrential rains spawned by Typhoon "Kai Tak" caused part of the mountain to collapse, burying at least 215 people. The government would like to close these dumps, but how will the residents be housed and fed? Where else will the city put its garbage?

FIGURE 21.4 Trash disposal has become a crisis in the developing world, where people have adopted cheap plastic goods and packaging but lack good recycling or disposal options.

Most developed countries forbid open dumping, at least in metropolitan areas, but illegal dumping is still a problem. You have undoubtedly seen trash accumulating along roadsides and in vacant, weedy lots in the poorer sections of cities. Is this just a question of aesthetics? Consider the problem of waste oil and solvents. An estimated 200 million liters of waste motor oil are poured into the sewers or allowed to soak into the ground every year in the United States. This is about five times as much as was spilled by the *Exxon Valdez* in Alaska in 1989! No one knows the volume of solvents and other chemicals disposed of by similar methods.

Increasingly, these toxic chemicals are showing up in the groundwater supplies on which nearly half the people in America depend for drinking (chapter 18). An alarmingly small amount of oil or other solvents can pollute large quanti- ties of drinking or irrigation water. One liter of gasoline, for instance, could theoretically make a million liters of water undrinkable. Open dumps are usually illegal in most devel- oped countries today. They remain common, however, in developing countries.

FIGURE 21.5 Dumping of trash at sea is a global problem. Even on the most remote islands, beaches are covered with plastic flotsam and jetsam.

Ocean dumping is nearly uncontrollable

The oceans are vast, but not so large that we can continue to treat them as carelessly as has been our habit. Every year some 25,000 metric tons (55 million lbs) of packaging, including half a million bottles, cans, and plastic containers, are dumped at sea. Beaches, even in remote regions, are littered with the nondegradable flotsam and jetsam of industrial society (fig. 21.5). About 150,000 tons (330 million lbs) of fishing gear—including more than 1,000 km (660 mi) of nets—are lost or discarded at sea each year. Environmental groups estimate that 50,000 northern fur seals are entangled in this refuse and drown or starve to death every year in the North Pacific alone (see fig. 18.20).

You may have seen a recent television special in which Jean-Michel Cousteau led an expedition to Kure Atoll, the most remote of the Northwest Hawaiian Island chain (Kure is about 4,800 km from Honolulu or twice that far from the U.S. mainland). Underwater, this is one of the last pristine large-scale coral reef systems in the Pacific. Onshore, unfortunately, the scene is very different. This chain of islands in the newest U.S. national monument is contaminated with a shocking amount of refuse. Where does it all come from? No one lives on these tiny islets. The answer is: from as far away as California, Mexico, and Japan. A giant circular ocean current sweeps up flotsam and jetsam into an area, about the size of Texas, called the eastern garbage patch. By some estimates more than 3 million tons of garbage circulate within this huge floating dump. Unfortunately, Hawaii lies in the path of these currents and even remote beaches accumulate trash that threatens endemic wildlife.

We often export waste to countries ill-equipped to handle it

Although most industrialized nations agreed to stop shipping hazardous and toxic waste to less-developed countries in 1989, the practice still continues. In 2006, for example, 400 tons of toxic waste were illegally dumped at 14 open dumps in Abidjan, the capital of the Ivory Coast. The black sludge—petroleum wastes containing hydrogen sulfide and volatile hydrocarbons—killed ten people and injured many others. At least 100,000 city residents sought medical treatment for vomiting, stomach pains, nausea, breathing difficulties, nosebleeds, and headaches. The sludge—which had been refused entry at European ports—was transported by an Amsterdam-based multinational company on a Panamanian-registered ship and handed over to an Ivorian firm (thought to be connected to corrupt government officials) to be dumped in the Ivory Coast. The Dutch company agreed to clean up the waste and pay the equivalent of (U.S.) $198 million to settle claims.

One of the greatest sources of toxic material currently going to developing countries is outdated electronic devices. There are at least 2 billion television sets and personal computers in use globally. Televisions often are discarded after only about five years, while computers, play-stations, cellular telephones, and other electronics become obsolete even faster. As many as 600 million computers are in use in the United States (twice as many as there are residents), and most will be discarded in the next few years. Only about 10 percent of the components are currently recycled. These computers contain at least 2.5 billion kg of lead (as well as mercury, gallium, germanium, nickel, palladium, beryllium, selenium, arsenic), and valuable metals, such as gold, silver, copper, and steel.

About 80 percent of **electronic waste** (or **e-waste**) is shipped overseas, mostly to China and other developing countries in Asia and Africa. There, villagers, including young children, break it apart to retrieve valuable metals. Often, this scrap recovery is done under primitive conditions where workers have little or no protective gear (fig. 21.6) and residue goes into open dumps. Health risks in this work are severe, especially for growing children. Soil, groundwater, and surface water contamination at these sites has been found to be as much as 200 times the World Health Organization's standards. An estimated 100,000 workers handle e-waste in China alone. The Basel Action Network, an international network of activists seeking to prevent the globalization of the toxic chemical trade, tracks international e-waste shipments and working conditions. The organization is named after the Swiss town where the agreement to ban international shipping of hazardous wastes was reached.

GURE 21.6 A Chinese woman smashes a cathode ray tube
ı a computer monitor in order to remove valuable metals. This kind of
rotected demanufacturing is highly hazardous to both workers and the
ironment.

Most of the world's obsolete ships are now dismantled and ycled in poor countries. The work is dangerous, and old ɔs often are full of toxic and hazardous materials, such as oil, diesel fuel, asbestos, and heavy metals. On India's Anlang Beach, for example, more than 40,000 workers tear rt outdated vessels using crowbars, cutting torches, and even ir bare hands. Metal is dragged away and sold for recycling. ;anic waste is often simply burned on the beach, where ashes oily residue wash back into the water.

'hink About It

cean dumping of both solid waste and hazardous waste is a ıronic problem. Suppose you were a captain or a sailor on an ɔean-going ship. What factors might influence your decision to ımp waste oil, garbage, or occasional litter overboard? (Money? me? legal considerations about your cargo or waste?) Whose sponsibility is ocean dumping? What steps could the international ɔmmunity take to reduce it?

Landfills receive most of our waste

Over the past 50 years most American and European cities have recognized the health and environmental hazards of open dumps. Increasingly, cities have turned to **sanitary landfills,** where solid waste disposal is regulated and controlled. To decrease smells and litter and to discourage insect and rodent populations, landfill operators are required to compact the refuse and cover it every day with a layer of dirt (fig. 21.7). This method helps control pollution, but the dirt fill also takes up as much as 20 percent of landfill space. Since 1994, all operating landfills in the United States have been required to control such hazardous substances as oil, chemical compounds, toxic metals, and contaminated rainwater that seeps through piles of waste. An impermeable clay and/or plastic lining underlies and encloses the storage area. Drainage systems are installed in and around the liner to catch drainage and to help monitor chemicals that may be leaking. Modern municipal solid-waste landfills now have many of the safeguards of hazardous waste repositories described later in this chapter.

Fresh kills Landfill on Staten Island, New York, was the world's largest (see photo p. 474). It officially closed in 2001, but then reopened to receive debris from the World Trade Center. It's named for the Fresh Kills River and esturary, which it spans.

More careful attention is now paid to the siting of new landfills. Sites located on highly permeable or faulted rock formations are passed over in favor of sites with less leaky geologic foundations. Landfills are being built away from rivers, lakes, floodplains, and aquifer recharge zones rather than near them, as was often done in the past. More care is being given to a landfill's long-term effects so that costly cleanups and rehabilitation can be avoided.

Historically, landfills have been a convenient and relatively inexpensive waste-disposal option in most places, but this situation is changing rapidly. Rising land prices and shipping

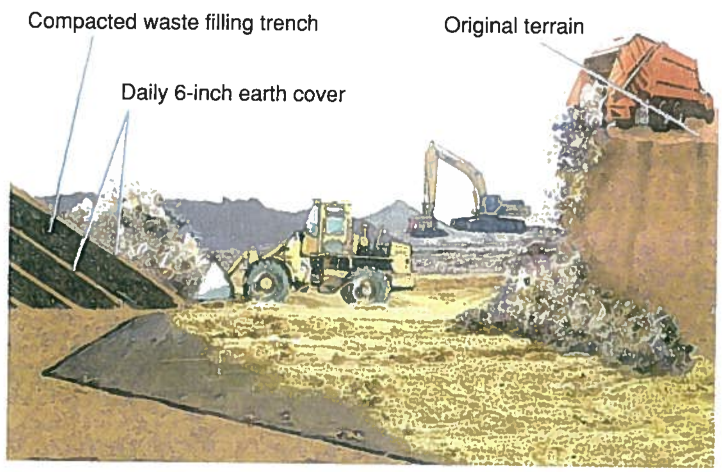


FIGURE 21.7 In a sanitary landfill, trash and garbage are crushed and covered each day to prevent accumulation of vermin and spread of disease. A waterproof lining is now required to prevent leaching of chemicals into underground aquifers.

costs, as well as increasingly demanding landfill construction and maintenance requirements, are making this a more expensive disposal method. The cost of disposing a ton of solid waste in Philadelphia went from $20 in 1980 to more than $100 in 1990. Union County, New York, experienced an even steeper price rise. In 1987, it paid $70 to get rid of a ton of waste; a year later, that same ton cost $420, or about $10 for a typical garbage bag. In the past decades, costs have continued to rise steadily, though not as sharply. The United States now spends about $10 billion per year to dispose of trash. A decade from now, it may cost Americans $100 billion per year to dispose of their garbage.

Suitable places for waste disposal are becoming scarce in many areas. Other uses compete for open space. Citizens have become more concerned and vocal about health hazards, as well as aesthetics. It is difficult to find a neighborhood or community willing to accept a new landfill. Since 1984, when stricter financial and environmental protection requirements for landfills took effect, more than 1,200 of the 1,500 existing landfills in the United States have closed. Many major cities are running out of local landfill space. They export their trash, at enormous expense, to neighboring communities and even other states. More than half the solid waste from New Jersey goes out of state, some of it up to 800 km (500 mi) away.

A positive trend in landfill management is methane recovery. Methane, or natural gas, is a natural product of decomposing garbage deep in a landfill. It is also an important "greenhouse gas." Normally methane seeps up to the landfill surface and escapes. At 300 U.S. landfills, the methane is being collected and burned. Cumulatively, these landfills could provide enough electricity for a city of a million people. Three times as many landfills could be recovering methane. Tax incentives could be developed to encourage this kind of resource recovery.

