21 Solid and Hazardous Waste

CORE CASE STUDY E-waste—an Exploding Problem

Electronic waste, or *e-waste,* consists of discarded television sets, cell phones, computers, e-toys, and other electronic devices (Figure 21-1). It is the fastest-growing solid waste problem in the United States and in the world. Each year, Americans discard an estimated 155 million cell phones, 48 million personal computers, and many more millions of television sets, iPods, Blackberries, and other electronic products.

Most e-waste ends up in landfills and incinerators. It includes high-quality plastics and valuable metals such as aluminum, copper, nickel, platinum, silver, and gold. E-waste is also a source of toxic and hazardous pollutants, including polyvinylchloride (PVC), brominated flame retardants, lead, and mercury, which can contaminate air, surface water, groundwater, and soil and cause serious health problems and even early death for e-waste workers.

© Fotopic/Miles Simmons/PhototakeUSA

Figure 21-1 *Rapidly growing electronic waste* (e-waste) from discarded computers and other electronic devices represents a waste of resources and pollutes the air, water, and land with harmful compounds. **Question:** Have you disposed of an electronic device lately? If so, how did you dispose of it?

According to a 2005 report by the U.N.-sponsored Basel Action Network, about 70% of the world's e-waste is shipped to China, while most of the rest goes to India and poor African nations where labor is cheap and environmental regulations are weak. Workers there—many of them children—dismantle such products to recover valuable metals and reusable parts. As they do this, they are exposed to toxic metals and other harmful chemicals. The remaining scrap is dumped in waterways and fields or burned in open fires, exposing many people to toxic dioxins.

Transferring hazardous waste from developed to developing countries is banned by the International Basel Convention. Even so, much e-waste is not classified as hazardous waste or is illegally smuggled to countries such as China. The United States can export this waste legally because it is one of only three countries that have not ratified the Basel Convention (the other two are Afghanistan and Haiti).

The European Union (EU) has led the way in dealing with e-waste. Its *cradle-to-grave* approach requires manufacturers to take back electronic products at the ends of their useful lives for repair, remanufacture, or recycling, and e-waste is banned from landfills and incinerators. Japan is also adopting cradle-to-grave standards for electronic devices and appliances.

The United States produces roughly half of the world's e-waste and recycles only about 10–15% of it; but that is beginning to change. Massachusetts and five other states have banned the disposal of computers and TV sets in landfills and incinerators. Some electronics manufacturers, including Apple, Intel, Hewlett-Packard, Dell, Sharp, Panasonic, and Sony, have free recycling programs for consumers, which are described on their websites. Some manufacturers will arrange for pickups or pay shipping costs. A growing consumer awareness of the problem has spawned highly profitable *e-cycling* businesses. In addition, nonprofit groups, such as Free Geek in Portland, Oregon, are motivating many people to donate, recycle, and reuse old electronic devices.

But recycling and reuse probably will not keep up with the explosive growth of e-waste. According to Jim Puckett, coordinator of the Basel Action Network, the only real long-term solution is a *prevention* approach that gets toxic materials out of electrical and electronic products through green design. Electronic waste is just one of many types of solid and hazardous waste discussed in this chapter.

Key Questions and Concepts

21-1 **What are solid waste and hazardous waste, and why are they problems?**

CONCEPT 21-1 Solid waste represents pollution and unnecessary waste of resources, and hazardous waste contributes to pollution, natural capital degradation, health problems, and premature deaths.

21-2 **How should we deal with solid waste?**

CONCEPT 21-2 A sustainable approach to solid waste is first to reduce it, then to reuse or recycle it, and finally to safely dispose of what is left.

21-3 **Why is reusing and recycling materials so important?**

CONCEPT 21-3 Reusing items decreases the use of matter and energy resources and reduces pollution and natural capital degradation; recycling does so to a lesser degree.

21-4 **What are the advantages and disadvantages of burning or burying solid waste?**

CONCEPT 21-4 Technologies for burning and burying solid wastes are well developed, but burning contributes to pollution and greenhouse gas emissions, and buried wastes eventually contribute to pollution and land degradation.

21-5 **How should we deal with hazardous waste?**

CONCEPT 21-5 A sustainable approach to hazardous waste is first to produce less of it, then to reuse or recycle it, then to convert it to less hazardous materials, and finally, to safely store what is left.

21-6 **How can we make the transition to a more sustainable low-waste society?**

CONCEPT 21-6 Shifting to a low-waste society requires individuals and businesses to reduce resource use and to reuse and recycle wastes at local, national, and global levels.

Note: Supplements 2 (p. S4), 3 (p. S10), 6 (p. S39) and 13 (p. S78) can be used with this chapter.

Solid wastes are only raw materials we're too stupid to use.

ARTHUR C. CLARKE

21-1 What Are Solid Waste and Hazardous Waste, and Why Are They Problems?

CONCEPT 21-1 Solid waste represents pollution and unnecessary waste of resources, and hazardous waste contributes to pollution, natural capital degradation, health problems, and premature deaths.

We Throw Away Huge Amounts of Useful Things and Hazardous Materials

In nature, there is essentially no waste because the wastes of one organism become nutrients for others (Figure 3-14, p. 63, and **Concept 3-3B**, p. 57). CONCEPT LINK This recycling of nutrients is the basis for one of the four **scientific principles of sustainability** (see back cover). SUSTAINABILITY

Humans, on the other hand, produce huge amounts of wastes that go unused and pollute the environment. Because of the law of conservation of matter (**Concept 2-3**, p. 39) and the nature of human lifestyles, we will always produce some waste, but the amount can be drastically reduced. CONCEPT LINK

One major category of waste is **solid waste**—any unwanted or discarded material we produce that is not a liquid or a gas. Solid waste can be divided into two types. One type is **industrial solid waste** produced by mines, agriculture, and industries that supply people with goods and services. The other is **municipal solid waste (MSW),** often called *garbage* or *trash,* which consists of the combined solid waste produced by homes and workplaces. Examples include paper and cardboard, food wastes, cans, bottles, yard wastes, furniture, plastics, metals, glass, wood, and e-waste (**Core Case Study**). In developed countries, most MSW is buried in landfills or burned in CORE CASE STUDY

What Harmful Chemicals Are in Your Home?

Cleaning

- Disinfectants
- Drain, toilet, and window cleaners
- Spot removers
- Septic tank cleaners

Paint Products

- Paints, stains, varnishes, and lacquers
- Paint thinners, solvents, and strippers
- Wood preservatives
- Artist paints and inks

General

- Dry-cell batteries (mercury and cadmium)
- Glues and cements

Gardening

- Pesticides
- Weed killers
- Ant and rodent killers
- Flea powders

Automotive

- Gasoline
- Used motor oil
- Antifreeze
- Battery acid
- Brake and transmission fluid

Figure 21-2 Harmful chemicals found in many homes. The U.S. Congress has exempted disposal of these materials from government regulation. **Question:** Which of these chemicals are in your home?

incinerators. In many developing countries, much of it ends up in open dumps, where poor people eke out a living finding items they can sell for reuse or recycling (Figure 1-6, p. 11).

Another major category of waste is **hazardous,** or **toxic, waste,** which threatens human health or the environment because it is poisonous, dangerously chemically reactive, corrosive, or flammable. Examples include industrial solvents, hospital medical waste, car batteries (containing lead and acids), household pesticide products, dry-cell batteries (containing mercury and cadmium), and incinerator ash. Figure 21-2 lists some of the harmful chemicals found in many homes. The two largest classes of hazardous wastes are *organic compounds* (such as various solvents, pesticides, PCBs, and dioxins) and nondegradable *toxic heavy metals* (such as lead, mercury, and arsenic).

Another form of extremely hazardous waste is highly radioactive waste produced by nuclear power plants (p. 392) and nuclear weapons facilities. Such wastes must be stored safely for 10,000 to 240,000 years depending on what radioactive isotopes are present. After 60 years of research, there is still considerable scientific disagreement over how to store such dangerous wastes and political controversy over where to store them (Case Study, p. 393).

According to the U.N. Environment Programme (UNEP), developed countries produce 80–90% of the world's hazardous wastes. The United States produces more of such wastes than any other country; chemical and mining industries and the military are the top three producers. As China continues to industrialize with inadequate pollution controls, it may take over the number one spot. Ways to deal with hazardous wastes are discussed later in this chapter in Section 21-5 (p. 577).

There are two reasons for sharply reducing the amount of solid and hazardous wastes we produce. One reason is that at least three-fourths of these materials represent an unnecessary waste of the earth's resources. Studies show that we could reduce resource use and reuse and recycle up to 90% of the MSW we produce, using existing technology and waste prevention, reuse, and recycling systems.

Instead we collect, mix, crush, and bury many of these potentially valuable resources in holes or landfills all over the planet. Once these materials are mixed, it is usually too expensive to recover them. Mixing trash also disperses hazardous materials with the rest of the trash and prohibits separating them out for safe disposal or recycling. We also burn hazardous wastes in incinerators, which pollutes the air and leaves a toxic ash that we usually have to bury. Another approach, sometimes misleadingly called pollution prevention or waste reduction, is for wealthy countries to move polluting industries and hazardous wastes to poor countries where environmental laws are weak or nonexistent.

A second reason for sharply reducing our output of solid waste is that, in producing the products we use

Lineair Fotochief/Peter Arnold, Inc.

Figure 21-3 **Natural capital degradation:** solid wastes polluting a river in Jakarta, Indonesia, a city of more than 11 million people. The man in the boat is looking for items to salvage or sell.

and often discard, we create huge amounts of air pollution, greenhouse gases, water pollution (Figure 21-3), and land degradation (**Concept 21-1**).

Solid Waste in the United States

The United States leads the world in producing solid waste. With only 4.6% of the world's population, the U.S. produces about one-third of the world's solid waste. About 98.5% of all solid waste produced in the United States is industrial solid waste from mining (76%), agriculture (13%), and industry (9.5%).

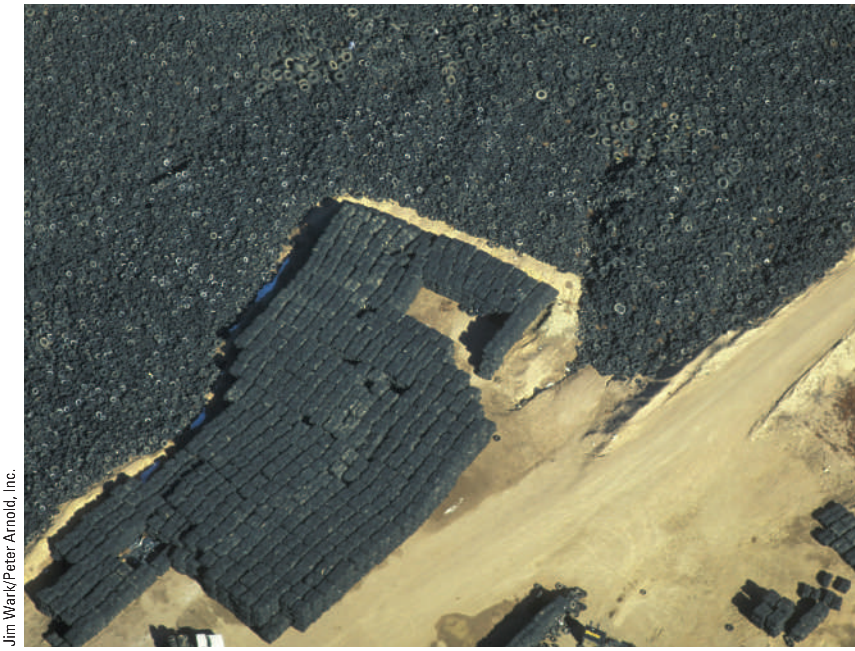
Suppose you buy a desktop computer. You may not know that manufacturing it required 700 or more different materials obtained from mines, oil wells, and chemical factories all over the world. You may also be unaware that for every 0.5 kilogram (1 pound) of electronics it contains, approximately 3,600 kilograms (8,000 pounds) of solid and liquid wastes were created. The manufacture of a single semiconductor computer chip generates about 630 times its weight in solid and hazardous wastes.

Extracting these resources and using them to make your computer also required large amounts of energy that was produced mostly by burning fossil fuels, which emitted CO_2 and numerous other pollutants into the atmosphere. If you consider all the computers and other products made every year, you can see how industrial solid wastes and hazardous wastes mount up.

The remaining 1.5% of the solid waste produced in the United States is municipal solid waste (MSW), the largest categories of which are paper and cardboard (37%), yard waste (12%), food waste (11%), plastics (11%), and metals (8%). Figure 15, p. S18, in Supplement 3 shows the total and per capita production of MSW in the United States between 1960 and 2005. Each year, the United States generates enough MSW to fill a bumper-to-bumper convoy of garbage trucks long enough to encircle the globe almost eight times!

Consider some of the solid wastes that consumers throw away in the high-waste economy of the United States:

- Enough tires each year to encircle the planet almost three times (Figure 21-4)
- An amount of disposable diapers each year that, if linked end to end, would reach to the moon and back seven times
- Enough carpet each year to cover the U.S. state of Delaware
- About 2.5 million nonreturnable plastic bottles *every hour*
- About 274 million plastic shopping bags per day, an average of about 3,200 every second



Jim Wark/Peter Arnold, Inc.

Figure 21-4 Hundreds of millions of discarded tires have accumulated in this massive tire dump in Midway, Colorado (USA). Lehigh Technologies has developed a way to freeze the material in a scrap tire with liquid nitrogen. This converts the rubber to a brittle form that can be pulverized into a fine powder, which can be used in a variety of products such as paints, sealants, and coating. A prevention approach would be to double the average lifetime of tires in order to reduce the number thrown away each year.

- Enough office paper each year to build a wall 3.5 meters (11 feet) high across the country from New York City to San Francisco, California
- Some 186 billion pieces of junk mail (an average of 660 pieces per American) each year, about 45% of which are thrown into the trash unopened*
- Around 132,000 personal computers and 425,000 cell phones each day (**Core Case Study**).

CORE CASE STUDY

The United States also leads the world in trash production (by weight) per person, and Canada takes second place. Each day the average American produces more than 2.0 kilograms (4.5 pounds) of MSW; three-fourths of it is dumped into landfills or incinerated. That is about twice the amount of solid waste produced per person in other industrial countries such as Japan and Germany, and 5–10 times that amount produced in most developing countries.

Some encouraging news is that since 1990, the average annual production of MSW by weight per American has leveled off (Figure 15, p. S18, Supplement 3), mostly because of increased recycling (Figure 16, p. S19, in Supplement 3) and the use of lighter products. Historical analysis reveals some surprises about U.S. waste production (Case Study, p. 564).

*You can register to stop receiving direct marketing mail from most companies for five years at www.the-dma.org/consumers/offmailinglist.html.

■ CASE STUDY

Trash Production and Recycling in New York City: Past, Present, and Future

You might guess that trash production in New York City has been rising steadily. You would be wrong. In 2002, Columbia University adjunct professor Daniel C. Walsh discovered some surprising facts when analyzing detailed records about what residents of New York City threw away between 1900 and 2000.

He found that the per person output, by weight, of trash dumped by New Yorkers was higher between 1920 and 1940 than it is today—mostly because of the coal ash produced by people burning coal for heat and cooking. The city's highest trash output per person was in 1940, when the rate was more than two times today's output.

During 1962 and 1963, the trash output per New Yorker was at its lowest level during the 20th century, as household coal burning had been phased out and paper was the largest component of trash. However, coal ash has not gone away. Now this waste is laced with toxic metals, as it is produced in large quantities by electric power plants. Instead of being classified as MSW, coal ash is now a form of toxic waste that must be disposed of safely.

Between 1964 and 1974, the city's trash output per person rose to slightly above today's levels as returnable, refillable bottles were phased out and the use of throwaway items increased. Since 1975, the weight of trash per New Yorker has remained about the same because materials thrown away are lighter and because of an increase in recycling.

In 1999, New York City passed a mandatory recycling law, but it was not the city's first experience with such recycling. Between 1896 and 1914, the city had a mandatory recycling program that required curbside separation of trash. But this recycling effort faded and died before World War I.

Professor Walsh also found that trash output per person rose in good economic times when people could buy more and fell in bad times as people reduced their spending.

Despite its efforts to limit MSW, New York City was one of the first U.S. cities to run out of landfill space. Until 2001, most of the city's garbage was buried in its Fresh Kills landfill on Staten Island, the world's largest public landfill. At its busiest in 2001, this landfill, a monument to a throwaway society, was deeper than the city's Statue of Liberty is tall. However, after filling up in 2001, it was closed. Now it is being transformed into recreational facilities, restored wetlands, and a large public parkland.

Since 2001, the city has been hauling its massive amounts of garbage to landfill sites in New Jersey, Pennsylvania, and Virginia. Each day, some 600 energy-inefficient and polluting tractor trailers, which if lined up would form a convoy nearly 14 kilometers (9 miles) long, haul trash out of New York City to landfills as far as 480 kilometers (300 miles) away. Similarly, in 2002, Canada's largest city Toronto closed its last landfill and, since then, has been shipping all of its garbage to Wayne County, Michigan (USA), for burial.

As oil prices rise and concerns over CO_2 emissions increase, it may become too expensive at some point for New York (and for other cities) to haul garbage long distances to burial sites. Then what?

THINKING ABOUT
Analyzing Trash

What are two lessons that we can learn from this analysis of data on New York City's trash?

21-2 How Should We Deal with Solid Waste?

▶ **CONCEPT 21-2 A sustainable approach to solid waste is first to reduce it, then to reuse or recycle it, and finally to safely dispose of what is left.**

We Can Burn or Bury Solid Waste or Produce Less of It

We can deal with the solid wastes we create in two ways. One is **waste management,** in which we attempt to reduce the environmental impact of MSW without seriously trying to reduce the amount of waste produced. This output approach begins with the question: "What do we do with solid waste?" It typically involves mixing wastes together and then transferring them from one part of the environment to another, usually by burying them, burning them, or shipping them to another location. This is the most common approach to dealing with e-waste (**Core Case Study**). CORE CASE STUDY

The second approach is **waste reduction,** in which much less waste and pollution are produced, and the wastes that are produced are viewed as potential resources that can be reused, recycled, or composted (**Concept 21-2**). It begins with the question: "How can we avoid producing so much solid waste?" With

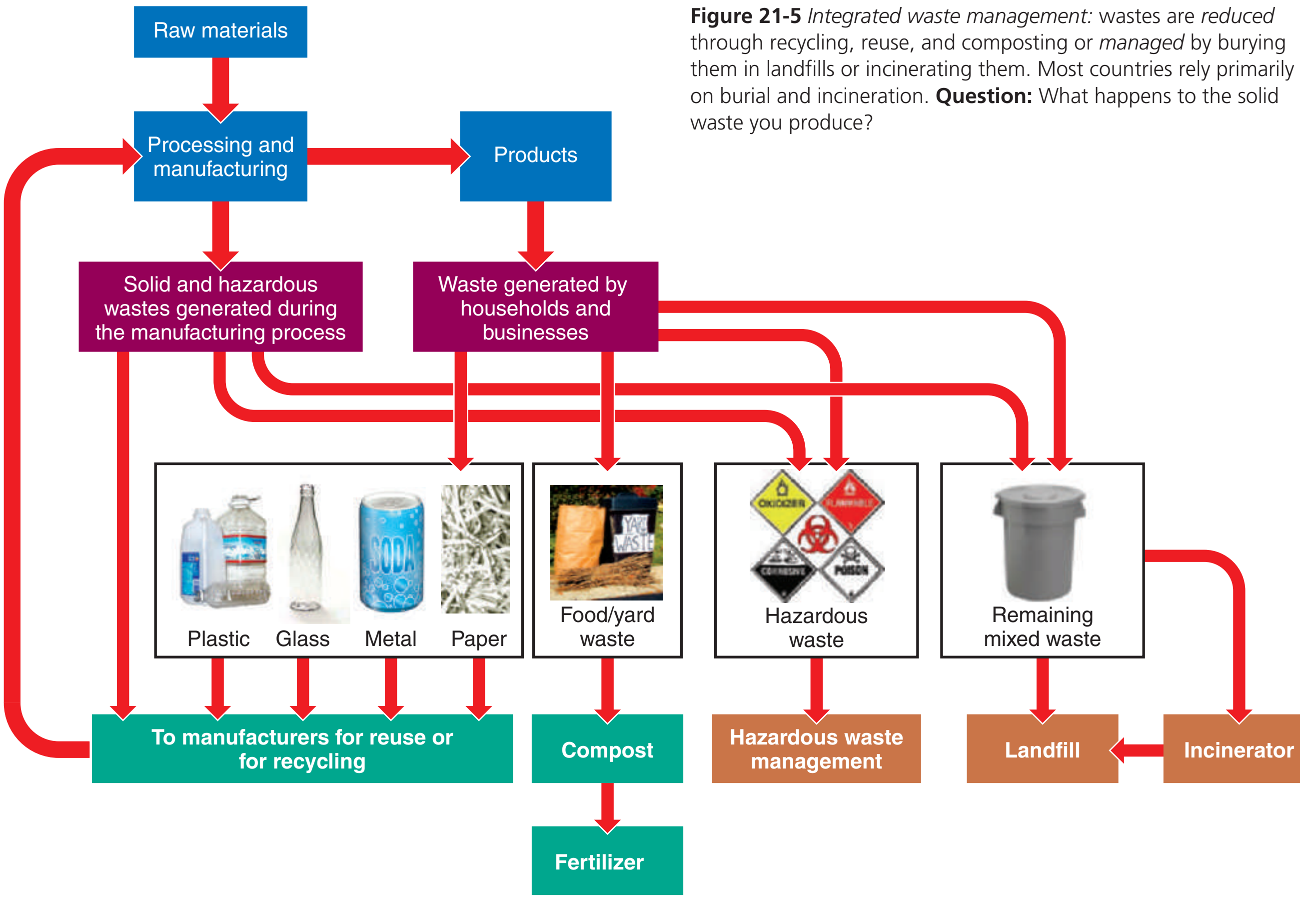


Figure 21-5 *Integrated waste management:* wastes are *reduced* through recycling, reuse, and composting or *managed* by burying them in landfills or incinerating them. Most countries rely primarily on burial and incineration. **Question:** What happens to the solid waste you produce?

this prevention approach (**Concept 1-4**, p. 16), we could think of trash cans and garbage trucks as *resource containers* that are on their way to recycling or composting facilities.

There is no single solution to the solid waste problem. Most analysts call for using **integrated waste management**—a variety of strategies for both waste reduction and waste management (Figure 21-5). Scientists call for much greater emphasis on waste reduction (Figure 21-6). But this is not done in the United States (or in most industrialized countries) where 54% of the MSW is buried in landfills (Science Focus, p. 566), 25% is recycled, 14% is incinerated, and 7% is composted.

Some scientists and economists have estimated that 75–90% of the solid waste we produce could be eliminated by a combination of the strategies shown in Figure 21-5. Let us look more closely at these options in the order of the priorities suggested by these scientists.

First Priority

Primary Pollution and Waste Prevention

- Change industrial process to eliminate use of harmful chemicals
- Use less of a harmful product
- Reduce packaging and materials in products
- Make products that last longer and are recyclable, reusable, or easy to repair

Second Priority

Secondary Pollution and Waste Prevention

- Reuse
- Repair
- Recycle
- Compost
- Buy reusable and recyclable products

Last Priority

Waste Management

- Treat waste to reduce toxicity
- Incinerate waste
- Bury waste in landfills
- Release waste into environment for dispersal or dilution

Figure 21-6 *Integrated waste management:* priorities suggested by the U.S. National Academy of Sciences for dealing with solid waste. To date, these waste reduction priorities have not been followed in the United States or in most other countries. Instead, most efforts are devoted to waste management (bury it or burn it). **Question:** Why do you think most countries do not follow these priorities, even though they are based on reliable science? (Data from U.S. Environmental Protection Agency and U.S. National Academy of Sciences)

SCIENCE FOCUS

Garbology

How do we know the composition of trash in landfills? Much of this knowledge comes from research by *garbologists* such as William Rathje, who was a pioneer in his field in the 1970s at the University of Arizona. These scientists work in the fashion of archaeologists, training their students to sort, weigh, and itemize people's trash, and to bore holes in garbage dumps and analyze what they find.

Many people think of landfills as huge compost piles where biodegradable wastes are decomposed within a few months. But garbologists looking at the contents of landfills found 50-year-old newspapers that were still readable and hot dogs and pork chops buried for decades that still looked edible. In landfills (as opposed to open dumps, Figure 1-6, p. 11), trash can resist decomposition for perhaps centuries because it is tightly packed and protected from sunlight, water, and air.

Critical Thinking

Should landfills be exposed to more air and water to hasten decomposition of their wastes? Explain.

We Can Cut Solid Wastes by Reducing, Reusing, and Recycling

Waste reduction (**Concept 21-2**) is based on three Rs:

- **Reduce:** consume less and live a simpler lifestyle.
- **Reuse:** rely more on items that can be used repeatedly instead of on throwaway items. Buy necessary items secondhand or borrow or rent them. Take a refillable coffee cup to class or to the coffee shop and use it instead of using throwaway cups.
- **Recycle:** separate and recycle paper, glass, cans, plastics, metal, and other items, and buy products made from recycled materials.

From an environmental standpoint, the first two Rs are preferred because they are input or prevention approaches that tackle the problem of waste production at the front end—before it occurs. Any such input approach also saves matter and energy resources, reduces pollution (including greenhouse gas emissions), helps protect biodiversity, and saves money. Recycling is important, but it is an output approach based on dealing with wastes after they have been produced.

Figure 21-7 lists some ways in which you can use the 3Rs to reduce your output of solid waste.

Here are seven strategies with which industries and communities can reduce resource use, waste, and pollution.

First, *redesign manufacturing processes and products to use less material and energy.* The weight of a typical car has been reduced by about one-fourth since the 1960s through use of lighter steel and lightweight plastics and composite materials. Plastic milk jugs contain less plastic and weigh 40% less than they did in the 1970s, and soft drink cans contain one-third less aluminum. Disposable diapers contain 50% less paper pulp because of improved absorbent-gel technology. Dry-cell batteries contain much less toxic mercury than they did in the 1980s, and the small amount of mercury in today's compact fluorescent lightbulbs is being reduced. Downloading music from the Internet reduces the use of materials and energy in packaging records and CDs and in shipping them long distances.