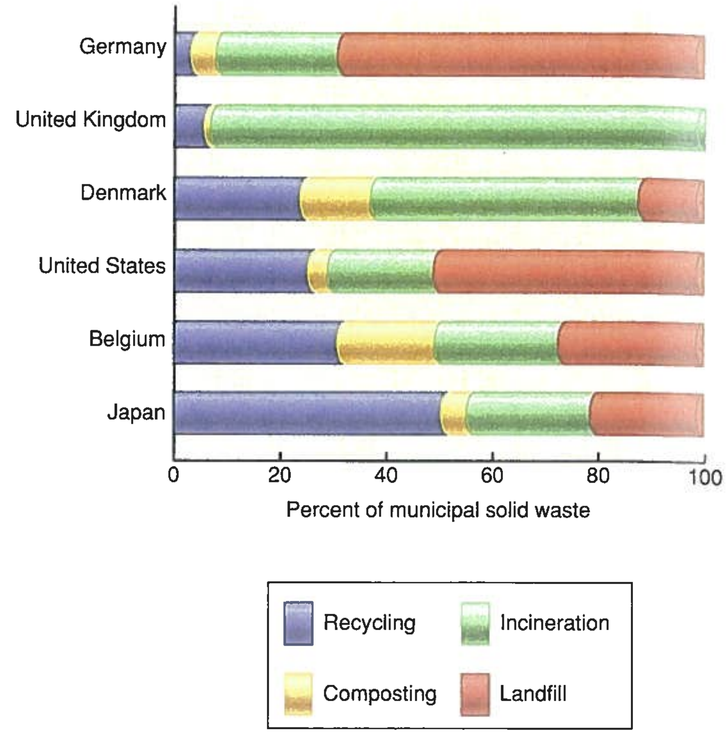


FIGURE 21.8 Percentage of municipal solid waste recycled, composted, incinerated, and landfilled in selected developed countries.
Source: Eurostat, UNEP, 2003.

Incineration produces energy but causes pollution

Landfilling is still the disposal method for the majority of municipal waste in the United States (fig. 21.8). Faced with growing piles of garbage and a lack of available landfills at any price, however, public officials are investigating other disposal methods. The method to which they frequently turn is burning. Another term commonly used for this technology is **energy recovery,** or waste-to-energy, because the heat derived from incinerated refuse is a useful resource. Burning garbage can produce steam used directly for heating buildings or generating electricity. Internationally, well over 1,000 waste-to-energy plants in Brazil, Japan, and western Europe generate much-needed energy while also reducing the amount that needs to be landfilled. In the United States, more than 110 waste incinerators burn 45,000 tons of garbage daily. Some of these are simple incinerators; others produce steam and/or electricity.

Types of Incinerators

Municipal incinerators are specially designed burning plants capable of burning thousands of tons of waste per day. In some plants, refuse is sorted as it comes in to remove unburnable or recyclable materials before combustion. This is called **refuse-derived fuel** because the enriched burnable fraction has a higher energy content than the raw trash. Another approach, called **mass burn,** is to dump everything smaller than sofas and refrigerators into a giant furnace and burn as much as possible (fig. 21.9).

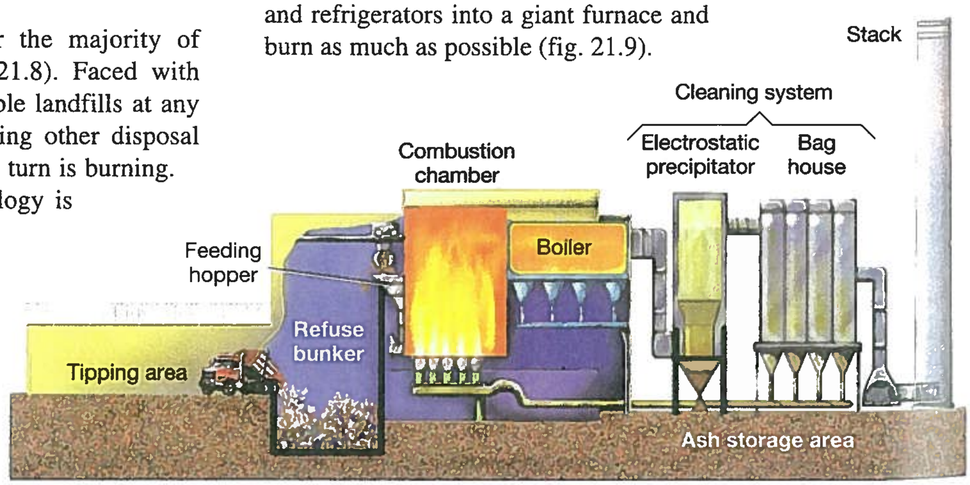


FIGURE 21.9 A diagram of a municipal "mass burn" garbage incinerator. Steam produced in the boiler can be used to generate electricity or to heat nearby buildings.

This technique avoids the expensive and unpleasant job of sorting through the garbage for nonburnable materials, but it often causes greater problems with air pollution and corrosion of burner grates and chimneys.

In either case, residual ash and unburnable residues representing 10 to 20 percent of the original volume are usually taken to a landfill for disposal. Because the volume of burned garbage is reduced by 80 to 90 percent, disposal is a smaller task. However, the residual ash usually contains a variety of toxic components that make it an environmental hazard if not disposed of properly. Ironically, one worry about incinerators is whether enough garbage will be available to feed them. Some communities in which recycling has been really successful have had to buy garbage from neighbors to meet contractual obligations to waste-to-energy facilities. In other places, fears that this might happen have discouraged recycling efforts.

Incinerator Cost and Safety

The cost-effectiveness of garbage incinerators is the subject of heated debates. Initial construction costs are high—usually between \$100 million and \$300 million for a typical municipal facility. Tipping fees at an incinerator, the fee charged to haulers for each ton of garbage dumped, are often much higher than those at a landfill. As landfill space near metropolitan areas becomes more scarce and more expensive, however, landfill rates are certain to rise. It may pay in the long run to incinerate refuse so that the lifetime of existing landfills will be extended.

Environmental safety of incinerators is another point of concern. The EPA has found alarmingly high levels of dioxins, furans, lead, and cadmium in incinerator ash. These toxic materials were more concentrated in the fly ash (lighter, airborne particles capable of penetrating deep into the lungs) than in heavy bottom ash. Dioxin levels can be as high as 780 parts per billion. One part per billion of TCDD, the most toxic dioxin, is considered a health concern. All of the incinerators studied exceeded cadmium standards, and 80 percent exceeded lead standards. Proponents of incineration argue that if they are run properly and equipped with appropriate pollution-control devices, incinerators are safe to the general public. Opponents counter that neither public officials nor pollution-control equipment can be trusted to keep the air clean. They argue that recycling and source reduction efforts are better ways to deal with waste problems.

The EPA, which generally supports incineration, acknowledges the health threat of incinerator emissions but holds that the danger is very slight. The EPA estimates that dioxin emissions from a typical municipal incinerator may cause one death per million people in 70 years of operation. Critics of incineration claim that a more accurate estimate is 250 deaths per million in 70 years.

One way to reduce these dangerous emissions is to remove batteries containing heavy metals and plastics containing chlorine before wastes are burned. Bremen, West Germany, is one of several European cities now trying to control dioxin emissions by keeping all plastics out of incinerator waste. Bremen is requiring households to separate plastics from other garbage. This is expected to eliminate nearly all dioxins and other combustion by-products and prevent the expense of installing costly pollution-control equipment that otherwise would be necessary to keep the burners operating. Several cities have initiated a recycling program for the small "button" batteries used in hearing aids, watches, and calculators in an attempt to lower mercury emissions from its incinerator.

21.3 Shrinking the Waste Stream

Having less waste to discard is obviously better than struggling with disposal methods, all of which have disadvantages and drawbacks. In this section we will explore some of our options for recycling, reuse, and reduction of the wastes we produce.

Recycling captures resources from garbage

The term *recycling* has two meanings in common usage. Sometimes we say we are *recycling* when we really are *reusing* something, such as refillable beverage containers. In terms of solid waste management, however, **recycling** is the reprocessing of discarded materials into new, useful products (fig. 21.10). Some recycling processes reuse materials for the same purposes; for instance, old aluminum cans and glass bottles are usually melted and recast into new cans and bottles. Other recycling processes turn old materials into entirely new products. Old tires, for instance, are shredded and turned into rubberized road surfacing. Newspapers become cellulose insulation, kitchen wastes become a valuable soil amendment, and steel cans become new automobiles and construction materials.

FIGURE 21.10 Trucks with multiple compartments pick up residential recyclables at curbside, greatly reducing the amount of waste that needs to be buried or burned. For many materials, however, collection costs are too high and markets are lacking for recycling to be profitable.

What Do You Think?

Environmental Justice

Who do you suppose lives closest to toxic waste dumps, Superfund sites, or other polluted areas in your city or county? If you answered poor people and minorities, you are probably right. Everyday experiences tell us that minority neighborhoods are much more likely to have high pollution levels and unpopular industrial facilities such as toxic waste dumps, landfills, smelters, refineries, and incinerators than are middle- or upper-class, white neighborhoods.

One of the first systematic studies showing this inequitable distribution of environmental hazards based on race in the United States was conducted by Robert D. Bullard in 1978. Asked for help by a predominantly black community in Houston that was slated for a waste incinerator, Bullard discovered that all five of the city's existing landfills and six of eight incinerators were located in African-American neighborhoods. In a book entitled *Dumping on Dixie,* Bullard showed that this pattern of risk exposure in minority communities is common throughout the United States (fig. 1).

In 1987, the Commission for Racial Justice of the United Church of Christ published an extensive study of environmental racism. Its conclusion was that race is the most significant variable in determining the location of toxic waste sites in the United States. Among the findings of this study are:

- three of the five largest commercial hazardous waste landfills accounting for about 40 percent of all hazardous waste disposal in the United States are located in predominantly black or Hispanic communities.
- 60 percent of African Americans and Latinos and nearly half of all Asians, Pacific Islanders, and Native Americans live in communities with uncontrolled toxic waste sites.
- The average percentage of the population made up by minorities in communities without a hazardous waste facility is 12 percent. By contrast, communities with one hazardous waste facility have, on average, twice as high (24 percent) a minority population, while those with two or more such facilities average three times as high a minority population (38 percent) as those without one.
- The "dirtiest" or most polluted zip codes in California are in riot-torn South Central Los Angeles where the population is predominantly African American or Latino. Three-quarters of all blacks and half of all Hispanics in Los Angeles live in these polluted areas, while only one-third of all whites live there.

Race is claimed to be the strongest determinant of who is exposed to environmental hazards. Where whites can often "vote with their feet" and move out of polluted and dangerous neighborhoods, minorities are restricted by color barriers and prejudice to less desirable locations. In some areas, though, class or income also are associated with environmental hazards. The difference between *environmental racism* and other kinds of *environmental injustice* can be hard to define. Economic opportunity is often closely tied to race and cultural background in the United States.

Racial inequities also are revealed in the way the government cleans up toxic waste sites and punishes polluters (fig. 2). White communities see faster responses and get better results once toxic wastes are discovered than do minority communities. Penalties assessed against polluters of white communities average six times higher than those against polluters of minority communities. Cleanup is more thorough in white communities as well. Most toxic wastes in white communities are removed or destroyed. By contrast, waste sites in minority neighborhoods are generally only "contained" by putting a cap over them, leaving contaminants in place to potentially resurface or leak into groundwater at a later date. The growing environmental justice movement works to combine civil rights and social justice with environmental concerns to call for a decent, livable environment and equal environmental protection for everyone.