Second, *redesign manufacturing processes to produce less waste and pollution.* In the *ecoindustrial revolution* (Case Study, p. 366), manufacturing processes are being redesigned to mimic how nature reduces and recycles wastes (**Concept 1-6**, p. 23). This includes designing industrial ecosystems in which the wastes of some businesses are used as raw materials by

CONCEPT LINK

WHAT CAN YOU DO?

Solid Waste

- Follow the three Rs of resource use: Reduce, Reuse, and Recycle
- Ask yourself whether you really need a particular item, and refuse packaging where possible
- Rent, borrow, or barter goods and services when you can, buy secondhand, and donate or sell unused items
- Buy things that are reusable, recyclable, or compostable, and be sure to reuse, recycle, and compost them
- Avoid disposables, and do not use throwaway paper and plastic plates, cups, and eating utensils, and other disposable items when reusable or refillable versions are available
- Use e-mail or text-messaging in place of conventional paper mail
- Read newspapers and magazines online
- Buy products in bulk or concentrated form whenever possible

Figure 21-7 **Individuals matter:** ways to save resources by reducing your output of solid waste and pollution. **Questions:** Which three of these actions do you think are the most important? Why? Which of these things do you do?

other businesses (Figure 14-25, p. 367) in what is in effect, an industrial resource web that mimics a natural food web (Figure 3-14, p. 63). In addition, to reducing waste production and pollution, these changes also save energy and reduce resource use.

Ways to reduce the waste outputs of industrial processes include recycling most toxic organic solvents within factories or replacing them with water-based or citrus-based solvents (Individuals Matter, p. 459) and using hydrogen peroxide instead of toxic chlorine to bleach paper and other materials. In addition, toxic chemicals used in dry cleaning can be replaced. One method uses a nontoxic silicone solvent in conventional dry-cleaning machines and another involves submersing clothes in liquid carbon dioxide. Check your local phone directory to locate dry cleaners that use these alternative methods. A promising new approach is to develop nanotechnology coatings (Case Study, p. 362) that would eliminate the need for dry cleaning, although these materials would have to be carefully tested to avoid any harmful consequences of using them.

Third, *develop products that are easy to repair, reuse, remanufacture, compost, or recycle*. For example, a Xerox photocopier made of reusable or recyclable parts that allow for easy remanufacturing could eventually save the company $1 billion in manufacturing costs. And, the automobile industry, led by European automakers, now designs motor vehicles with bar coded parts so that the vehicles can be more easily disassembled and recycled. At a plant in Corinth, Mississippi (USA), the heavy equipment manufacturer Caterpillar disassembles some 17 truckloads of diesel engines a day, repairs worn parts, and reassembles the engines, which are then as good as new. Sales of the reassembled engines are about $1 billion a year and are growing at 15% a year.

RESEARCH FRONTIER

Inventing less wasteful and less polluting manufacturing processes and products. See **academic.cengage.com/biology/miller**.

Fourth, *eliminate or reduce unnecessary packaging*. Use the following hierarchy for packaging: no packaging, minimal packaging, reusable packaging, and recyclable packaging. Canada has set a goal of using the first three of these priorities to cut excess packaging in half. The European Union has instituted a requirement for recycling 55–80% of all packaging waste. In 2007, Wal-Mart asked its suppliers to cut down on the amount of packaging used in products sold in its stores and introduced a scorecard to rate its vendors. The company estimates that it could save $3.4 billion by reducing the packaging of its products by 5% by 2013.

Fifth, *use fee-per-bag waste collection systems* that charge consumers for the amount of waste they throw away but provide free pickup of recyclable and reusable items.

Sixth, *establish cradle-to-grave responsibility laws* that require companies to take back various consumer products such as electronic equipment (**Core Case Study**), appliances, and motor vehicles, as Japan and many European countries do.

CORE CASE STUDY

Seventh, *restructure urban transportation systems* to rely more on mass transit and bicycles than on cars. An urban bus can carry about as many people as 60 cars. And using a bicycle represents a small fraction of the resource use and solid waste involved with manufacturing and using a motor vehicle.

21-3 Why Is Reusing and Recycling Materials So Important?

CONCEPT 21-3 Reusing items decreases the use of matter and energy resources and reduces pollution and natural capital degradation; recycling does so to a lesser degree.

Reuse Is an Important Way to Reduce Solid Waste and Pollution and to Save Money

In today's modern societies, we have increasingly substituted throwaway items for reusable ones, which has resulted in growing masses of waste. For example, if the 1 billion throwaway paper coffee cups used by one famous chain of donut shops each year were lined up end-to-end, they would encircle the earth two times. Rewarding those who bring their own refillable coffee mugs would help to reduce this waste.

Reuse involves cleaning and using materials over and over and thus increasing the typical life span of a product (see following Case Study). This form of waste reduction decreases the use of matter and energy resources, cuts pollution, creates local jobs, and saves money (**Concept 21-3**).

Reuse is alive and well in most developing countries, but it has a downside. The poor who scavenge in open dumps (Figure 1-6, p. 11) for food scraps and items they can reuse or sell are often exposed to toxins and infectious diseases.

Traditional forms of reuse include salvaging automobile parts from older cars in junkyards and recovering materials from old houses and buildings. By 2015, the European Union will require that 95% of any discarded car must be reused or recycled. Other reuse strategies involve yard sales, flea markets, secondhand stores, traditional and online auctions, classified newspaper ads, and online sites such as e-Bay and Craigslist. An international website at **www.freecycle.org** links people who want to give away household belongings free to people in their area who want or need them.

Technology allows reuse of many items such as batteries. The latest rechargeable batteries come fully charged, can hold a charge for up to 2 years when they are not used, can be recharged in as few as 15 minutes, and greatly reduce toxic waste when used in place of discarded conventional batteries. They cost more than conventional batteries but the extra cost is recovered quickly, because replacement batteries do not have to be purchased as often.

■ **CASE STUDY**

Use of Refillable Containers

Two examples of reusable items are refillable glass beverage bottles and refillable soft drink bottles made of polyethylene terephthalate (PET) plastic. Typically, such bottles make 15 round-trips before they become too damaged for reuse and then are recycled. Reusing these containers saves energy (Figure 21-8) reduces CO_2 emissions, air pollution, water pollution, and solid wastes, and stimulates local economies by creating local jobs related to their collection and refilling. Moreover, studies by Coca-Cola and PepsiCo of Canada show that their soft drinks in 0.5-liter (21-ounce) bottles, on average, cost consumers one-third less in refillable bottles than in throwaway bottles.

But big companies make more money by producing and shipping beverages and food in throwaway containers at centralized facilities. This shift has put many small local bottling companies, breweries, and canneries out of business and hurt local economies. However, some U.S. dairies now deliver milk to their customers in refillable glass or plastic acrylic bottles that can be reused 50 to 100 times. And a few U.S. breweries have switched back to refillable bottles.

Parts of Canada and 11 U.S. states have bottle laws that place a deposit fee on all beverage containers. Retailers must accept the used containers and pass them on for recycling or reuse. Large beverage industries have used their political and financial clout to keep most U.S. states from passing bottle laws, arguing that they lead to a loss of jobs and higher beverage costs for consumers. But experience in Canada and U.S. states with bottle bills shows that more jobs are gained than lost, costs to consumers have not risen, resources are saved, and roadside litter decreases.

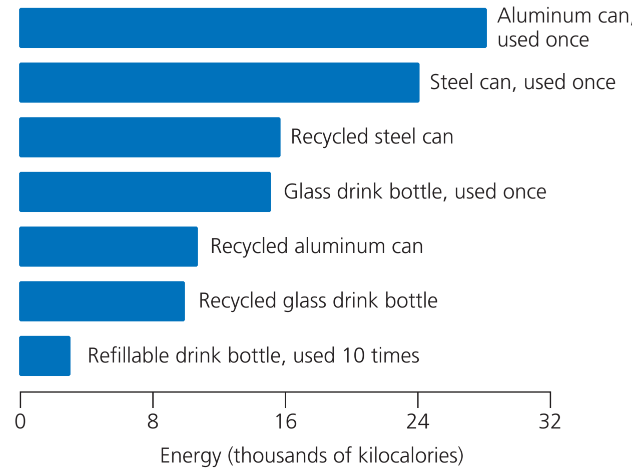


Figure 21-8 Energy consumption involved with using different types of 350-milliliter (12-fluid-ounce) beverage containers. (Data from Argonne National Laboratory)

Some analysts call for a national bottle bill in the United States, while others would ban all beverage containers that cannot be reused, as Denmark, Finland, and Canada's Prince Edward Island have done. Ecuador levies a refundable beverage container deposit fee that amounts to 50% of the cost of the drink. In Finland, 95% of the soft drink, beer, wine, and spirits containers are refillable.

HOW WOULD YOU VOTE?

Do you support banning all beverage containers that cannot be reused as Denmark has done? Cast your vote online at **academic.cengage.com/biology/miller**.

Reusable cloth bags can be used instead of throwaway paper or plastic bags to carry groceries and other items. Both paper and plastic bags are environmentally harmful, and the question of which is more damaging has no clear-cut answer.

According to Vincent Cobb, founder of **reusablebags.com**, an estimated 500 billion to 1 trillion plastic bags are used and usually discarded each year throughout the world. Producing them requires large amounts of oil because most are made from ethylene, a petroleum byproduct. And each discarded bag can take from 400 to 1,000 years to break down. Less than 1% of the estimated 100 billion plastic bags used each year in the United States are recycled.

In a number of African countries, the landscape is littered with plastic bags. In addition to being an eyesore and a waste of resources the bags block drains and sewage systems and can kill wildlife and livestock that eat them. They also kill plants and spread malaria by holding mini-pools of warm water where mosquitoes can breed.

There is a growing backlash against plastic shopping bags. To encourage people to use reusable bags, the governments of Ireland, Taiwan, and the Netherlands tax plastic shopping bags. In Ireland, a tax of about 25¢ per bag has cut plastic bag litter by 90% as people have switched to reusable bags. Bangladesh, Bhutan, Rwanda, South Africa, parts of India, Taiwan, Kenya, South Africa, Uganda, China, Australia, France, Italy, and the U.S. city of San Francisco have banned the use of all or most types of plastic shopping bags. But the plastics industry and some businesses have mounted a successful campaign against such bans in most of the United States.

HOW WOULD YOU VOTE?

Should consumers have to pay for plastic or paper bags at grocery and other stores? Cast your vote online at **academic .cengage.com/biology/miller.**

WHAT CAN YOU DO?

Reuse

- Buy beverages in refillable glass containers instead of cans or throwaway bottles
- Use reusable plastic or metal lunchboxes
- Carry sandwiches and store food in the refrigerator in reusable containers instead of wrapping them in aluminum foil or plastic wrap
- Use rechargeable batteries and recycle them when their useful life is over
- Carry groceries and other items in a reusable basket, a canvas or string bag, or a small cart
- Use reusable sponges and washable cloth napkins, dish towels, and handkerchiefs instead of throwaway paper ones
- Buy used furniture, computers, cars, and other items instead of buying new
- Give away or sell items you no longer use

Figure 21-9 **Individuals matter:** ways to reuse some of the items you buy. **Question:** Which three of these actions do you think are the most important? Why?

There are many other ways to reuse various items (Figure 21-9). For example, an increasing number of coffeehouses and university food services offer discounts to customers who bring their own refillable mugs. Some environmentally conscious coffee consumers are boycotting coffeehouses that do not provide discounts for customers bringing their own mugs.

There Are Two Types of Recycling

Recycling involves reprocessing discarded solid materials into new, useful products. In addition to saving resources and reducing solid waste and pollution, recycling also reduces unsightly and environmentally harmful litter.

Households and workplaces produce five major types of materials that can be recycled: paper products, glass, aluminum, steel, and some plastics. Such materials can be reprocessed in two ways. In **primary** or **closed-loop recycling,** these materials are recycled into new products of the same type—turning used aluminum cans into new aluminum cans, for example. In **secondary recycling,** waste materials are converted into different products. For example, used tires can be shredded and turned into rubberized road surfacing, newspapers can be reprocessed into cellulose insulation, and plastics can be reprocessed into various items. Engineer Henry Liu has developed a process for making bricks from recycled fly ash produced by coal-burning power plants. The process saves energy, reduces air pollution, and costs at least 20% less than the cost of making conventional bricks.

Scientists distinguish between two types of wastes that can be recycled: *preconsumer* or *internal waste* generated in a manufacturing process and *postconsumer* or *external waste* generated by consumer use of products. Preconsumer waste makes up more than three-fourths of the total.

Just about anything is recyclable, but there are two key questions. *First,* are the items separated for recycling actually recycled? Sometimes they are mixed with other wastes and sent to landfills or incinerated. *Second,* will businesses and individuals complete the recycling loop by buying products that are made from recycled materials?

Switzerland and Japan recycle about half of their MSW. The United States recycles about 25% of its MSW—up from 6.4% in 1960. This increase has gotten a boost by almost 9,000 curbside pickup recycling programs, which serve about half of the U.S. population.

In 2007, the United States recycled about 60% of its steel, 56% of its aluminum cans, 56% of its paper and cardboard, 36% of its tires, 22% of its glass, and 5% of its plastics. Experts say that with education and proper incentives, the United States could recycle 60–70% of these and many other forms of solid waste, in keeping with one of the four **scientific principles of sustainability** (see back cover).

We Can Mix or Separate Household Solid Wastes for Recycling

One way to recycle is to send mixed urban wastes to centralized *materials-recovery facilities* (MRFs or "murfs"). There, machines or workers separate the mixed waste to recover valuable materials for sale to manufacturers as raw materials. The remaining paper, plastics, and other combustible wastes are recycled or burned to produce steam or electricity to run the recovery plant or to sell to nearby industries or homes.

Such plants are expensive to build, operate, and maintain. If not operated properly, they can emit CO_2 and toxic air pollutants, and they produce a toxic ash that must be disposed of safely, usually in landfills. Because MRFs require a steady diet of garbage to make them financially successful, their owners have a vested interest in increasing the throughput of matter and energy resources to produce more trash—the reverse of what prominent scientists believe we should be doing (Figure 21-6).

To many experts, it makes more environmental and economic sense for households and businesses to separate their trash into recyclable categories such as glass, paper, metals, certain types of plastics, and compostable materials. This *source separation* approach produces much less air and water pollution and costs less to implement than MRFs cost. It also saves more energy, provides more jobs per unit of material, and yields cleaner and usually more valuable recyclables. In addition, sorting material educates people about the need for recycling.

To promote separation of wastes for recycling, more than 4,000 communities in the United States use a *pay-as-you-throw* or *fee-per-bag* waste collection system. It charges households and businesses for the amount of mixed waste picked up, but does not charge for pickup of materials separated for recycling or reuse. In the U.S. city of Ft. Worth, Texas, the proportion of households recycling went from 21% to 85% when such a system was implemented. And the city went from losing $600,000 in its recycling program to making $1 million a year because of increased sales of recycled materials to industries.

Using a similar program, the U.S. city of San José, California reuses or recycles 62% of its MSW and is becoming a model for cities everywhere. It is now focusing on reducing the large flow of waste from demolition and construction sites by separating such waste materials into recyclable piles of scrap metal, wood, and cement. The salvaged scrap metal goes to recycling plants, wood is converted into wood chips or mulch for fueling power plants, and concrete is recycled to build road banks.

HOW WOULD YOU VOTE?

Should households and businesses be charged for the amount of mixed waste picked up but not for pickup of materials separated for recycling? Cast your vote online at **academic .cengage.com/biology/miller**.

We Can Copy Nature and Recycle Biodegradable Solid Wastes

Composting is a form of recycling that mimics nature's recycling of nutrients—one of the four **scientific principles of sustainability**. It involves allowing decomposer bacteria to recycle yard trimmings, food scraps, and other biodegradable organic wastes. The resulting organic material can be added to soil to supply plant nutrients, slow soil erosion, retain water, and improve crop yields. Homeowners can compost such wastes in simple backyard containers, in composting piles that must be turned over occasionally, or in small composting drums (Figure 21-10) that can be rotated to mix the wastes and to speed up the decomposition process. Over 6 million homes in North America compost their organic wastes and the number is increasing. For details on composting, see the website for this chapter.

The United States has about 3,300 municipal composting programs that recycle about 37% of country's yard wastes. This is likely to rise as the number of states (now 20) that ban yard wastes from sanitary landfills increases. The resulting compost can be used as organic soil fertilizer, topsoil, or landfill cover. It can also be used to help restore eroded soil on hillsides and along highways, and on strip-mined land, overgrazed areas, and eroded cropland.

Courtesy of Green Culture

Figure 21-10 Backyard composter drum in which bacteria convert kitchen waste into rich compost. When the compost is ready, the device can be wheeled out to the garden or flowerbeds.

To be successful, a large-scale composting program must be located carefully and odors must be controlled, because people do not want to live near a giant compost pile or plant. Some cities in Canada and many European Union countries compost more than 85% of their biodegradable wastes in centralized community facilities. Sometimes composting takes place in huge indoor buildings. In the Canadian city of Edmonton, Alberta, an indoor composting facility the size of eight football fields composts 50% of the city's organic solid waste. Composting programs must also exclude toxic materials that can contaminate the compost and make it unsafe for use as fertilizer.

■ CASE STUDY
Recycling Paper

About 55% of the world's industrial tree harvest is used to make paper. The pulp and paper industry is the world's fifth largest energy user and uses more water to produce a metric ton of its product than any other industry. In both Canada and the United States, it is the third-largest industrial energy user and polluter, and paper is the dominant material in the MSW of both countries. The Internet was supposed to reduce paper use by giving users access to vast amounts of electronic information. However, because most users print out their search results there has been no drop in per capita paper consumption in the United States (and in most other countries).

Paper (especially newspaper and cardboard) is easy to recycle. Recycling newspaper involves removing its ink, glue, and coating and then reconverting it to pulp, which is pressed into new paper. Making recycled paper uses 64% less energy and produces 35% less water pollution and 74% less air pollution than does making paper from wood, and, of course, no trees are cut down.

In 2007, the United States recycled about 56% of its wastepaper (up from 25% in 1989). At least 10 other countries recycle 50–97% of their wastepaper and paperboard, and the global recycling rate is 43%. Paper recycling leaders are Denmark (97%), South Korea (77%), and Germany (72%).

Despite a 56% recycling rate, the amount of paper thrown away each year in the United States is more than all of the paper used in China. Also, about 95% of books and magazines produced in the United States are printed on virgin paper. In producing this textbook we strive to use paper with a high percentage of recycled fibers. However, recycled paper of the quality required is often hard to get and costs more than conventional paper, which adds to the price of this book. Being green often involves trade-offs.

One problem associated with making paper is the chlorine (Cl_2) and chlorine compounds (such as chlorine dioxide, ClO_2), used to bleach about 40% of the world's pulp for making paper. These compounds are corrosive to processing equipment, hazardous for workers, hard to recover and reuse, and harmful when released into the environment. A growing number of paper mills (mostly in the European Union) are replacing chlorine-based bleaching chemicals with chemicals such as hydrogen peroxide (H_2O_2) or oxygen (O_2).

■ CASE STUDY
Recycling Plastics

Plastics consist of various types of large polymers, or *resins*—organic molecules made by chemically linking monomer molecules produced mostly from oil and natural gas (Figure 15-4, p. 375). About 46 different types of plastics are used in consumer products, and some products contain several kinds of plastic.

Many plastic containers and other items are thrown away and end up as litter on roadsides, beaches (Figure 21-11), and oceans and other bodies of water. Each year they threaten millions of seabirds, marine mammals (Figure 11-5, p. 254), and sea turtles, which can mistake a floating plastic sandwich bag for a jellyfish or get caught in discarded plastic nets (Figure 11-10, right, p. 260). About 80% of the plastics in the ocean are

UNEP/Peter Arnold, Inc.

Figure 21-11 Discarded solid waste litters beaches, poses a threat to beach users, and washes into the ocean and threatens marine animals.

INDIVIDUALS MATTER

Mike Biddle's Contribution to Recycling Plastics

Only 4% of the huge amount of plastics discarded each year in the United States is recycled. This is beginning to change.

In 1994, Mike Biddle, a former PhD engineer with Dow Chemical, and Trip Allen founded MBA Polymers, Inc. Their goal was to develop a commercial process for recycling high-value plastics from complex streams of goods such as computers, electronics, appliances, and automobiles. They succeeded by designing a 21-step automated process that separates plastics from nonplastic items in mixed waste streams, and then separates plastics from each other by type and grade and converts them to pellets that can be used to make new products.

The pellets are cheaper than virgin plastics, because the company's process uses 90% less energy than that needed to make a new plastic, and because the raw material is cheap or free junk. The environment also wins because greenhouse gas emissions are much lower than those generated in the making of virgin plastics. Also, recycling waste plastics reduces the need to incinerate them or bury them in landfills.

MBA Polymers is considered a world leader in plastics recycling. It operates a large state-of-the-art research and recycling plant in Richmond, California, and recently opened the world's two most advanced plastics recycling plants in China and Austria. It has won many awards, including the 2002 Thomas Alva Edison Award for Innovation, and was selected by *Inc.* magazine as one of "America's Most Innovative Companies."

Those who grew up with Mike Biddle are not surprised that he played a major role in developing an innovative and money-making process that many scientists and engineers thought impossible. As a kid growing up in Kentucky, he hated waste. He says he drove his parents crazy by following them around the house turning off lights in rooms that were not being used. Maybe you can be an environmental entrepreneur by using your brainpower to develop an environmentally beneficial and financially profitable process or business.

blown or washed in from beaches, rivers, storm drains, and other sources, and the rest gets dumped into the ocean from vessels and fishing boats.

Plastics discarded on beaches or dumped into the ocean from ships can disintegrate into particles the size of sand grains that resemble the prey of a variety of organisms. These particles can fill the stomachs of birds and other sea creatures and cause dehydration, malnutrition, and eventually starvation. Because tiny plastic particles can accumulate as they move through food webs, some level of plastic is found in most of the seafood people eat.

Currently, only about 4% by weight of all plastic wastes in the United States is recycled. As American comedian Lily Tomlin observes, "We buy a wastebasket and take it home in a plastic bag. Then we take the wastebasket out of the bag, and put the bag in the wastebasket." The percentage of plastic waste that is recycled is low for three reasons. *First,* many plastics are hard to isolate from other wastes because the many different resins used to make them are often difficult to identify, and some plastics are composites of different resins. For example, a plastic ketchup bottle might have as many as six different layers of plastics bonded together. Most plastics also contain stabilizers and other chemicals that must be removed before recycling.

Second, recovering individual plastic resins does not yield much material because only small amounts of any given resin are used in each product.

Third, the inflation-adjusted price of oil used to produce petrochemicals for making plastic resins is low enough to make the cost of virgin plastic resins much lower than that of recycled resins. An exception is PET (polyethylene terephthalate), used mostly in plastic drink bottles. However, PET collected for recycling must not have other plastics mixed with it; a single PVC (polyvinyl chloride) bottle in a truckload of PET can render it useless for recycling. Despite its economic value, only about 20% of the PET used in plastic containers in the United States is recycled. However, in 2007, Coca-Cola announced a goal of reusing or recycling 100% of the PET bottles it sells in the United States.

Progress is being made in the recycling of plastics (Individuals Matter, above) and in the development of more degradable bioplastics (Science Focus, at right).

Recycling Has Advantages and Disadvantages

Figure 21-12 lists the advantages and disadvantages of recycling (**Concept 21-3**). Whether recycling makes economic sense depends on how you look at its economic and environmental benefits and costs.

Critics say recycling does not make sense if it costs more to recycle materials than to send them to a landfill or incinerator. They concede that recycling may make economic sense for valuable and easy-to-recycle materials such as aluminum, paper, and steel, but probably not for cheap or plentiful resources such as glass made from silica. They also argue that recycling should pay for itself.

Proponents of recycling point out that conventional garbage disposal systems are funded by charges to households and businesses. So why should recycling be held to a different standard and forced to compete on an uneven playing field? Proponents also point to studies showing that the net economic, health, and environmental benefits of recycling (Figure 21-12, left) far outweigh the costs. They argue that the U.S. recycling industry employs about 1.1 million people and that its annual revenues are much larger than those of the waste management industry.

Cities that make money by recycling and have higher recycling rates tend to use a *single-pickup system* for both recyclable and nonrecyclable materials, instead of a more expensive dual-pickup system. Successful systems also tend to use a pay-as-you-throw approach. San Francisco, California (USA), uses such a system to recycle almost half of its MSW.

We Can Encourage Reuse and Recycling

Three factors hinder reuse and recycling. *First,* we have a faulty and misleading accounting system in which the market price of a product does not include the harmful environmental and health costs associated with the product during its life cycle.

Second, there is an uneven economic playing field, because in most countries, resource-extracting industries receive more government tax breaks and subsidies than recycling and reuse industries get.

Third, the demand and thus the price paid for recycled materials fluctuates, mostly because buying goods made with recycled materials is not a priority for most governments, businesses, and individuals.

How can we encourage reuse and recycling? Proponents say that leveling the economic playing field is the best way to start. Governments can *increase* subsidies and tax breaks for reusing and recycling materials (the carrot) and *decrease* subsidies and tax breaks for making items from virgin resources (the stick).

TRADE-OFFS

Recycling

Advantages	Disadvantages
Reduces air and water pollution	Can cost more than burying in areas with ample landfill space
Saves energy	May lose money for items such as glass and some plastics
Reduces mineral demand	Reduces profits for landfill and incinerator owners
Reduces greenhouse gas emissions	Source separation is inconvenient for some people
Reduces solid waste production and disposal	
Helps protect biodiversity	
Can save landfill space	
Important part of economy	

Figure 21-12 Advantages and disadvantages of recycling solid waste (**Concept 21-3**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

SCIENCE FOCUS

Bioplastics

Most of today's plastics are made from organic polymers produced from petroleum-based chemicals (petrochemicals). This may change as scientists develop more *bioplastics* or plastics made from biologically based chemicals.