Ethical Considerations

What are the ethical considerations in waste disposal? Does everyone have a right to live in a clean environment or only a right to buy one if they can afford it? What would be a fair way to distribute the risks of toxic wastes? If you had to choose between an incinerator, a secure landfill, or a composting facility for your neighborhood, which would you take?

FIGURE 1 Native Americans protest toxic waste dumping on tribal lands.

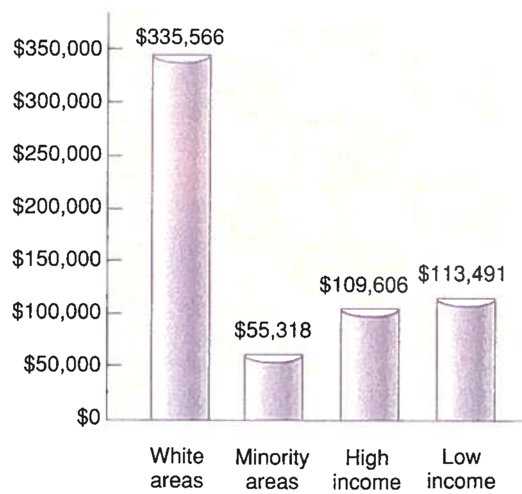


FIGURE 2 Hazardous waste law enforcement. The average fines or penalties per site for violation of the Resource Conservation and Recovery Act vary dramatically with racial composition of the communities where waste was dumped.

Source: M. Lavelle and M. Coyle, *The National Law Journal,* Vol. 15: 52–56, No. 3, September 21, 1992.

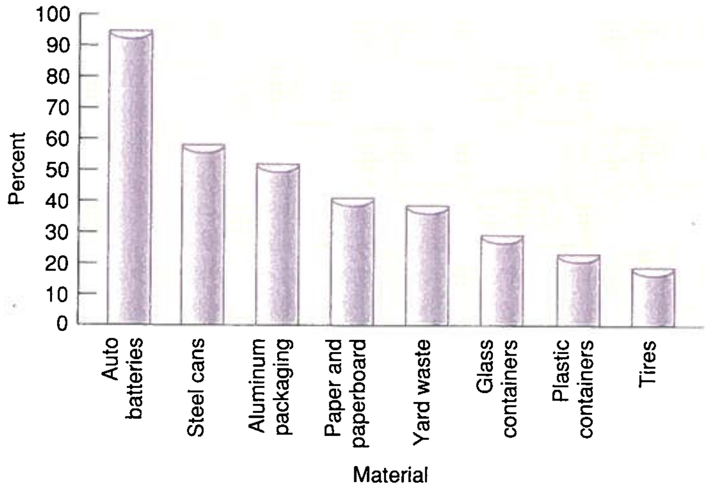


FIGURE 21.11 Recycling rates of selected materials in the United States.
Source: Environmental Protection Agency, 2003.

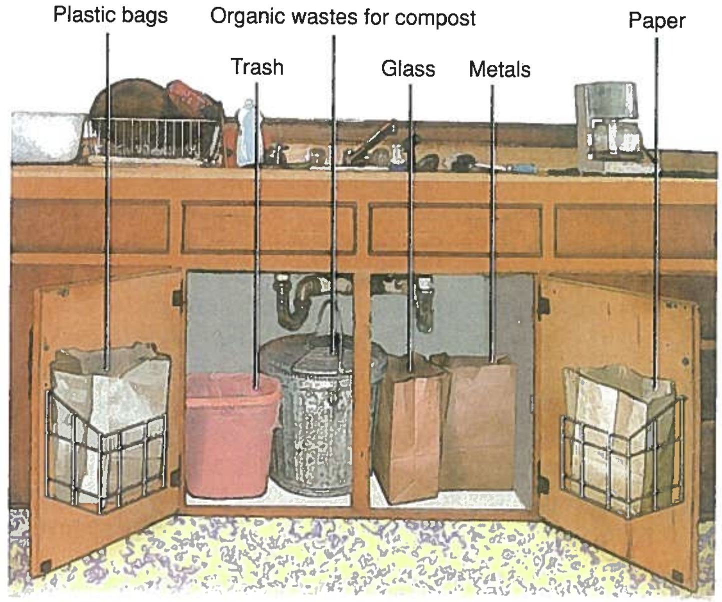


FIGURE 21.12 Source separation in the kitchen—the first step in a strong recycling program. One benefit of recycling is that it reminds us of our responsibility for waste management.

The high value of aluminum scrap ($2,500 per ton in 2007) has spurred a large percentage of aluminum recycling nearly everywhere (fig. 21.11). About two-thirds of all aluminum beverage cans are now recycled; up from only 15 percent in 1970. Aluminum recycling is so rapid that half of the cans now on grocery shelves will be made into another can within two months. Copper has been so valuable recently that thieves have been stripping copper pipes out of empty houses. Gas leaks have caused explosions.

These wild fluctuations in commodity prices are a big problem for recyclers. Newsprint, for example, which jumped to $160 a ton in 1995, dropped to $30 per ton in 2000 then climbed to $95 per ton in 2005. One day, it's so valuable that people are stealing it off the curb; the next day it's literally down in the dumps. It's hard to build a recycling program when you can't count on a stable price for your product.

Recycling saves money, materials, energy, and space

Recycling is usually a better alternative to either dumping or burning wastes. It saves money, energy, raw materials, and land space, while also reducing pollution. Recycling also encourages individual awareness and responsibility for the refuse produced (fig. 21.12). Some recycling facilities now have mechanical sorting machines so that homeowners don't have to separate recyclables into different categories. Everything can be placed in a single container.

Curbside pickup of recyclables costs around $35 per ton, as opposed to the $80 paid to dispose of them at an average metropolitan landfill. Many recycling programs cover their own expenses with materials sales and may even bring revenue to the community. Landfills continue to dominate American waste disposal but recycling (including composting) has quadrupled since 1980 (fig. 21.13).

Another benefit of recycling is that it could cut our waste volumes drastically. Philadelphia is investing in neighborhood collection centers that will recycle 600 tons a day, enough to eliminate the need for a previously planned, high-priced incinerator. New York City closed its last remaining landfill, Fresh Kills, in 2001. The city now exports its 11,000 tons per day

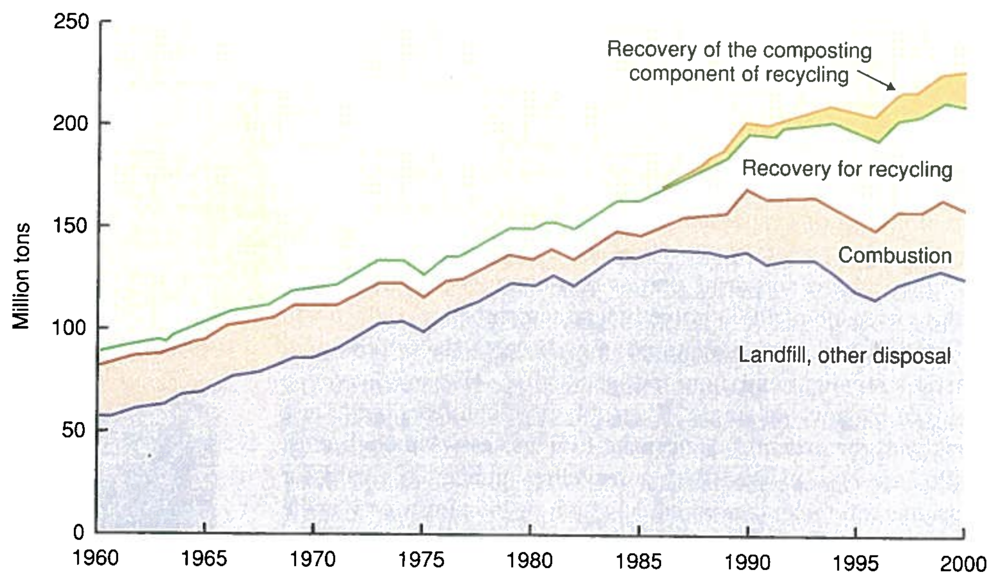


FIGURE 21.13 Disposal of municipal solid waste from 1960 to 2000. Landfills remain the dominant destination, but recycling and composting are increasing.
Source: Environmental Protection Agency, 2003.

of waste by truck, train, and barge, to New Jersey, Pennsylvania, Virginia, South Carolina, and Ohio. New York has set ambitious recycling goals of 50 percent waste reduction, but still the city recycles less than 30 percent of its household and office waste. In contrast, Minneapolis and Seattle recycle nearly 60 percent of domestic waste, Los Angeles and Chicago over 40 percent. In 2002, New York Mayor Michael Bloomberg raised a national outcry by canceling most of the city's recycling program. He argued that the program didn't pay for itself and the money should be spent to balance the city's budget. A year later, Bloomberg relented after realizing that it cost more to ship garbage than to recycle. Recycling was reinstated for nearly all recyclable materials.

Japan is probably the world's leader in recycling (see fig. 21.8). Short of land for landfills, Japan recycles about half its municipal waste and incinerates about 20 percent. The country has begun a push to increase recycling, because incineration costs almost as much. Some communities have raised recycling rates to 80 percent, and others aim to reduce waste altogether by 2020. This level of recycling is most successful when waste is well sorted. In Yokohama, a city of 3.5 million, there are now 10 categories of recyclables, including used clothing and sorted plastics. Some communities have 30 or 40 categories for sorting recyclables.

Recycling lowers our demands for raw resources. In the United States, we cut down 2 million trees every day to produce newsprint and paper products, a heavy drain on our forests. Recycling the print run of a single Sunday issue of the *New York Times* would spare 75,000 trees. Every piece of plastic we make reduces the reserves supply of petroleum and makes us more dependent on foreign oil. Recycling 1 ton of aluminum saves 4 tons of bauxite (aluminum ore) and 700 kg (1,540 lb) of petroleum coke and pitch, as well as keeping 35 kg (77 lb) of aluminum fluoride out of the air.

Recycling also reduces energy consumption and air pollution. Plastic bottle recycling can save 50 to 60 percent of the energy needed to make new ones. Making new steel from old scrap offers up to 75 percent energy savings. Producing aluminum from scrap instead of bauxite ore cuts energy use by 95 percent, yet we still throw away more than a million tons of aluminum every year. If aluminum recovery were doubled worldwide, more than a million tons of air pollutants would be eliminated every year.

Another problem in recycling is contamination. Most of the 24 billion plastic soft drink bottles sold every year in the United States are made of PET (polyethylene terephthalate), which can be melted and remanufactured into carpet, fleece clothing, plastic-strapping, and nonfood packaging. However, even a smidgen of vinyl—a single PVC (polyvinyl chloride) bottle in a truckload, for example—can make PET useless. Although most bottles are now marked with a recycling number, it's hard for consumers to remember which is which. A looming worry is the prospect of single-use, plastic beer bottles. Already being test marketed, these bottles are made of PET but are amber colored to block sunlight and have a special chemical coating to keep out oxygen, which would ruin the beer. The special color, interior coating, and vinyl cap lining will make these bottles incompatible with regular PET, and it will probably cost more to remove them from the waste stream than the reclaimed plastic is worth. Plastic recycling already is down 50 percent from a decade ago because so many soft drink bottles are sold and consumed on the go, and never make it into recycling bins. Throw-away beer bottles are a looming threat to this industry.

Reducing litter is an important benefit of recycling. Ever since disposable paper, glass, metal, foam, and plastic packaging began to accompany nearly everything we buy, these discarded wrappings have collected on our roadsides and in our lakes, rivers, and oceans. Without incentives to properly dispose of beverage cans, bottles, and papers, it often seems easier to just toss them aside when we have finished using them. Litter is a costly as well as unsightly problem. The United States pays an estimated 32 cents for each piece of litter picked up by crews along state highways, which adds up to $500 million every year. "Bottle-bills" requiring deposits on bottles and cans have reduced littering in many states.

Our present public policies often tend to favor extraction of new raw materials. Energy, water, and raw materials are often sold to industries below their real cost to create jobs and stimulate the economy. For instance, in 1999, a pound of recycled clear PET, the material in most soft drink bottles, sold for about 40¢. By contrast, a pound of off-grade, virgin PET cost 25¢. Setting the prices of natural resources at their real cost would tend to encourage efficiency and recycling. State, local, and national statutes requiring government agencies to purchase a minimum amount of recycled material have helped create a market for used materials. Each of us can play a role in creating markets, as well. If we buy things made from recycled materials—or ask for them if they aren't available—we will help make it possible for recycling programs to succeed (fig. 21.14).

FIGURE 21.14 Commercial-scale recycling recovers and markets resources on a large scale. Consumers can help build markets for recycled goods.

Commercial-scale recycling and composting is an area of innovation

Recycling household waste is the bedrock of recycling programs, but large-scale recycling is growing rapidly. The most common large-scale recycling is **composting** municipal yard waste and tree trimmings. Composting allows natural aerobic (oxygen-rich) decomposition to reduce organic debris to a nutrient-rich soil amendment. Many people compost yard and garden waste in their backyards. Increasingly, cities and towns are providing compost facilities in order to save landfill space. Organic debris such as yard waste makes up 12 percent of our waste stream, and almost half of organic waste is composted (see fig. 21.3).

While compost is a useful material, its market value is low. Many new and exciting technologies are emerging that create still more marketable products, such as energy, from garbage. The Swiss company Kompogas, for example, ferments organic waste in giant tanks, producing natural gas (methane), compost, and fertilizer. The company makes money on both ends, by collecting waste and selling energy and fertilizer.

Every year thousands of tons of debris from building sites and demolition heads to landfills, but recycling facilities are collecting, sorting, and reselling increasing portions of this debris. One recycling facility in Newburgh, New York, recycles over 95 percent of the mixed wood, brick, concrete, metal scrap, and wallboard it receives each day. After sorting and separating, these materials are sold as mulch, crushed stone, gypsum, and recyclable metal and paper. The same company sorted and recycled over 500,000 tons of debris from the World Trade Center towers in just 9 months.

About 6 billion tons of animal wastes are produced from feedlots and processing plants each year in the United States, and these are especially difficult to process because they carry noxious odors and diseases. Industry produces another 5 billion tons per year of plastics, tires, waste oil, asphalt and other organic debris. A new technique called a thermal conversion process (TCP) has attracted much attention since 2003, when articles about it appeared in *Scientific American* and the *MIT Review.* This method essentially pressure-cooks animal manure, plastics, paper-processing waste, and even tires and urban sewage sludge. Extreme heat and pressure reduce organic molecules to simple hydrocarbons—oil, gasoline, and natural gas. An experimental plant in Missouri began commercial fuel production in 2004.

Although landfills and incinerators dwarf these new recycling technologies, recycling is likely to grow as land values and fuel prices continue to rise.

Demanufacturing is necessary for appliances and e-waste

Demanufacturing is the disassembly and recycling of obsolete products, such as TV sets, computers, refrigerators, and air conditioners. As we mentioned earlier, electronics and appliances are among the fastest-growing components of the global waste stream. Americans throw away about 54 million household appliances, such as stoves and refrigerators, 12 million computers, and uncounted cell phones each year. Most office computers are used only 3 years; televisions last 5 years or so; refrigerators last longer, an average of 12 years. In the United States, an estimated 300 million computers await disposal in storage rooms and garages.

Demanufacturing is key to reducing the environmental costs of e-waste and appliances. A single personal computer can contain 700 different chemical compounds, including toxic materials (mercury, lead, and gallium), and valuable metals (gold, silver, copper), as well as brominated fire retardants and plastics. A typical personal computer has about $6 worth of gold, $5 worth of copper, and $1 of silver. Approximately 40 percent of lead entering U.S. landfills, and 70 percent of heavy metals, comes from e-waste. Batteries and switches in toys and electronics make up another 10 to 20 percent of heavy metals in our waste stream. These contaminants can enter groundwater if computers are landfilled, or the air if they are incinerated. When collected, these materials can become a valuable resource—and an alternative to newly mined materials.

To reduce these environmental hazards, the European Union now requires cradle-to-grave responsibility for electronic products. Manufacturers now have to accept used products or fund independent collectors. An extra $20 (less than one percent of the price of most computers) is added to the purchase price to pay for collection and demanufacturing. Manufacturers selling computers, televisions, refrigerators, and other appliances in Europe must also phase out many of the toxic compounds used in production. Japan is rapidly adopting European environmental standards, and some U.S. companies are following suit, in order to maintain their international markets. In the United States, at least 29 states have passed, or are considering, legislation to control disposal of appliances and computers, in order to protect groundwater and air quality.

Reuse is even more efficient than recycling

Even better than recycling or composting is cleaning and reusing materials in their present form, thus saving the cost and energy of remaking them into something else. We do this already with some specialized items. Auto parts are regularly sold from junkyards, especially for older car models. In some areas, stained glass windows, brass fittings, fine woodwork, and bricks salvaged from old houses bring high prices. Some communities sort and reuse a variety of materials received in their dumps (fig. 21.15).

In many cities, glass and plastic bottles are routinely returned to beverage producers for washing and refilling. The reusable, refillable bottle is the most efficient beverage container we have. This is better for the environment than remelting and more profitable for local communities. A reusable glass container makes an average of 15 round-trips between factory and customer before it becomes so scratched and chipped that it has to be recycled. Reusable containers also favor local bottling companies and help preserve regional differences.

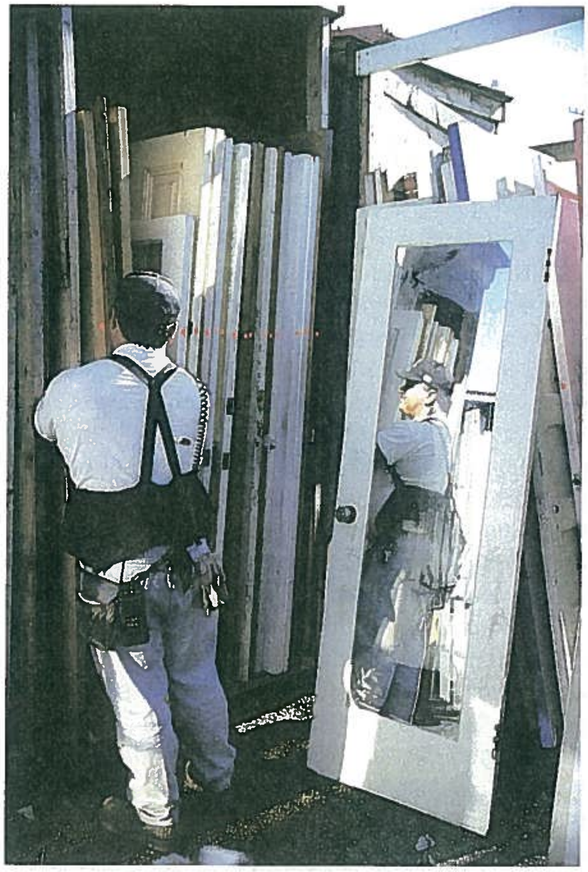


FIGURE 21.15 Reusing discarded products is a creative and efficient way to reduce wastes. This recycling center in Berkeley, California, is a valuable source of used building supplies and a money saver for the whole community.

Since the advent of cheap, lightweight, disposable food and beverage containers, many small, local breweries, canneries, and bottling companies have been forced out of business by huge national conglomerates. These big companies can afford to ship food and beverages great distances as long as it is a one-way trip. If they had to collect their containers and reuse them, canning and bottling factories serving large regions would be uneconomical. Consequently, the national companies favor recycling rather than refilling because they prefer fewer, larger plants and don't want to be responsible for collecting and reusing containers. In some circumstances, life-cycle assessment shows that washing and decontaminating containers takes as much energy and produces as much air and water pollution as manufacturing new ones.

In less affluent nations, reuse of all sorts of manufactured goods is an established tradition. Where most manufactured products are expensive and labor is cheap, it pays to salvage, clean, and repair products. Cairo, Manila, Mexico City, and many other cities have large populations of poor people who make a living by scavenging. Entire ethnic populations may survive on scavenging, sorting, and reprocessing scraps from city dumps.

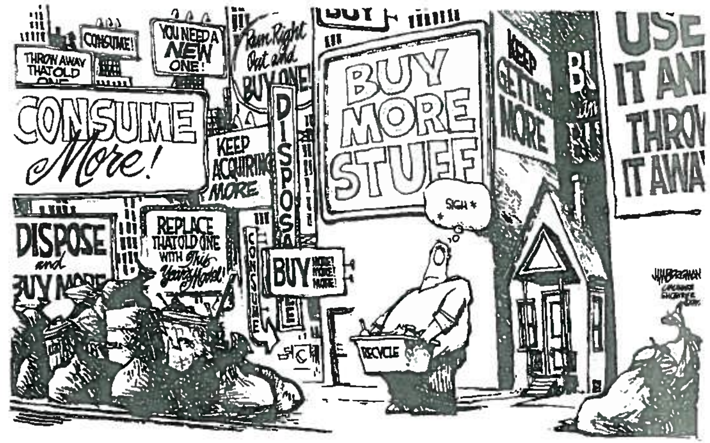


FIGURE 21.16 How much more do we need? Where will we put what we already have?
Source: Reprinted with special permission of Universal Press Syndicate.

Reducing waste is often the cheapest option

South Africa's effort to reduce the consumption of plastic bags (opening case study) demonstrates the multiple benefits of producing less waste. Excess packaging of food and consumer products is one of our greatest sources of unnecessary waste. Paper, plastic, glass, and metal packaging material make up 50 percent of our domestic trash by volume. Much of that packaging is primarily for marketing and has little to do with product protection (fig. 21.16). Manufacturers and retailers might be persuaded to reduce these wasteful practices if consumers ask for products without excess packaging. Canada's National Packaging Protocol (NPP) recommends that packaging minimize depletion of virgin resources and production of toxins in manufacturing. The preferred hierarchy is (1) no packaging, (2) minimal packaging, (3) reusable packaging, and (4) recyclable packaging.