The search for biologically based plastics dates from 1913 when a French scientist and a British scientist each filed for patents on a soy-based plastic. At that time, there was intense competition between the petrochemical and agricultural industries to dominate the market for plastics made from organic polymers.

Henry Ford, who developed the first motorcar, supported research on the development of a bioplastic made from soybeans. A 1914 photograph showed him using an ax to strike the body of a car made from soy bioplastic to demonstrate its strength.

But as oil became widely available, petrochemical plastics took over the market. Now with climate change and other environmental problems associated with the use of oil, chemists are stepping up efforts to make biodegradable and more environmentally sustainable plastics from a variety of green polymers. Such bioplastics can be made from corn, soy, sugarcane, switchgrass (Figure 16-26, p. 425), chicken feathers, some components of garbage, and CO_2 extracted from coal-burning power plant emissions.

The key to making such biopolymers is to find chemicals called *catalysts,* which accelerate reactions that form polymers from biologically based chemicals without having to use high temperatures. With proper design and mass production, bioplastics could be lighter, stronger, and cheaper, and could use less energy and produce less pollution per unit of weight than conventional petroleum-based plastics do.

Instead of being sent to landfills, packaging made from bioplastics could be composted to produce a soil conditioner, thus mimicking nature by implementing the nutrient recycling **principle of sustainability**.

Toyota is investing $38 billion in a process that makes plastics from plants. By 2020, it expects to control two-thirds of the world's supply of such bioplastics.

Critical Thinking

What might be some disadvantages of more rapidly degradable bioplastics? Do you think they outweigh the advantages?

Other strategies are to greatly increase use of the fee-per-bag waste collection system and to encourage or require government purchases of recycled products to help increase demand and lower prices. Governments can also pass laws requiring companies to take back and recycle or reuse packaging and electronic waste discarded by consumers (**Core Case Study**), as is done in Japan and some European Union countries.

CORE CASE STUDY

HOW WOULD YOU VOTE?

CORE CASE STUDY

Should governments pass laws requiring manufacturers to take back and reuse or recycle all packaging waste, appliances, electronic equipment (**Core Case Study**), and motor vehicles at the end of their useful lives? Cast your vote online at **academic.cengage.com/biology/miller**.

Citizens can pressure governments to require labels on all products listing recycled content and the types and amounts of any hazardous materials they contain. This would help consumers to be better informed about the environmental consequences of buying certain products.

One reason for the popularity of recycling is that it helps to soothe people's consciences in a throwaway society. Many people think that recycling their newspapers and aluminum cans is all they need do to meet their environmental responsibilities. Recycling is important, but reducing resource consumption and reusing resources are more effective ways to reduce the flow and waste of resources (**Concept 21-3**).

21-4 What Are the Advantages and Disadvantages of Burning or Burying Solid Waste?

CONCEPT 21-4 Technologies for burning and burying solid wastes are well developed, but burning contributes to pollution and greenhouse gas emissions, and buried wastes eventually contribute to pollution and land degradation.

Burning Solid Waste Has Advantages and Disadvantages

Globally, MSW is burned in more than 600 large *waste-to-energy incinerators* (98 in the United States), which burn MSW to boil water to make steam for heating water or space, or for producing electricity. Great Britain burns about 90% of its MSW in incinerators, compared to 16% in the United States and 8% in Canada. Trace the flow of materials through this process, as diagrammed in Figure 21-13.

In addition to producing energy, incinerators reduce the volume of solid waste by 90%. However, without expensive air pollution control devices and careful monitoring, incinerators pollute the air with particulates, carbon monoxide, toxic metals such as mercury, and other toxic materials. They also add CO_2 to the atmosphere, although they emit about 38% less CO_2 per unit of energy than coal-burning power plants emit. Incinerators produce large quantities of toxic bottom ash and fly ash (removed by air pollution control devices), which must be disposed of safely, ideally in specially licensed hazardous waste landfills.

To be economically feasible, incinerators must be fed huge volumes of trash every day. This encourages trash production and discourages reuse, recycling, and waste reduction. Since 1985, more than 280 new incinerator projects have been delayed or canceled in the United States because of high costs, concern over air pollution, and intense citizen opposition.

Figure 21-14 lists the advantages and disadvantages of using incinerators to burn solid waste.

HOW WOULD YOU VOTE?

Do the advantages of incinerating solid waste outweigh the disadvantages? Cast your vote online at **academic.cengage.com/biology/miller**.

Burying Solid Waste Has Advantages and Disadvantages

About 54% by weight of the MSW in the United States is buried in sanitary landfills, compared to 80% in Canada, 15% in Japan, and 12% in Switzerland.

There are two types of landfills. **Open dumps** are essentially fields or holes in the ground where garbage is deposited and sometimes burned. They are rare in developed countries, but are widely used near major cities in many developing countries (Figure 1-6, p. 11)

In newer landfills, called **sanitary landfills** (Figure 21-15, p. 576), solid wastes are spread out in thin

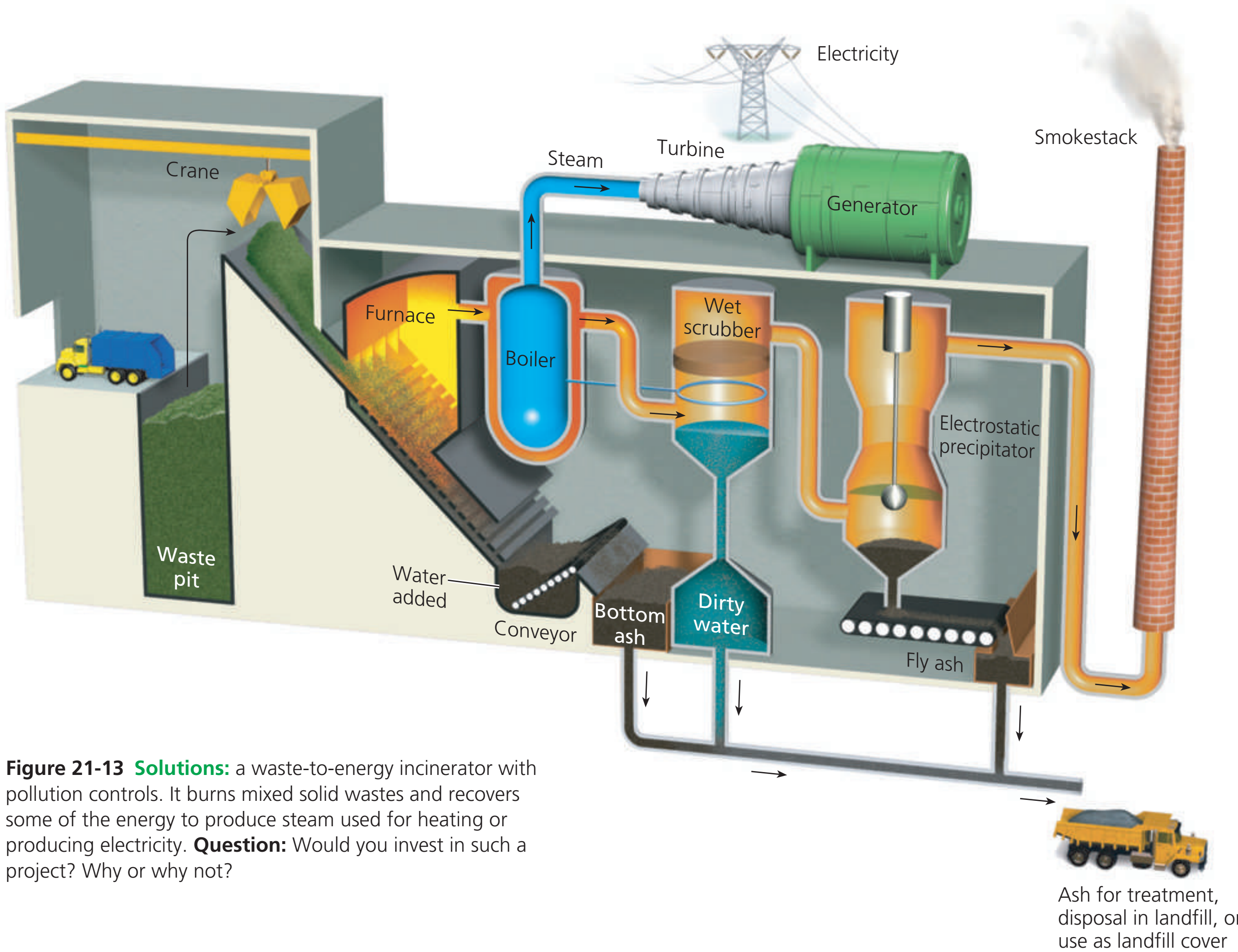


Figure 21-13 **Solutions:** a waste-to-energy incinerator with pollution controls. It burns mixed solid wastes and recovers some of the energy to produce steam used for heating or producing electricity. **Question:** Would you invest in such a project? Why or why not?

TRADE-OFFS

Incineration

Advantages	Disadvantages
Reduces trash volume	Expensive to build
Less need for landfills	Costs more than short-distance hauling to landfills
Low water pollution	Difficult to site because of citizen opposition
Concentrates hazardous substances into ash for burial	Some air pollution and CO_2 emissions
Sale of energy reduces cost	Older or poorly managed facilities can release large amounts of air pollution
Modern controls reduce air pollution	Output approach that encourages waste production
Some facilities recover and sell metals	Can compete with recycling for burnable materials such as newspaper

Figure 21-14 Advantages and disadvantages of incinerating solid waste (**Concept 21-4**). These trade-offs also apply to the incineration of hazardous waste. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

layers, compacted, and covered daily with a fresh layer of clay or plastic foam, which helps to keep the material dry and reduces leakage of contaminated water (leachate) from the landfill. This covering also lessens the risk of fire, decreases odor, and reduces accessibility to vermin.

Figure 21-16 (p. 576) lists the advantages and disadvantages of using sanitary landfills to dispose of solid waste. According to the EPA, all landfills eventually leak, passing both the effects of contamination and cleanup costs on to future generations. In the United States, some people were shocked to learn that radioactive materials from nuclear weapons facilities run by the Department of Energy were being dumped into regular landfills with little tracking of their dispersal, despite intense public opposition.

HOW WOULD YOU VOTE?

Do the advantages of burying solid waste in sanitary landfills outweigh the disadvantages? Cast your vote online at **academic.cengage.com/biology/miller**.

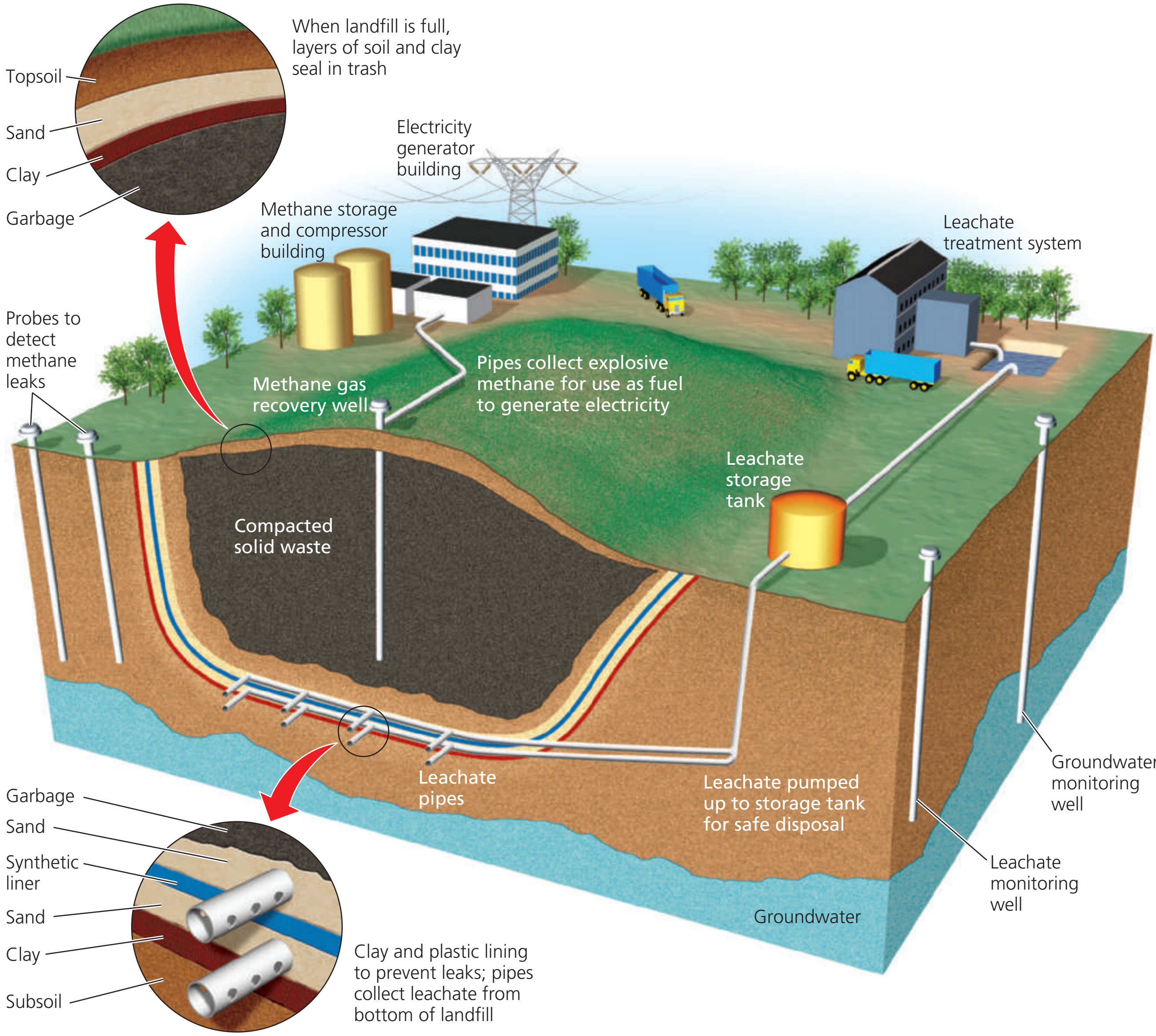


Figure 21-15 **Solutions:** state-of-the-art *sanitary landfill,* which is designed to eliminate or minimize environmental problems that plague older landfills. Since 1997, only modern sanitary landfills are allowed in the United States. As a result, many small, older local landfills have been closed and replaced with larger regional landfills. **Question:** How do you think sanitary landfills could develop leaks of toxic liquids?