Where disposable packaging is necessary, we still can reduce the volume of waste in our landfills by using materials that are compostable or degradable. **Photodegradable plastics** break down when exposed to ultraviolet radiation. **Biodegradable plastics** incorporate such materials as cornstarch that can be decomposed by microorganisms. These degradable plastics often don't decompose completely; they only break down to small particles that remain in the environment. In doing so, they can release toxic chemicals into the environment. And in modern, lined landfills they don't decompose at all. Furthermore, they make recycling less feasible and may lead people to believe that littering is okay.

Most of our attention in waste management focuses on recycling. But slowing the consumption of throw-away products is by far the most effective way to save energy, materials, and money. The 3R waste hierarchy—reduce, reuse, recycle—lists the most important strategy first. Industries are increasingly finding that reducing saves money. Soft drink makers use less aluminum per can than they did 20 years ago, and plastic bottles use less plastic. 3M has saved over $500 million in the past

What Can You Do?

Reducing Waste

1. Buy foods that come with less packaging; shop at farmers' markets or co-ops, using your own containers.
2. Take your own washable refillable beverage container to meetings or convenience stores.
3. When you have a choice at the grocery store between plastic, glass, or metal containers for the same food, buy the reusable or easier-to-recycle glass or metal.
4. When buying plastic products, pay a few cents extra for environmentally degradable varieties.
5. Separate your cans, bottles, papers, and plastics for recycling.
6. Wash and reuse bottles, aluminum foil, plastic bags, etc., for your personal use.
7. Compost yard and garden wastes, leaves, and grass clippings.
8. Write to your senators and representatives and urge them to vote for container deposits, recycling, and safe incinerators or landfills.

ource: Minnesota Pollution Control Agency.

0 years by reducing its use of raw materials, reusing waste roducts, and increasing efficiency. Individual action is essential, ›o (What Can You Do? p. 487).

In 2007, the European Union adopted new regulations that ım to reduce both landfills and waste incineration. For the first me, the waste hierarchy—prevention, reuse, recycling, then disɔsal only as a last resort—is formalized in law. By 2020, half f all E.U. municipal solid waste and 70 percent of all construcɔn waste is expected to be reused or recycled as a result of this w. No recyclable waste will be allowed in landfills. This law so establishes the "polluter pays" principle (those who create ɔllution should pay for it), and the "proximity principle," which ıys that waste should be treated in the nearest appropriate facil-y to the site at which it was produced. Mixing of toxic waste also forbidden, making reuse and reprocessing easier.

1.4 Hazardous and Toxic Wastes

ıe most dangerous aspect of the waste stream we have scribed is that it often contains highly toxic and hazardous aterials that are injurious to both human health and environental quality. We now produce and use a vast array of flamable, explosive, caustic, acidic, and highly toxic chemical bstances for industrial, agricultural, and domestic purposes g. 21.17). According to the EPA, industries in the United ates generate about 265 million metric tons of *officially* clasied hazardous wastes each year, slightly more than 1 ton for

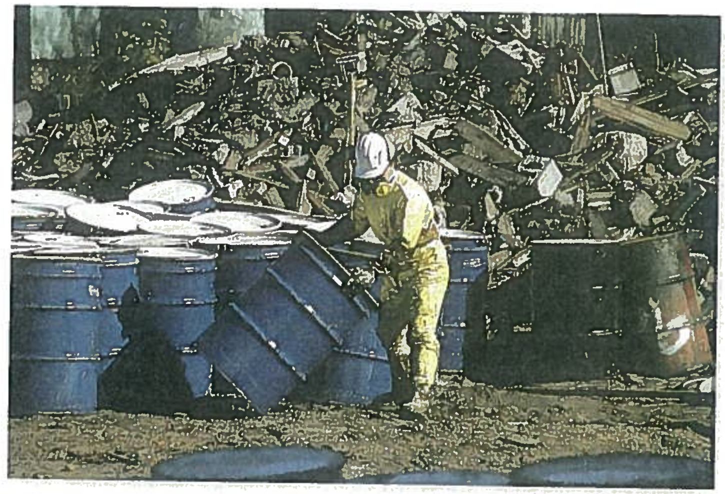


FIGURE 21.17 According to the U.S. Environmental Protection Agency, industries produce about one ton of hazardous waste per year for every person in the United States. Responsible handling and disposal is essential.

each person in the country. In addition, considerably more toxic and hazardous waste material is generated by industries or processes not regulated by the EPA. Shockingly, at least 40 million metric tons (22 billion lbs) of toxic and hazardous wastes are released into the air, water, and land in the United States each year. The biggest source of these toxins are the chemical and petroleum industries (fig. 21.18).

Hazardous waste must be recycled, contained, or detoxified

Legally, a **hazardous waste** is any discarded material, liquid or solid, that contains substances known to be (1) fatal to humans or laboratory animals in low doses, (2) toxic, carcinogenic, mutagenic, or teratogenic to humans or other life-forms, (3) ignitable with a flash point less than 60°C, (4) corrosive, or (5) explosive or highly reactive (undergoes violent chemical reactions either by itself or when mixed with other materials). Notice that this definition includes both toxic and hazardous materials as defined in chapter 8. Certain compounds are exempt from regulation as hazardous waste

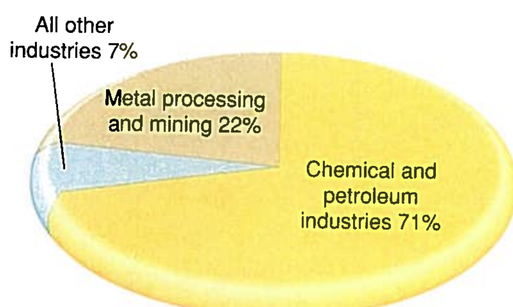


FIGURE 21.18 Producers of hazardous wastes in the United States.
Source: Data from the U.S. EPA, 2002.

if they are accumulated in less than 1 kg (2.2 lb) of commercial chemicals or 100 kg of contaminated soil, water, or debris. Even larger amounts (up to 1,000 kg) are exempt when stored at an approved waste treatment facility for the purpose of being beneficially used, recycled, reclaimed, detoxified, or destroyed.

Most hazardous waste is recycled, converted to nonhazardous forms, stored, or otherwise disposed of on-site by the generators—chemical companies, petroleum refiners, and other large industrial facilities—so that it doesn't become a public problem. Still, the hazardous waste that does enter the waste stream or the environment represents a serious environmental problem. And orphan wastes left behind by abandoned industries remain a serious threat to both environmental quality and human health. For years, little attention was paid to this material. Wastes stored on private property, buried, or allowed to soak into the ground were considered of little concern to the public. An estimated 5 billion metric tons of highly poisonous chemicals were improperly disposed of in the United States between 1950 and 1975 before regulatory controls became more stringent.

Think About It

Hazardous waste is often poorly managed because it is invisible to the public. What steps do we take to make it invisible? Should the public be more involved in, or take more responsibility for, hazardous waste management? If most waste is produced by the chemical and petroleum industries (fig. 21.18), is there any way that you and your friends or family might help control hazardous waste production?

Federal Legislation

Two important federal laws regulate hazardous waste management and disposal in the United States. The Resource Conservation and Recovery Act (RCRA, pronounced "rickra") of 1976 is a comprehensive program that requires rigorous testing and management of toxic and hazardous substances. A complex set of rules require generators, shippers, users, and disposers of these materials to keep meticulous account of everything they handle and what happens to it from generation (cradle) to ultimate disposal (grave) (fig. 21.19).

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA or Superfund Act), passed in 1980 and modified in 1984 by the Superfund Amendments and Reauthorization Act (SARA), is aimed at rapid containment, cleanup, or remediation of abandoned toxic waste sites. This statute authorizes the Environmental Protection Agency to undertake emergency actions when a threat exists that toxic material will leak into the environment. The agency is empowered to bring suit for the recovery of its costs from potentially responsible parties such as site owners, operators, waste generators, or transporters.

SARA also established (under title III) community right to know and state emergency response plans that give citizens access to information about what is present in their communities. One of the most useful tools in this respect is the **Toxic Release Inventory,** which requires 20,000 manufacturing facilities to report annually on releases of more than 300 toxic materials. You can find specific information there about what is in your neighborhood.

The government does not have to prove that anyone violated a law or what role they played in a Superfund site. Rather, liability under CERCLA is "strict, joint, and several," meaning that anyone associated with a site can be held responsible for the entire cost of cleaning it up no matter

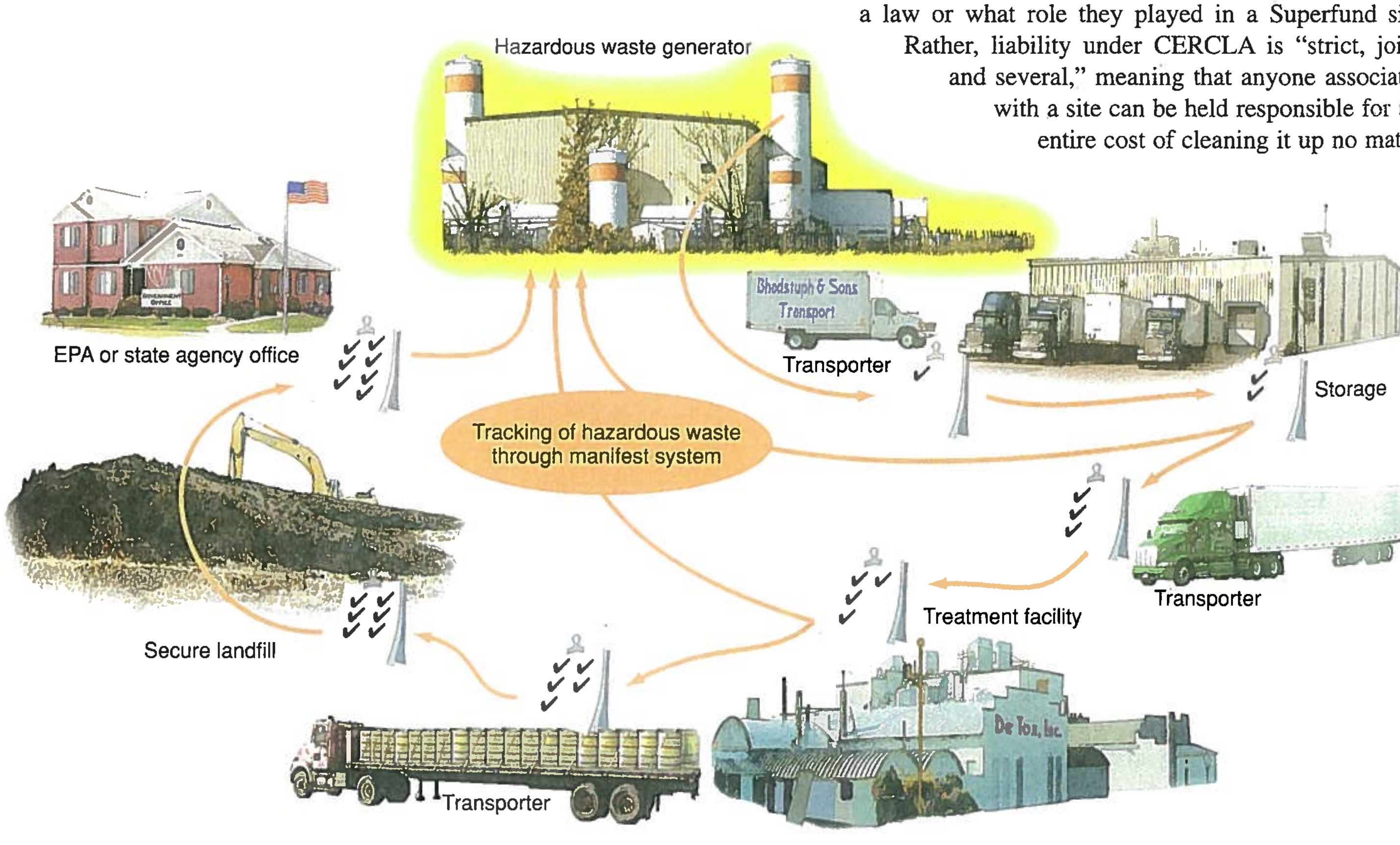


FIGURE 21.19 Toxic and hazardous wastes must be tracked from "cradle to grave" by detailed shipping manifests.

w much of the mess they made. In some cases, property own- have been assessed millions of dollars for removal of wastes : there years earlier by previous owners. This strict liability has ǝn a headache for the real estate and insurance businesses.

CERCLA was amended in 1995 to make some of its provi- ns less onerous. In cases where treatment is unavailable or too ıtly and it is likely that a less-costly remedy will become avail- e within a reasonable time, interim containment is now ɔwed. The EPA also now has the discretion to set site-specific anup levels rather than adhere to rigid national standards.

ıperfund sites are those listed r federal cleanup

: EPA estimates that there are at least 36,000 seriously con- ıinated sites in the United States. The General Accounting ice (GAO) places the number much higher, perhaps more than),000 when all are identified. By 2007, some 1,680 sites had been placed on the National Priority List (NPL) for cleanup with financing from the federal Superfund program. The **ɔerfund** is a revolving pool designed to (1) provide an immedi- response to emergency situations that pose imminent hazards, (2) to clean up or remediate abandoned or inactive sites. With- this fund, sites would languish for years or decades while the rts decided who was responsible to pay for the cleanup. Origi- y a $1.6 billion pool, the fund peaked at $3.6 billion. From its ption, the fund was financed by taxes on producers of toxic hazardous wastes. Industries opposed this "polluter pays" tax, ause current manufacturers are often not the ones responsible the original contamination. In 1995, Congress agreed to let the expire. Since then the Superfund has dwindled, and the public picked up an increasing share of the bill. In the 1980s the lic covered less than 20 percent of the Superfund. Now, public ls have to pick up the entire cost of toxic waste cleanup.

Total costs for hazardous waste cleanup in the United States estimated between $370 billion and $1.7 trillion, depending ıow clean sites must be and what methods are used. For years, erfund money was spent mostly on lawyers and consultants, cleanup efforts were often bogged down in disputes over ility and best cleanup methods. During the 1990s, however, ;ress improved substantially, with a combination of rule ıstments and administrative commitment to cleanup. From 3 to 2000, the number of completed NPL cleanups jumped ı 155 to 757, almost half the list's 1,680 sites (fig. 21.20). :e 2000, progress has slowed again, due to underfunding and wer priority in the federal government.

What qualifies a site for the NPL? These sites are considered e especially hazardous to human health and environmental ity because they are known to be leaking or have a potential leaking supertoxic, carcinogenic, teratogenic, or mutagenic ɛrials (chapter 8). The ten substances of greatest concern or t commonly detected at Superfund sites are lead, trichloroeth- e, toluene, benzene, PCBs, chloroform, phenol, arsenic, cad- m, and chromium. These and other hazardous or toxic ɛrials are known to have contaminated groundwater at 75 per- of the sites now on the NPL. In addition, 56 percent of these sites have contaminated surface waters, and airborne materials are found at 20 percent of the sites.

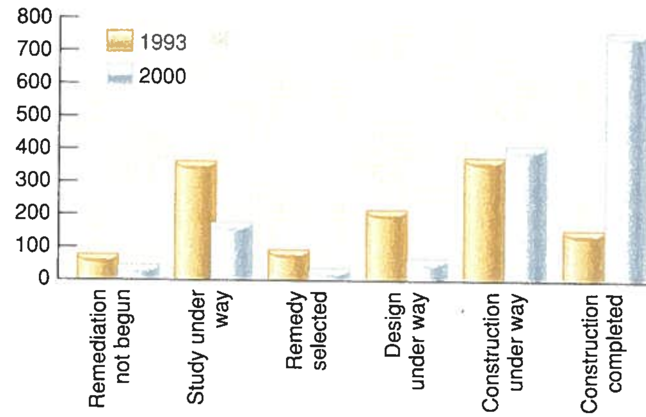


FIGURE 21.20 Progress on Superfund National Priority List (NPL) sites. After years of little progress, the number of completed sites jumped from 155 in 1993 to 757 in 2000. Over 90 percent of the 1,500 NPL sites are under construction or completed.
Source: Environmental Protection Agency, 2001.

Where are these thousands of hazardous waste sites, and how did they get contaminated? Old industrial facilities such as smelt- ers, mills, petroleum refineries, and chemical manufacturing plants are highly likely to have been sources of toxic wastes. Regions of the country with high concentrations of aging facto- ries such as the "rust belt" around the Great Lakes or the Gulf Coast petrochemical centers have large numbers of Superfund sites (fig. 21.21). Mining districts also are prime sources of toxic and hazardous waste. Within cities, factories and places such as railroad yards, bus repair barns, and filling stations where sol- vents, gasoline, oil, and other petrochemicals were spilled or dumped on the ground often are highly contaminated.

Some of the most infamous toxic waste sites were old dumps where many different materials were mixed together

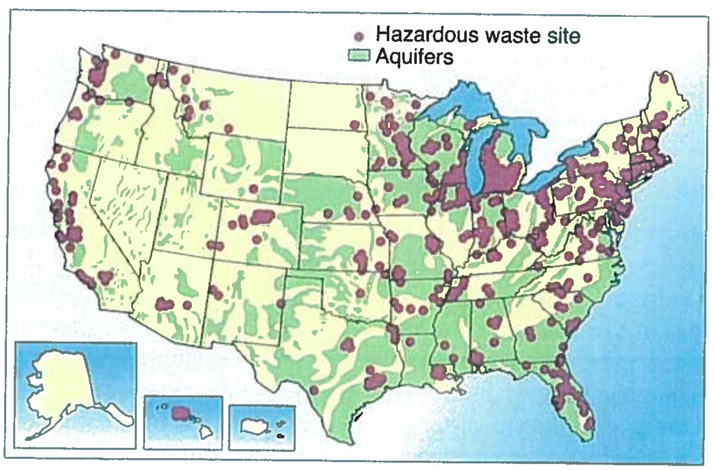


FIGURE 21.21 Some of the hazardous waste sites on the EPA priority cleanup list. Sites located on aquifer recharge zones represent an especially serious threat. Once groundwater is contaminated, cleanup is difficult and expensive. In some cases, it may not be possible.
Source: Environmental Protection Agency.

Exploring SCIENCE

Cleaning Up Toxic Waste with Plants

Getting contaminants out of soil and groundwater is one of the most widespread and persistent problems in waste cleanup. Once leaked into the ground, solvents, metals, radioactive elements, and other contaminants are dispersed and difficult to collect and treat. The main method of cleaning up contaminated soil is to dig it up, then decontaminate it or haul it away and store it in a landfill in perpetuity. At a single site, thousands of tons of tainted dirt and rock may require incineration or other treatment. Cleaning up contaminated groundwater usually entails pumping vast amounts of water out of the ground—hopefully extracting the contaminated water faster than it can spread through the water table or aquifer. In the United States alone, there are tens of thousands of contaminated sites on factories, farms, gas stations, military facilities, sewage treatment plants, landfills, chemical warehouses, and other types of facilities. Cleaning up these sites is expected to cost at least $700 billion.

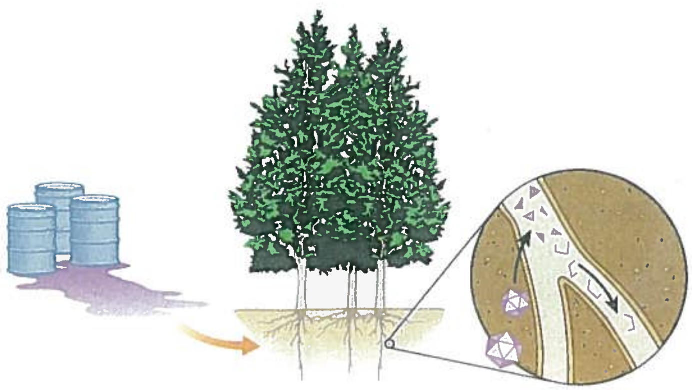
Recently, a number of promising alternatives have been developed using plants, fungi, and bacteria to clean up our messes. *Phytoremediation* (remediation, or cleanup, using plants) can include a variety of strategies for absorbing, extracting, or neutralizing toxic compounds. Certain types of mustards and sunflowers can extract lead, arsenic, zinc, and other metals (*phytoextraction*). Poplar trees can absorb and break down toxic organic chemicals (*phytodegradation*). Reeds and other water-loving plants can filter water tainted with sewage, metals, or other contaminants. Natural bacteria in groundwater, when provided with plenty of oxygen, can neutralize contaminants in aquifers, minimizing or even eliminating the need to extract and treat water deep in the ground. Radioactive strontium and cesium have been extracted from soil near the Chernobyl nuclear power plant using common sunflowers.

How do the plants, bacteria, and fungi do all this? Many of the biophysical details are poorly understood, but in general, plant roots are designed to efficiently extract nutrients, water, and minerals from soil and groundwater. The mechanisms involved may aid extraction of metallic and organic contaminants. Some plants also use toxic elements as a defense against herbivores—locoweed, for example, selectively absorbs elements such as selenium, concentrating toxic levels in its leaves. Absorption can be extremely seffective. Braken fern growing in Florida was found to contain arsenic at concentrations more than 200 times higher than the soil in which it was growing.

Genetically modified plants are also being developed to process toxins. Poplars have been grown with a gene borrowed from bacteria that transform a toxic compound of mercury into a safer form. In another experiment, a gene for producing mammalian liver enzymes, which specialize in breaking down toxic organic compounds, was inserted into tobacco plants. The plants succeeded in producing the liver enzymes and breaking down toxins absorbed through their roots.