TRADE-OFFS

Sanitary Landfills

Advantages	Disadvantages
No open burning	Noise and traffic
Little odor	Dust
Low groundwater pollution if sited properly	Air pollution from toxic gases and trucks
Can be built quickly	Releases greenhouse gases (methane and CO_2) unless they are collected
Low operating costs	Slow decomposition of wastes
Can handle large amounts of waste	Output approach that encourages waste production
Filled land can be used for other purposes	Eventually leaks and can contaminate groundwater
No shortage of landfill space in many areas	

Figure 21-16 Advantages and disadvantages of using sanitary landfills to dispose of solid waste (**Concept 21-4**). **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

21-5 How Should We Deal with Hazardous Waste?

CONCEPT 21-5 A sustainable approach to hazardous waste is first to produce less of it, then to reuse or recycle it, then to convert it to less hazardous materials, and finally, to safely store what is left.

We Can Use Integrated Management of Hazardous Waste

Figure 21-17 shows an integrated management approach suggested by the U.S. National Academy of Sciences that establishes three levels of priorities for dealing with hazardous waste: produce less of it; convert as much of it as possible to less hazardous substances; and put the rest in long-term, safe storage (**Concept 21-5**). Denmark follows these priorities, but most countries do not.

As with solid waste, the top priority should be pollution prevention and waste reduction. With this approach, industries try to find substitutes for toxic or hazardous materials, reuse or recycle them within industrial processes, or use them as raw materials for making other products (Figure 14-25, p. 367). (See Case Study, p. 366, and the Guest Essays on this subject by Lois Gibbs and Peter Montague at CengageNOW™.)

At least one-third of industrial hazardous wastes produced in Europe are exchanged through clearinghouses where they are sold as raw materials for use by other industries. The producers of these wastes do not have to pay for their disposal, and recipients get low-cost raw materials. About 10% of the hazardous waste in the United States is exchanged through such clearinghouses, a figure that could be raised significantly.

Integrated waste management could be used more for dealing with postconsumer hazardous waste, but such waste is not well managed, globally. For example, most e-waste recycling efforts (**Core Case Study**) create further hazards, especially for workers in some developing countries (see following Case Study).

■ CASE STUDY
Recycling E-Waste

In e-waste recycling operations in some countries, workers—many of them children—are often exposed to toxic chemicals as they dismantle e-wastes to extract valuable metals or parts that can be reused or recycled (**Core Case Study**).

According to the United Nations, more than 70% of the world's e-waste ends up in China. A center for such waste is the small port city of Guiyu, where the air reeks of burning plastic and acid fumes. There, more than 5,500 small-scale e-waste businesses employ over 30,000 people (sometimes including children) who work at very low wages in dangerous conditions to extract valuable metals like gold and copper from millions of discarded computers, television sets, and cell phones.

These workers usually wear no masks or gloves, often work in rooms with no ventilation, and are usually exposed to a cocktail of toxic chemicals. They carry out dangerous activities, such as smashing TV picture tubes by hand to recover glass and electronic parts—a method that releases large amounts of toxic lead dust. They also burn computer wires to expose copper, melt circuit boards in metal pots to extract lead and other metals, and douse the boards with strong acid to extract gold.

After the valuable metals are removed, leftover parts are burned or dumped in rivers or on the land. Atmospheric levels of deadly dioxin in Guiyu are up to 86 times as high as WHO safety standards, and an estimated 82% of the area's children younger than age 6 suffer from lead poisoning.

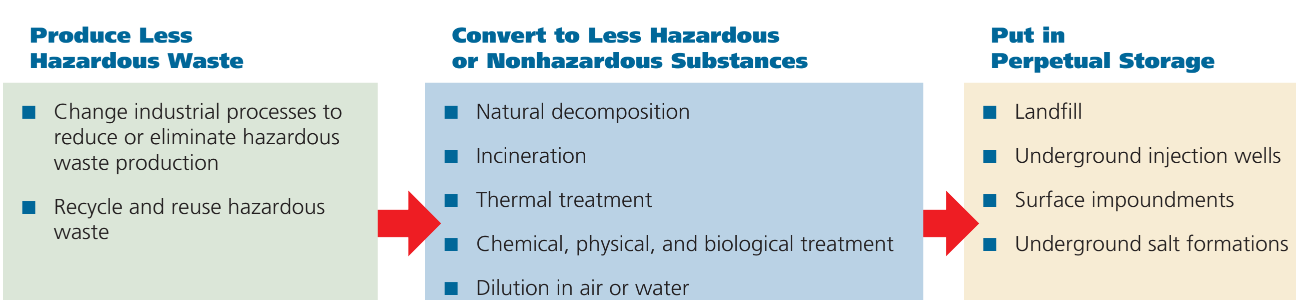


Figure 21-17 *Integrated hazardous waste management:* priorities suggested by the U.S. National Academy of Sciences for dealing with hazardous waste (**Concept 21-5**). To date, these priorities have not been followed in the United States and in most other countries. **Question:** Why do you think that most countries do not follow these priorities? (Data from U.S. National Academy of Sciences)

Partly in response to this problem, Hewlett Packard and Dell Inc., which together sell more than half of the personal computers in the United States, have reduced the use of toxic components and will take back their products for recycling when consumers discard them. Still, in 2007, only 10–15% of the e-waste in the United States was recycled, and up to 80% of that was shipped overseas to dismantling shops such as the one in Guiyu.

Sarah Westervelt of the Basal Action Network (BAN) warns, in fact, that "most of those businesses calling themselves recyclers are little more than international waste distributors. They take your old equipment for free, or pocket your recycling fee, and then simply load it into a sea-going container and ship it to China, India, or Nigeria." In 2008, BAN implemented its *e-Stewards Initiative,* designed to help people find responsible recyclers who work according to strict environmental and health standards.

You can find your closest e-Steward recycler at **ban.org/pledge1.html**. Also see **phones4charity.org** to find out how to recycle or donate your used cell phone. And see **recycle.org** to find out how to donate your used computer for reuse or recycling.

THINKING ABOUT
E-Waste Recycling

Would you pay more for a computer if you knew the higher price would keep the computer out of recycling shops such as those described above? If so, what percentage increase in the price would you accept?

We Can Detoxify Hazardous Wastes

The first step in dealing with hazardous wastes is to collect them. In Denmark, all hazardous and toxic waste from industries and households is delivered to 21 transfer stations throughout the country. From there it is taken to a large treatment facility, where three-fourths of the waste is detoxified by physical, chemical, and biological methods. The rest is buried in a carefully designed and monitored landfill.

Physical methods for detoxifying hazardous wastes include using charcoal or resins to filter out harmful solids and distilling liquid mixtures to separate out harmful chemicals. Especially deadly wastes can be encapsulated in glass, cement, or ceramics and then put in secure storage sites.

Chemical methods are used to convert hazardous chemicals to harmless or less harmful chemicals through chemical reactions. Currently, for example, chemists are testing the use of *cyclodextrin* to remove toxic materials such as solvents and pesticides from contaminated soil and groundwater. After this molecular-sponge-type material moves through the soil or groundwater, picking up various toxic chemicals, it is pumped out of the ground, stripped of its contaminants, and reused.

Another approach is the use of *nanomagnets,* magnetic nanoparticles coated with certain compounds that can remove various pollutants from water. For example, nanomagnets coated with *chitosan,* a chemical derived from the exoskeletons of shrimps and crabs, can be used to remove oil and other organic pollutants from contaminated water. Magnetic fields are then used to remove the pollutant coated magnetic nanoparticles. The pollutants are then separated out and disposed of or recycled. And the magnetic nanoparticles can be reused.

Some scientists and engineers consider *biological methods* for treatment of hazardous waste to be the wave of the future. One such approach is *bioremediation,* in which bacteria and enzymes help to destroy toxic or hazardous substances or convert them to harmless compounds. (See the Guest Essay by John Pichtel on this topic on the website for this chapter.)

In bioremediation, a contaminated site is inoculated with an army of microorganisms that break down specific hazardous chemicals, such as organic solvents, PCBs, pesticides, and oil, and leave behind harmless substances such as water and water-soluble chloride salts. So far, more than 1,000 different types of bacteria and fungi have been used to detoxify various types of hazardous waste. Bioremediation takes a little longer to work than most physical and chemical methods, but it costs much less.

Another approach is *phytoremediation,* which involves using natural or genetically engineered plants to absorb, filter, and remove contaminants from polluted soil and water, as shown in Figure 21-18. Various plants have been identified as "pollution sponges," which can help to clean up soil and water contaminated with chemicals such as pesticides, organic solvents, and radioactive or toxic metals. Figure 21-19 lists advantages and disadvantages of phytoremediation.

HOW WOULD YOU VOTE? ✓

Do the advantages of using phytoremediation to detoxify hazardous waste outweigh the disadvantages? Cast your vote online at **academic.cengage.com/biology/miller**.

Hazardous wastes can be incinerated to break them down and convert them to harmless or less harmful chemicals such as carbon dioxide and water. This has the same mixture of advantages and disadvantages as burning solid wastes (Figure 21-14). But incinerating hazardous waste can release air pollutants such as toxic dioxins, and it produces a highly toxic ash that must be safely and permanently stored in a landfill or vault especially designed for hazardous waste.

RESEARCH FRONTIER

Improving current methods and finding new ways to detoxify wastes. See **academic.cengage.com/biology/miller**.

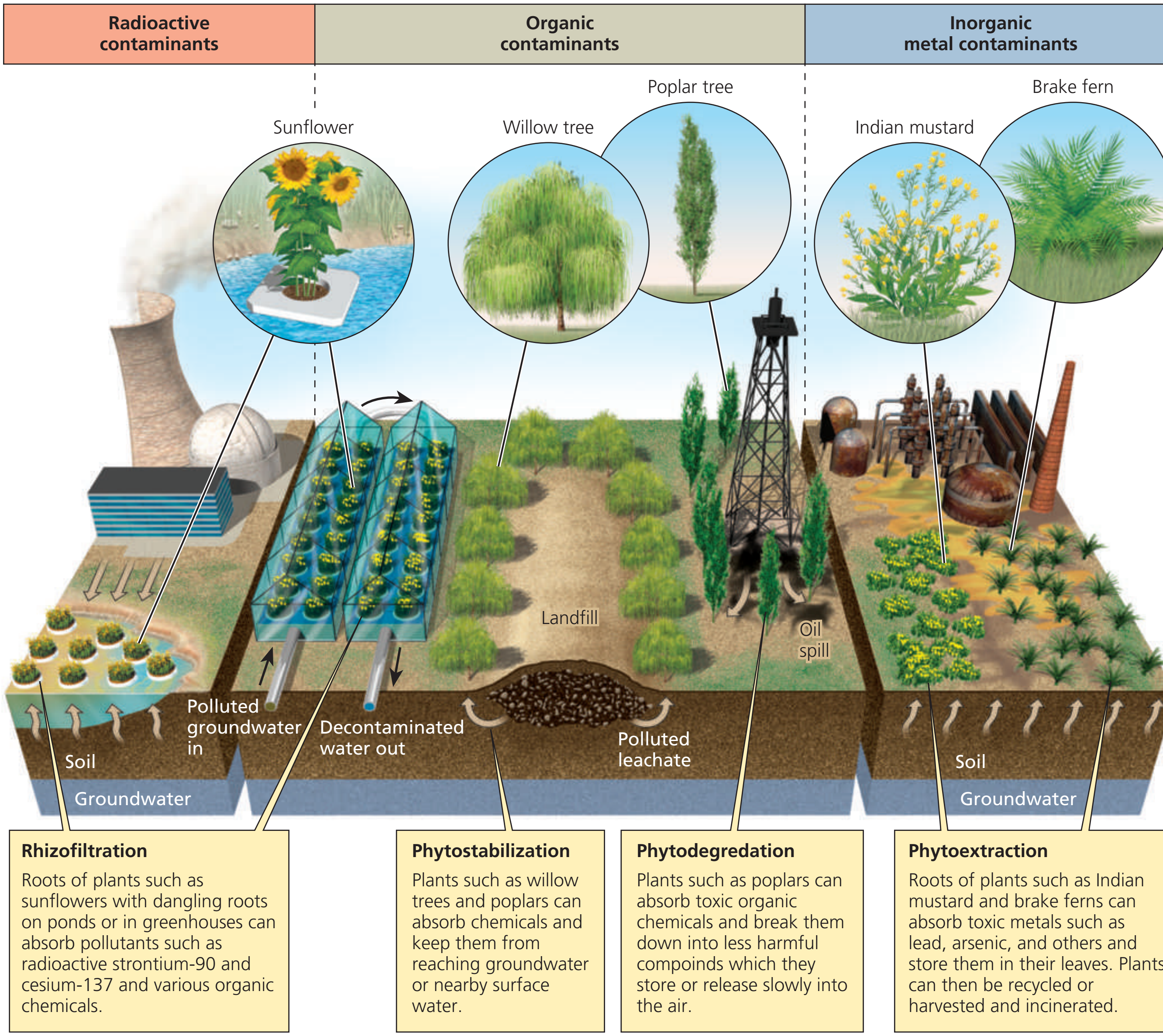


Figure 21-18 **Solutions:** *phytoremediation.* Various types of plants can be used as pollution sponges to clean up soil and water and radioactive substances (left), organic compounds (center), and toxic metals (right). (Data from American Society of Plant Physiologists, U.S. Environmental Protection Agency, and Edenspace)