These remediation methods are not without risks. As plants take up toxins, insects could consume leaves, allowing contaminants to enter the food web. Some absorbed contaminants are volatilized, or emitted in gaseous form, through pores in plant leaves. Once toxic contaminants are absorbed into plants, the plants themselves are usually toxic and must be landfilled. But the cost of phytoremediation can be less than half the cost of landfilling or treating toxic soil, and the volume of plant material requiring secure storage ends up being a fraction of a percent of the volume of the contaminated dirt.

Cleaning up hazardous and toxic waste sites will be a big business for the foreseeable future, both in the United States and around the world. Innovations such as phytoremediation offer promising prospects for business growth as well as for environmental health and saving taxpayers' money.



Plants can absorb, concentrate, and even decompose toxic contaminants in soil and groundwater.

indiscriminately. For instance, Love Canal in Niagara Falls, New York, was an open dump used by both the city and nearby chemical factories as a disposal site. More than 20,000 tons of toxic chemical waste was buried under what later became a housing development. Another infamous example occurred in Hardeman County, Tennessee, where about a quarter of a million barrels of chemical waste were buried in shallow pits that leaked toxins into the groundwater. In other sites, liquid wastes were pumped into open lagoons or abandoned in warehouses.

Studies of who lives closest to Superfund and toxic release inventory sites reveal that minorities often are overrepresented in these neighborhoods. Charges of environmental racism have been made, but this is difficult to show conclusively (What Do You Think? p. 482).

Brownfields present both liability and opportunity

Among the biggest problems in cleaning up hazardous waste sites are questions of liability and the degree of purity required. In many cities, these problems have created large areas of contaminated properties known as **brownfields** that have been abandoned or are not being used up to their potential because of real or suspected pollution. Up to one-third of all commercial and industrial sites in the urban core of many big cities fall in this category. In heavy industrial corridors the percentage typically is higher.

For years, no one was interested in redeveloping brownfields because of liability risks. Who would buy a property knowing that they might be forced to spend years in litigation and negotiations and be forced to pay millions of dollars for pollution they didn't create? Even if a site has been cleaned to current standards, there is a worry that additional pollution might be found in the future or that more stringent standards might be applied.

In many cases, property owners complain that unreasonably high levels of purity are demanded in remediation programs. Consider the case of Columbia, Mississippi. For many years a 35 ha (81 acre) site in Columbia was used for turpentine and pine tar manufacturing. Soil tests showed concentrations of phenols and other toxic organic compounds exceeding federal safety standards. The site was added to the Superfund NPL and remediation was ordered. Some experts recommended that the best solution was to simply cover the surface with clean soil and enclose the property with a fence to keep people out. The total costs would have been about $1 million.

Instead, the EPA ordered Reichhold Chemical, the last known property owner, to excavate more than 12,500 tons of soil and haul it to a commercial hazardous waste dump in Louisiana at a cost of some $4 million. The intention is to make the site safe enough to be used for any purpose, including housing—even though no one has proposed building anything there. According to the EPA, the dirt must be clean enough for children to play in it—even eat it every day for 70 years—without risk.

Similarly, in places where contaminants have seeped into groundwater, the EPA generally demands that cleanup be carried to drinking water standards. Many critics believe that these pristine standards are unreasonable. Former Congressman Jim Florio, a principal author of the original Superfund Act, says, "It doesn't make any sense to clean up a rail yard in downtown Newark so it can be used as a drinking water reservoir." Depending on where the site is, what else is around it, and what its intended uses are, much less stringent standards may be perfectly acceptable.

Recognizing that reusing contaminated properties can play a significant role in rebuilding old cities, creating jobs, increasing the tax base, and preventing needless destruction of open space at urban margins, programs have been established at both federal and state levels to encourage brownfield recycling. Adjusting purity standards according to planned uses and providing liability protection for nonresponsible parties gives developers and future purchasers confidence that they won't be unpleasantly surprised in the future with further cleanup costs. In some communities, former brownfields are being turned into "eco-industrial parks" that feature environmentally friendly businesses and bring in much needed jobs to inner-city neighborhoods.

Hazardous waste storage must be safe

What shall we do with toxic and hazardous wastes? In our homes, we can reduce waste generation and choose less toxic materials. Buy only what you need for the job at hand. Use up the last little bit or share leftovers with a friend or neighbor. Many common materials that you probably already have make excellent alternatives to commercial products (What Can You Do? p. 491). Dispose of unneeded materials responsibly (table 21.1).

Produce Less Waste

As with other wastes, the safest and least expensive way to avoid hazardous waste problems is to avoid creating the wastes in the

What Can You Do?

Alternatives to Hazardous Household Chemicals

Chrome cleaner: Use vinegar and nonmetallic scouring pad.

Copper cleaner: Rub with lemon juice and salt mixture.

Floor cleaner: Mop linoleum floors with 1 cup vinegar mixed with 2 gallons of water. Polish with club soda.

Brass polish: Use Worcestershire sauce.

Silver polish: Rub with toothpaste on a soft cloth.

Furniture polish: Rub in olive, almond, or lemon oil.

Ceramic tile cleaner: Mix 1/4 cup baking soda, 1/2 cup white vinegar, and 1 cup ammonia in 1 gallon warm water (good general purpose cleaner).

Drain opener: Use plunger or plumber's snake, pour boiling water down drain.

Upholstery cleaner: Clean stains with club soda.

Carpet shampoo: Mix 1/2 cup liquid detergent in 1 pint hot water. Whip into stiff foam with mixer. Apply to carpet with damp sponge. Rinse with 1 cup vinegar in 1 gal water. Don't soak carpet—it may mildew.

Window cleaner: Mix 1/3 cup ammonia, 1/4 cup white vinegar in 1 quart warm water. Spray on window. Wipe with soft cloth.

Spot remover: For butter, coffee, gravy, or chocolate stains: Sponge up or scrape off as much as possible immediately. Dab with cloth dampened with a solution of 1 teaspoon white vinegar in 1 quart cold water.

Toilet cleaner: Pour 1/2 cup liquid chlorine bleach into toilet bowl. Let stand for 30 minutes, scrub with brush, flush.

Pest control: Spray plants with soap-and-water solution (3 tablespoons soap per gallon water) for aphids, mealybugs, mites, and whiteflies. Interplant with pest repellent plants such as marigolds, coriander, thyme, yarrow, rue, and tansy. Introduce natural predators such as ladybugs or lacewings.

Indoor pests: Grind or blend 1 garlic clove and 1 onion. Add 1 tablespoon cayenne pepper and 1 quart water. Add 1 tablespoon liquid soap.

Moths: Use cedar chips or bay leaves.

Ants: Find where they are entering house, spread cream of tartar, cinnamon, red chili pepper, or perfume to block trail.

Fleas: Vacuum area, mix brewer's yeast with pet food.

Mosquitoes: Brewer's yeast tablets taken daily repel mosquitoes.

Note: test cleaners in small, inconspicuous area before using.

TABLE 21.1

How Should You Dispose of Household Hazardous Waste?

Flush to sewer system (drain or toilet)	Cleaning agents with ammonia or bleach, disinfectants, glass cleaner, toilet cleaner
Put dried solids in household trash	Cosmetics, putty, grout, caulking, empty solvent containers, water-based glue, fertilizer (without weed killer)
Save and deliver to a waste collection center	*Solvents:* cleaning agents (drain cleaner, floor wax-stripper, furniture polish, metal cleaner, oven cleaner), paint thinner and other solvents, glue with solvents, varnish, nail polish remover
	Metals: mercury thermometers, button batteries, NiCad batteries, auto batteries, paints with lead or mercury, fluorescent light bulbs/tubes/ballasts, electronics and appliances
	Poisons: bug spray, pesticides, weed killers, rat poison, insect poison, mothballs
	Other chemicals: antifreeze, gasoline, fuel oil, brake fluid, transmission fluid, paint, rust remover, hairspray, photo chemicals

Source: EPA, 2005.

first place. Manufacturing processes can be modified to reduce or eliminate waste production. In Minnesota, the 3M Company reformulated products and redesigned manufacturing processes to eliminate more than 140,000 metric tons of solid and hazardous wastes, 4 billion l (1 billion gal) of wastewater, and 80,000 metric tons of air pollution each year. They frequently found that these new processes not only spared the environment but also saved money by using less energy and fewer raw materials.

Recycling and reusing materials also eliminates hazardous wastes and pollution. Many waste products of one process or industry are valuable commodities in another. Already, about 10 percent of the wastes that would otherwise enter the waste stream in the United States are sent to surplus material exchanges where they are sold as raw materials for use by other industries. This figure could probably be raised substantially with better waste management. In Europe, at least one-third of all industrial wastes are exchanged through clearinghouses where beneficial uses are found. This represents a double savings: The generator doesn't have to pay for disposal, and the recipient pays little, if anything, for raw materials.

Convert to Less Hazardous Substances

Several processes are available to make hazardous materials less toxic. *Physical treatments* tie up or isolate substances. Charcoal or resin filters absorb toxins. Distillation separates hazardous components from aqueous solutions. Precipitation and immobilization in ceramics, glass, or cement isolate toxins from the environment so that they become essentially nonhazardous. One of the few ways to dispose of metals and radioactive substances is to fuse them in silica at high temperatures to make a stable, impermeable glass that is suitable for long-term storage.

Incineration is a quick way to dispose of many kinds of hazardous waste. Incineration is not necessarily cheap—nor always clean—unless it is done correctly. Wastes must be heated to over 1,000°C (2,000°F) for a sufficient period of time to complete destruction. The ash resulting from thorough incineration is reduced in volume up to 90 percent and often is safer to store in a landfill or other disposal site than the original wastes. Nevertheless, incineration remains a highly controversial topic (fig. 21.22).

Several sophisticated features of modern incinerators improve their effectiveness. Liquid injection nozzles atomize liquids and mix air into the wastes so they burn thoroughly. Fluidized bed burners pump air from the bottom up through burning solid waste as it travels on a metal chain grate through the furnace. The air velocity is sufficient to keep the burning waste partially suspended. Plenty of oxygen is available, and burning is quick and complete. Afterburners add to the completeness of burning by igniting gaseous hydrocarbons not consumed in the incinerator. Scrubbers and precipitators remove minerals, particulates, and other pollutants from the stack gases.

Chemical processing can transform materials so they become nontoxic. Included in this category are neutralization, removal of metals or halogens (chlorine, bromine, etc.), and oxidation. The

FIGURE 21.22 Actor Martin Sheen joins local activists in a protest in East Liverpool, Ohio, site of the largest hazardous waste incinerator in the United States. About 1,000 people marched to the plant to pray, sing, and express their opposition. Involving celebrities draws attention to your cause. A peaceful, well-planned rally builds support and acceptance in the broader community.

Sunohio Corporation of Canton, Ohio, for instance, has developed a process called PCBx in which chlorine in such molecules as PCBs is replaced with other ions that render the compounds less toxic. A portable unit can be moved to the location of the hazardous waste, eliminating the need for shipping them.