TRADE-OFFS

Phytoremediation

Advantages	Disadvantages
Easy to establish	Slow (can take several growing seasons)
Inexpensive	Effective only at depth plant roots can reach
Can reduce material dumped into landfills	Some toxic organic chemicals may evaporate from plant leaves
Produces little air pollution compared to incineration	Some plants can become toxic to animals
Low energy use	

Figure 21-19 Advantages and disadvantages of using *phytoremediation* to remove or detoxify hazardous waste. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

TRADE-OFFS

Plasma Arc

Advantages	Disadvantages
Small	High cost
Mobile. Easy to move to different sites	Produces CO_2 and CO
Produces no toxic ash	Can release particulates and chlorine gas
	Can vaporize and release toxic metals and radioactive elements

Figure 21-20 Advantages and disadvantages of using a *plasma arc torch* to detoxify hazardous wastes. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

We can also detoxify hazardous wastes by using a *plasma arc torch,* somewhat similar to a welding torch, to incinerate them at very high temperatures. Passing an electrical current through a gas to generate an electric arc and very high temperatures creates *plasma*—an ionized gas made up of electrically conductive ions and electrons.

This process decomposes liquid or solid hazardous organic waste into ions and atoms that can be converted into simple molecules of a synthetic gas (syngas) consisting mostly of hydrogen (H_2) and carbon monoxide (CO). The syngas can then be used to make fuels such as hydrogen, natural gas (CH_4), or ethanol. The high temperatures can also convert hazardous inorganic matter into a molten glassy material that can be used to encapsulate toxic metals to keep them from leaching into groundwater. Figure 21-20 lists the advantages and disadvantages of using this process.

HOW WOULD YOU VOTE?

Do the advantages of using a plasma arc torch to detoxify hazardous waste outweigh the disadvantages? Cast your vote online at **academic.cengage.com/biology/miller**.

We Can Store Some Forms of Hazardous Waste

Ideally, burial on land or long-term storage of hazardous and toxic wastes should be used only as the third resort after the first two priorities have been exhausted (Figure 21-17 and **Concept 21-5**). But currently, burial on land is the most widely used method in the United States and most countries, largely because it is the least costly method for waste producers.

The most common form of burial is *deep-well disposal,* in which liquid hazardous wastes are pumped through a pipe into dry, porous rock formations far beneath aquifers, many of which are tapped for drinking and irrigation water. Theoretically, these liquids soak into the porous rock and are isolated from overlying groundwater by essentially impermeable layers of clay and rock.

However, there are a limited number of such sites and limited space within them. Sometimes the wastes leak into groundwater from the well shaft or migrate into groundwater in unexpected ways. In the United States, roughly 64% of liquid hazardous wastes are injected into deep disposal wells. Many scientists believe that current regulations for deep-well disposal in the United States are inadequate and should be improved. Figure 21-21 lists the advantages and disadvantages of deep-well disposal of liquid hazardous wastes.

HOW WOULD YOU VOTE?

Do the advantages of deep-well disposal of hazardous waste outweigh the disadvantages? Cast your vote online at **academic.cengage.com/biology/miller**.

Surface impoundments are ponds, pits, or lagoons into which liners are placed and liquid hazardous wastes are stored (Figure 21-22). As the water evaporates, the waste settles and becomes more concentrated. But inadequate seals can allow such wastes to percolate into the groundwater, and volatile harmful chemicals can

TRADE-OFFS

Deep-Well Disposal

Advantages	Disadvantages
Safe method if sites are chosen carefully	Leaks or spills at surface
Wastes can often be retrieved if problems develop	Leaks from corrosion of well casing
Easy to do	Existing fractures or earthquakes can allow wastes to escape into groundwater
Low cost	Output approach that encourages waste production

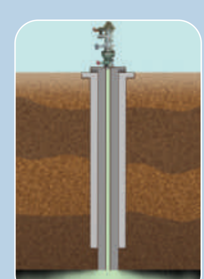


Figure 21-21 Advantages and disadvantages of injecting liquid hazardous wastes into deep underground wells. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

Ken Sherman/Bruce Coleman USA, Inc.

Figure 21-22 *Surface impoundment* in Niagara Falls, New York (USA). Such sites can pollute the air and nearby groundwater and surface water.

TRADE-OFFS

Surface Impoundments

Advantages	**Disadvantages**
Low construction costs	Groundwater contamination from leaking liners (or no lining)
Low operating costs	Air pollution from volatile organic compounds
Can be built quickly	Overflow from flooding
Wastes can often be retrieved if necessary	Disruption and leakage from earthquakes
Can store wastes indefinitely with secure double liners	Output approach that encourages waste production

Figure 21-23 Advantages and disadvantages of storing liquid hazardous wastes in surface impoundments. **Question:** Which single advantage and which single disadvantage do you think are the most important? Why?

evaporate into the air. Also, powerful storms can cause these impoundments to overflow. Figure 21-23 lists the advantages and disadvantages of this method.

EPA studies found that 70% of these storage basins in the United States have no liners, and up to 90% of them may threaten groundwater. According to the EPA, eventually all liners probably will leak and could contaminate groundwater.

HOW WOULD YOU VOTE? ✓

Do the advantages of storing hazardous wastes in surface impoundments outweigh the disadvantages? Cast your vote online at **academic.cengage.com/biology/miller**.

There are some highly toxic materials (such as mercury, Science Focus, p. 450) that we cannot destroy, detoxify, or safely bury. The best way to deal with such materials is to prevent or reduce their use and to put waste from such materials in special containers. The containers are then stored aboveground in specially designed buildings or underground in salt mines or bedrock caverns, where they can be inspected on a regular basis and retrieved if necessary. Carefully designed aboveground storage buildings are a good option in areas where the water table is close to the surface and in areas that lie above aquifers used for drinking water. Such storage structures should be built to withstand storms and to prevent the release of toxic gases, and leaks should be carefully monitored.

Sometimes, liquid and solid hazardous wastes are put into drums or other containers and buried in carefully designed and monitored *secure hazardous waste landfills* (Figure 21-24, p. 582). This is the least used method because of the expense involved.

Some developed countries are careless with their hazardous wastes. In the United Kingdom, most such wastes are mixed with household garbage and stored

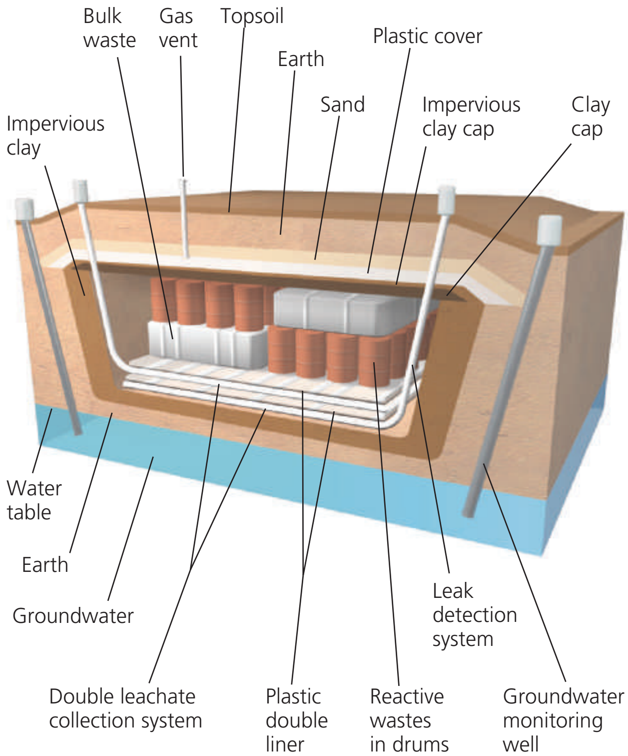


Figure 21-24 **Solutions:** secure hazardous waste landfill.

in hundreds of conventional landfills throughout the country. Most developing countries do little to regulate and control what happens to the hazardous wastes they produce.

Figure 21-25 lists some ways in which you can reduce your output of hazardous waste—the first step in dealing with it.

WHAT CAN YOU DO?

Hazardous Waste

- Avoid using pesticides and other hazardous chemicals, or use them in the smallest amounts possible
- Use less harmful substances instead of commercial chemicals for most household cleaners. For example, use vinegar to polish metals, clean surfaces, and remove stains and mildew; baking soda to clean household utensils and to deodorize and remove stains; and borax to remove stains and mildew.
- Do not dispose of pesticides, paints, solvents, oil, antifreeze, or other hazardous chemicals by flushing them down the toilet, pouring them down the drain, burying them, throwing them into the garbage, or dumping them down storm drains. Instead, use hazardous waste disposal services available in many cities.

Figure 21-25 **Individuals matter:** ways to reduce your output of hazardous waste (**Concept 21-5**). **Questions:** When was the last time you created hazardous waste? Could you have avoided it, and if so, how?

■ **CASE STUDY**

Hazardous Waste Regulation in the United States

About 5% of all hazardous waste produced in the United States is regulated under the Resource Conservation and Recovery Act (RCRA, pronounced "RICK-ra"), passed in 1976 and amended in 1984. The EPA sets standards for management of several types of hazardous waste and issues permits to companies allowing them to produce and dispose of a certain amount of wastes in acceptable ways. Permit holders must use a *cradle-to-grave* system to keep track of waste they transfer from a point of generation (cradle) to an approved disposal facility (grave), and they must submit proof of this disposal to the EPA.

RCRA is a good start, but this and other laws regulate only about 5% of the hazardous and toxic wastes, including e-waste, produced in the United States. In most other countries, especially developing countries, even less of this waste is regulated.

THINKING ABOUT
Hazardous Waste

CORE CASE STUDY

Why is it that 95% of the hazardous waste, including the growing mounds of e-waste (**Core Case Study**) produced in the United States, is not regulated? Do you favor regulating such wastes? What are the economic consequences of doing this? How would this change the way waste producers deal with the hazardous wastes they produce?

In 1980, the U.S. Congress passed the *Comprehensive Environmental Response, Compensation, and Liability Act*, commonly known as the *CERCLA* or *Superfund* program. Its goals are to identify sites where hazardous wastes have contaminated the environment (Figure 21-26) and to clean them up on a priority basis. The worst sites, which represent an immediate and severe threat to human health, are put on a *National Priorities List* and scheduled for total cleanup using the most cost-effective method.

In 2008, there were about 1,240 sites on this list. The Waste Management Research Institute estimates that at least 10,000 sites should be on the priority list and that cleanup of these sites would cost about $1.7 trillion, not including legal fees. This shows the economic and environmental value of emphasizing waste reduction and pollution prevention.

Since 1980, the EPA has dealt with 1,579 Superfund sites. So far 321 have been cleaned up and removed from the Superfund list. The degree of cleanup at the remaining sites varies.

In 1984, Congress amended the Superfund Act to give citizens the right to know what toxic chemicals are being stored or released in their communities. This required 23,800 large manufacturing facilities to report their annual releases of any of nearly 650 toxic chemicals into the environment. If you live in the United

States, you can find out what toxic chemicals are being stored and released in your neighborhood by going to the EPA's *Toxic Release Inventory* website at **www.epa.gov/tri/**.

The Superfund law, designed to have polluters pay for cleaning up abandoned hazardous waste sites, has virtually made illegal dump sites (Figure 21-26) relics of the past. It has forced waste producers, fearful of future liability claims, to reduce their production of such waste and to recycle or reuse much more of it. However, facing pressure from polluters, the U.S. Congress refused to renew the tax on oil and chemical companies that had financed the Superfund after it expired in 1995. The Superfund is now broke, and taxpayers, not polluters, are footing the bill for future cleanups when the responsible parties cannot be found. As a result, the pace of cleanup has slowed.