Biological waste treatment or **bioremediation** taps the great capacity of microorganisms to absorb, accumulate, and detoxify a variety of toxic compounds. Bacteria in activated sludge basins, aquatic plants (such as water hyacinths or cattails), soil microorganisms, and other species remove toxic materials and purify effluents. Recent experiments have produced bacteria that can decontaminate organic waste metals by converting them to harmless substances. Biotechnology offers exciting possibilities for finding or creating organisms to eliminate specific kinds of hazardous or toxic wastes. By using a combination of classic genetic selection techniques and high-technology gene-transfer techniques, for instance, scientists have recently been able to generate bacterial strains that are highly successful at metabolizing PCBs. There are concerns about releasing such exotic organisms into the environment, however (chapter 11). It may be better to keep these organisms contained in enclosed reaction vessels and feed contaminated material to them under controlled conditions.

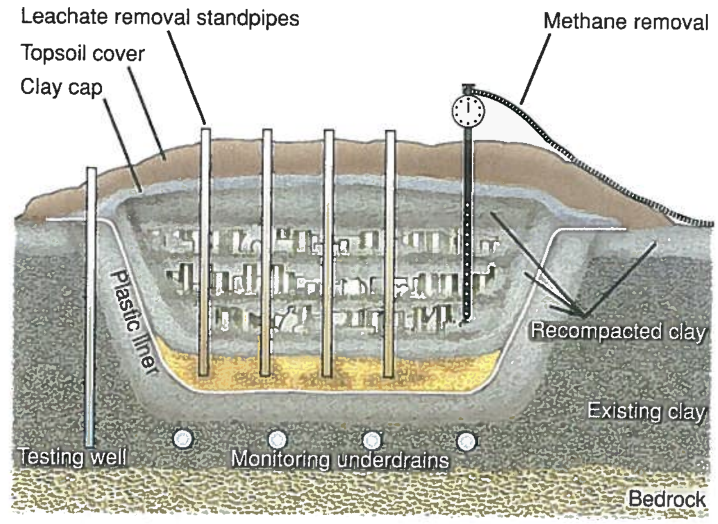


FIGURE 21.23 A secure landfill for toxic waste. A thick plastic liner and two or more layers of impervious compacted clay enclose the landfill. A gravel bed between the clay layers collects any leachate, which can then be pumped out and treated. Well samples are tested for escaping contaminants and methane is collected for combustion.

Store Permanently

Inevitably, there will be some materials that we can't destroy, make into something else, or otherwise cause to vanish. We will have to store them out of harm's way. There are differing opinions about how best to do this.

Retrievable Storage. Dumping wastes in the ocean or burying them in the ground generally means that we have lost control of them. If we learn later that our disposal technique was a mistake, it is difficult, if not impossible, to go back and recover the wastes. For many supertoxic materials, the best way to store them may be in **permanent retrievable storage.** This means placing waste storage containers in a secure building, salt mine, or bedrock cavern where they can be inspected periodically and retrieved, if necessary, for repacking or for transfer if a better means of disposal is developed. This technique is more expensive than burial in a landfill because the storage area must be guarded and monitored continuously to prevent leakage, vandalism, or other dispersal of toxic materials. Remedial measures are much cheaper with this technique, however, and it may be the best system in the long run.

Secure Landfills. One of the most popular solutions for hazardous waste disposal has been landfilling. Although, as we saw earlier in this chapter, many such landfills have been environmental disasters, newer techniques make it possible to create safe, modern **secure landfills** that are acceptable for disposing of many hazardous wastes. The first line of defense in a secure landfill is a thick bottom cushion of compacted clay that surrounds the pit like a bathtub (fig. 21.23). Moist clay is flexible and resists cracking if the ground shifts. It is impermeable to groundwater and will safely contain wastes. A layer of gravel is spread over the clay liner and perforated drain pipes are laid in a grid to collect any seepage that escapes from the stored material. A thick polyethylene liner, protected from punctures by soft padding materials, covers the gravel bed. A layer of soil or absorbent sand cushions the inner liner and the wastes are packed in drums, which then are placed into the pit, separated into small units by thick berms of soil or packing material.

When the landfill has reached its maximum capacity, a cover much like the bottom sandwich of clay, plastic, and soil—in that order—caps the site. Vegetation stabilizes the surface and improves its appearance. Sump pumps collect any liquids that filter through the landfill, either from rainwater or leaking drums. This leachate is treated and purified before being released. Monitoring wells check groundwater around the site to ensure that no toxins have escaped.

Most landfills are buried below ground level to be less conspicuous; however, in areas where the groundwater table is close to the surface, it is safer to build above-ground storage. The same protective construction techniques are used as in a buried pit. An advantage to such a facility is that leakage is easier to monitor because the bottom is at ground level.

Transportation of hazardous wastes to disposal sites is of concern because of the risk of accidents. Emergency preparedness officials conclude that the greatest risk in most urban areas is not nuclear war or natural disaster but crashes involving trucks or trains carrying hazardous chemicals through densely packed urban corridors. Another worry is who will bear financial responsibility for abandoned waste sites. The material remains toxic long after the businesses that created it are gone. As is the case with nuclear wastes (chapter 19), we may need new institutions for perpetual care of these wastes.

Conclusion

In many traditional societies, people reuse nearly everything because they can't afford to discard useful resources. Modern society, however, produces a prodigious amount of waste. Government policies and economies of scale make it cheaper and more convenient to extract virgin raw materials to make new consumer products rather than to reuse or recycle items that still have useful life. We're now beginning to recognize the impacts of this wasteful lifestyle. We see the problems associated with waste disposal as well as the impacts of energy and material resource extraction. The increasing toxicity of modern products makes waste reduction even more urgent. The mantra of reduction, reuse, and recycle is becoming more widely accepted.

There are increasing opportunities to exchange materials with others who can use them, or to recycle them into other products. A big market for used construction supplies and surplus chemicals allows salvage of stuff that would otherwise go to landfills. Vehicles, electronics, and other complex products are demanufactured to reclaim valuable metals. Paint, used carpet, food and beverage containers, and many other unwanted consumer products are transformed into new merchandise. Organic matter can be composted into beneficial soil amendments. Some pioneers in sustainability find they can live comfortably while producing no waste at all if they practice reduction, reuse, and recycling faithfully.

How much waste do you produce, and where does it go after you toss it into the garbage can? What can you do to reduce your personal waste flow? Is recycling and reuse widely accepted in your community? If not, what could you do to change attitudes toward trash?

Reviewing Learning Outcomes

By now you should be able to explain the following points:

21.1 Identify the components of solid waste.

- The waste stream is everything we throw away.

21.2 Describe how wastes have been—and are being—disposed of or treated.

- Open dumps release hazardous materials into air and water.
- Ocean dumping is nearly uncontrollable.
- We often export waste to countries ill-equipped to handle it.
- Landfills receive most of our waste.
- Incineration produces energy but causes pollution.

21.3 Identify how we might shrink the waste stream.

- Recycling captures resources from garbage.
- Recycling saves money, materials, energy, and space.
- Commercial-scale recycling and composting is an area of innovation.
- Demanufacturing is necessary for appliances and e-waste.
- Reuse is even more efficient than recycling.
- Reducing waste is often the cheapest option.

21.4 Investigate hazardous and toxic wastes.

- Hazardous waste must be recycled, contained, or detoxified.
- Superfund sites are those listed for federal cleanup.
- Brownfields present both liability and opportunity.
- Hazardous waste storage must be safe.

Practice Quiz

1. What are solid wastes and hazardous wastes? What is the difference between them?
2. Describe the difference between an open dump, a sanitary landfill, and a modern, secure, hazardous waste disposal site.
3. Why are landfill sites becoming limited around most major urban centers in the United States? What steps are being taken to solve this problem?
4. Describe some concerns about waste incineration.
5. List some benefits and drawbacks of recycling wastes. What are the major types of materials recycled from municipal waste and how are they used?
6. What is composting, and how does it fit into solid waste disposal?
7. Describe some ways that we can reduce the waste stream to avoid or reduce disposal problems.
8. List ten toxic substances in your home and how you would dispose of them.
9. What are brownfields and why do cities want to redevelop them?
10. What societal problems are associated with waste disposal? Why do people object to waste handling in their neighborhoods?

RITICAL THINKING AND DISCUSSION QUESTIONS

A toxic waste disposal site has been proposed for the Pine Ridge Indian Reservation in South Dakota. Many tribal members oppose this plan, but some favor it because of the jobs and income it will bring to an area with 70 percent unemployment. If local people choose immediate survival over long-term health, should we object or intervene?

There is often a tension between getting your personal life in order and working for larger structural changes in society. Evaluate the trade-offs between spending time and energy sorting recyclables at home compared to working in the public arena on a bill to ban excess packaging.

Should industry officials be held responsible for dumping chemicals that were legal when they did it but are now known to be extremely dangerous? At what point can we argue that they *should* have known about the hazards involved?

4. Look at the discussion of recycling or incineration presented in this chapter. List the premises (implicit or explicit) that underlie the presentation as well as the conclusions (stated or not) that seem to be drawn from them. Do the conclusions necessarily follow from these premises?
5. The Netherlands incinerates much of its toxic waste at sea by a shipborne incinerator. Would you support this as a way to dispose of our wastes as well? What are the critical considerations for or against this approach?

DATA analysis — How Much Waste Do You Produce, and How Much Could You Recycle?

people become aware of waste disposal problems in their ımunities, more people are recycling more materials. Some gs are easy to recycle, such as newsprint, office paper, or ninum drink cans. Other things are harder to classify. Most ıs give up pretty quickly and throw things in the trash if we e to think too hard about how to recycle them.

Take a poll to find out how many people in your class know how to recycle the items in the table shown here. Once you have taken your poll, convert the numbers to percentages: divide the number who know how to recycle each item by the number of students in your class, and then multiply by 100.

Now find someone on your campus who works on waste management. This might be someone in your university/college administration, or it might be someone who actually empties trash containers. (You might get more interesting and straightforward answers from the latter.) Ask the following questions: (1) Can this person fill in the items your class didn't know about? (2) Is there a college/university policy about recycling? What are some of the points on that policy? (3) How much does the college spend each year on waste disposal? How many tuition payments does that total? (4) What are the biggest parts of the waste stream? (5) Does the school have a plan for reducing that largest component?

Item	Percentage Who Know How to Recycle
Newspapers	
Paperboard (cereal boxes)	
Cardboard boxes	
Cardboard boxes with tape	
Plastic drink bottles	
Other plastic bottles	
Styrofoam food containers	
Food waste	
Plastic shopping bags	
Plastic packaging materials	
Furniture	
Last year's course books	
Left-over paint	

ır Additional Help in Studying This Chapter, please visit our website at www.mhhe.com/cunningham10e. You will ɟ additional practice quizzes and case studies, flashcards, regional examples, place markers for Google Earth™ mapping, and extensive reading list, all of which will help you learn environmental science.