HOW WOULD YOU VOTE?

Should the U.S. Congress reinstate the polluter-pays principle by using taxes from chemical, oil, mining, and smelting companies to reestablish a fund for cleaning up existing and new Superfund sites? Register your vote online at **academic.cengage.com/biology/miller**.

The U.S. Congress and several state legislatures have also passed laws that encourage the cleanup of *brownfields*—abandoned industrial and commercial sites such as factories, junkyards, older landfills, and gas stations. In most cases, they are contaminated with hazardous wastes. Brownfields can be cleaned up and reborn as parks, nature reserves, athletic fields, ecoindustrial parks (Figure 14-25, p. 367), and neighborhoods. By 2008, more than 42,000 former brownfield sites had been redeveloped in the United States.

Phototake, Inc.

Figure 21-26 Leaking barrels of toxic waste at a Superfund site in the United States. This site has since been cleaned up.

In addition to laws that are focused on cleaning up hazardous waste, other laws have been passed to try to prevent creation of such wastes. One of the most successful was the 1976 law requiring that use of leaded gasoline be phased out in the United States (Case Study, p. 474).

21-6 How Can We Make the Transition to a More Sustainable Low-Waste Society?

CONCEPT 21-6 Shifting to a low-waste society requires individuals and businesses to reduce resource use and to reuse and recycle wastes at local, national, and global levels.

Grassroots Action Has Led to Better Solid and Hazardous Waste Management

In the United States, individuals have organized to prevent the construction of hundreds of incinerators, landfills, treatment plants for hazardous and radioactive wastes, and polluting chemical plants in or near their communities. Health risks from incinerators and landfills, when averaged for the entire country, are quite low, but the risks for people living near such facilities are much higher.

Manufacturers and waste industry officials point out that something must be done with the toxic and hazardous wastes produced to provide people with certain goods and services. They contend that even if local citizens adopt a "not in my back yard" (NIMBY) approach, the waste will always end up in someone's back yard.

Many citizens do not accept this argument. To them, the best way to deal with most toxic and hazardous waste is to produce much less of it, as suggested by the U.S. National Academy of Sciences (Figure 21-17). For such materials, they believe that the goal should be "not in anyone's back yard" (NIABY) or "not on planet Earth" (NOPE), which calls for drastically reducing production of such wastes by emphasizing pollution prevention and using the precautionary principle (**Concepts 1-4**, p. 16, and **9-4C**, p. 206).

CONCEPT LINKS

Providing Environmental Justice for Everyone Is an Important Goal

Environmental justice is an ideal whereby every person is entitled to protection from environmental hazards regardless of race, gender, age, national origin, income, social class, or any political factor. (See the Guest Essay on this subject by Robert Bullard on the website for this chapter.)

Studies have shown that a disproportionate share of polluting factories, hazardous waste dumps, incinerators, and landfills in the United States are located in communities populated mostly by African Americans, Asian Americans, Latinos, and Native Americans and the working poor. Studies have also shown that, in general, toxic waste sites in white communities have been cleaned up faster and more completely than such sites in African American and Latino communities have.

Such environmental discrimination in the United States and in other parts of the world has led to a growing grassroots movement known as the *environmental justice movement.* Members of this group have pressured governments, businesses, and environmental groups to become aware of environmental injustice and to act to prevent it. They have made some progress toward their goals, but there is a long way to go.

THINKING ABOUT
Environmental Injustice

Have you or anyone in your family ever been a victim of environmental injustice? If so, describe what happened. What would you do to help prevent environmental injustice?

Countries Have Developed International Treaties to Reduce Hazardous Waste

Environmental justice also applies at the international level. For decades, some developed countries had been shipping hazardous wastes to developing countries. In 1989, the UNEP developed an international treaty known as the Basel Convention. It banned developed countries that participate in the treaty from shipping hazardous waste (including e-waste) to or through other countries without their permission. In 1995, the treaty was amended to outlaw all transfers of hazardous wastes from industrial countries to developing countries. By 2008, this agreement had been ratified by 152 countries, but not by the United States, Afghanistan, and Haiti.

This ban will help, but it will not wipe out the very profitable illegal waste trade. Smugglers evade the laws by using an array of tactics, including bribes, false permits, and mislabeling of hazardous wastes as materials to be recycled.

In 2000, delegates from 122 countries completed a global treaty to control 12 *persistent organic pollutants* (POPs). These widely used toxic chemicals are persistent, insoluble in water, and soluble in fat. This means that they can be concentrated in the fatty tissues of humans and other organisms feeding at high trophic levels in food webs to levels hundreds of thousands of times higher than levels in the general environment (Figure 9-19, p. 202). Because they are persistent, POPs can also be transported long distances by wind and water.

The original list of 12 chemicals, called the *dirty dozen,* includes DDT and 8 other chlorine-containing persistent pesticides, PCBs (Case Study, p. 449), dioxins, and furans. Using blood tests, medical researchers at New York City's Mount Sinai School of Medicine found that nearly every person on earth has detectable levels of POPs. The long-term health effects of this involuntary global chemical experiment are largely unknown.

The treaty seeks to ban or phase out use of these chemicals and to detoxify or isolate stockpiles of them. It allows 25 countries to continue using DDT to combat malaria until safer alternatives are available. The United States has not ratified this treaty.

Environmental scientists consider the POPs treaty to be an important milestone in international environmental law and pollution prevention because it uses the precautionary principle to manage and reduce the risks from toxic chemicals. The list of persistant organic pollutants is expected to grow.

In 2000, the Swedish Parliament enacted a law that, by 2020, will ban all chemicals that are persistent and can bioaccumulate in living tissue. This law also requires industries to perform risk assessments on the chemicals they use and to show that these chemicals are safe to use, as opposed to requiring the government to show that they are dangerous. In other words, chemicals are assumed to be guilty until proven innocent—the reverse of the current policy in the United States and in most countries. There is strong opposition to this approach in the United States, especially from most industries producing potentially dangerous chemicals. The European Union is also considering legislation that puts the burden of proof on manufacturers to show that about 30,000 industrial chemicals and substances are safe.

We Can Make the Transition to Low-Waste Societies

According to physicist Albert Einstein, "A clever person solves a problem, a wise person avoids it." Some are taking these words seriously. The governments of Norway, Austria, and the Netherlands have committed to reducing their resource waste by 75%. In a pilot study, residents of the U.S. city of East Hampton, New York, cut their solid waste production by 85%.

To prevent pollution and reduce waste, many environmental scientists urge us to understand and follow several key principles:

- Everything is connected.
- There is no *away,* as in *to throw away,* for the wastes we produce.
- Dilution is not always the solution to pollution.
- Polluters and producers should pay for the wastes they produce.
- Different categories of hazardous waste and recyclable waste should not be mixed.
- We should mimic nature by reusing, recycling, or composting at least 75% of the solid wastes we produce.
- The best and cheapest ways to deal with solid and hazardous wastes are waste reduction and pollution prevention.

CENGAGENOW™ Learn more about how shifting to a low-waste (low-throughput) economy would be the best long-term solution to environmental and resource problems at CengageNOW.

REVISITING E-Waste and Sustainability

CORE CASE STUDY

SUSTAINABILITY

The growing problem of e-waste (**Core Case Study**) and other topics discussed in this chapter represent the problems of maintaining a high-waste society. The challenge is to make the transition from a high-waste, throwaway mode to a low-waste, reducing-reusing-recycling economy.

Such a transition will require applying the four **scientific principles of sustainability**. Shifting from reliance on fossil fuels and nuclear power (which produces long-lived, hazardous, radioactive wastes) to greater use of renewable solar energy, wind, and flowing water will reduce our outputs of solid and hazardous waste, as will reusing and recycling materials by mimicking nature's chemical cycling processes. Integrated waste management (Figures 21-5 and 21-17), using a diversity of approaches with emphasis on waste reduction and pollution prevention, is another useful way to mimic nature. Reducing the human population and the resources used per person would also decrease the demand for materials that eventually become solid and hazardous wastes.

The key to addressing the challenge of toxics use and wastes
rests on a fairly straightforward principle:
harness the innovation and technical ingenuity
that has characterized the chemicals industry from its beginning
and channel these qualities in a new direction
that seeks to detoxify our economy.

ANNE PLATT MCGINN

REVIEW

1. Review the Key Questions and Concepts for this chapter on p. 561. Describe the problems associated with electronic waste (e-waste) (**Core Case Study**). CORE CASE STUDY

2. Distinguish among **solid waste, industrial solid waste, municipal solid waste (MSW),** and **hazardous (toxic) waste** and give an example of each. Give two reasons for sharply reducing the amount of solid and hazardous waste we produce. Describe the production of solid waste in the United States and what happens to such waste.

3. Distinguish among **waste management, waste reduction,** and **integrated waste management.** Describe the priorities that prominent scientists believe we should use for dealing with solid waste. What is garbology? Distinguish among **reducing, reusing,** and **recycling** as strategies for waste reduction. Describe six ways in which industries and communities can reduce resource use, waste, and pollution.

4. Explain why reusing and recycling materials are so important and give two examples of each. Describe the importance of using refillable containers and list five other ways to reuse various items. Distinguish between **primary (closed-loop)** and **secondary recycling** and give an example of each. Describe two approaches to recycling household solid wastes and evaluate each approach. What is a materials recovery facility? What is composting?

5. Describe the recycling of paper and the problems involved. Describe the recycling of plastics and the problems involved. Describe progress in recycling plastics. What are bioplastics? What are the major advantages and

disadvantages of recycling? What are three factors that discourage recycling? Describe three ways to encourage recycling and reuse.

6. What are the major advantages and disadvantages of using incinerators to burn solid and hazardous waste? Distinguish between **open dumps** and **sanitary landfills.** What are the major advantages and disadvantages of burying solid waste in sanitary landfills?

7. What are the priorities that scientists from the National Academy of Sciences believe we should use in dealing with hazardous waste? What is phytoremediation and what are the major advantages and disadvantages of using it to remove or detoxify hazardous wastes? What are the major advantages and disadvantages of using a plasma torch to detoxify hazardous wastes?

8. What are the major advantages and disadvantages of disposing of liquid hazardous wastes in **(a)** deep underground wells and **(b)** surface impoundments? What is a secure hazardous waste landfill? Describe the regulation of hazardous waste in the United States under the Resource Conservation and Recovery Act and the Comprehensive Environmental Response, Compensation, and Liability (or Superfund) Act. What is a brownfield?

9. How has grassroots action improved solid and hazardous waste management in the United States? What is **environmental justice** and how well has it been applied in locating and cleaning up hazardous waste sites in the United States? Describe regulation of hazardous wastes at the global level through the Basel Convention and the treaty to control persistent organic pollutants.

10. Describe connections between dealing with the growing problem if e-waste (**Core Case Study**) and the four **scientific principles of sustainability**.

CORE CASE STUDY SUSTAINABILITY

Note: Key Terms are in **bold** type.

CRITICAL THINKING

1. Do you think that manufacturers of computers and television sets and other forms of e-waste (**Core Case Study**) should be required to take them back at the ends of their useful lives for repair, remanufacture, or recycling? Explain. Would you be willing to pay more for these products to cover the costs of such a take-back program? If so, what percent more per purchase would you be willing to pay?

CORE CASE STUDY

2. Find three items you regularly use once and then throw away. Are there other reusable items that you could use in place of these disposable items? Compare the cost of using the disposable option for a year versus the cost of using the alternatives.

3. Use the second law of thermodynamics (p. 43) to explain why a *properly designed* source-separation recycling program takes less energy and produces less pollution than a centralized program that collects mixed waste over a large area and hauls it to a centralized facility where workers or machinery separate the wastes for recycling.

4. Changing World Technologies has built a pilot plant to test a process it has developed for converting a mixture of computers, old tires, turkey bones and feathers, and other wastes into oil by mimicking and speeding up natural processes for converting biomass into oil. If this recycling process turns out to be technologically and economically feasible, explain why it could increase waste production.

5. Would you oppose having a hazardous waste landfill, waste treatment plant, deep-injection well, or incinerator in your community? For each of these facilities, explain your answer. If you oppose these disposal facilities, how do you believe the hazardous waste generated in your community should be managed?

6. How does your school dispose of its solid and hazardous waste? Does it have a recycling program? How well does it work? Does it have a hazardous waste collection system? If so, what does it do with these wastes? List three ways to improve your school's waste reduction and management system.

7. Give your reasons for agreeing or disagreeing with each of the following proposals for dealing with hazardous waste:
   a. Reduce the production of hazardous waste and encourage recycling and reuse of hazardous materials by charging producers a tax or fee for each unit of waste generated.
   b. Ban all land disposal and incineration of hazardous waste to protect air, water, and soil from contamination and to encourage reuse, recycling, and treatment of wastes to make them less hazardous.
   c. Provide low-interest loans, tax breaks, and other financial incentives to encourage industries that produce hazardous waste to reduce, reuse, recycle, treat, and decompose such waste.

8. List three ways in which you could apply **Concept 21-6** to making your lifestyle more environmentally sustainable.

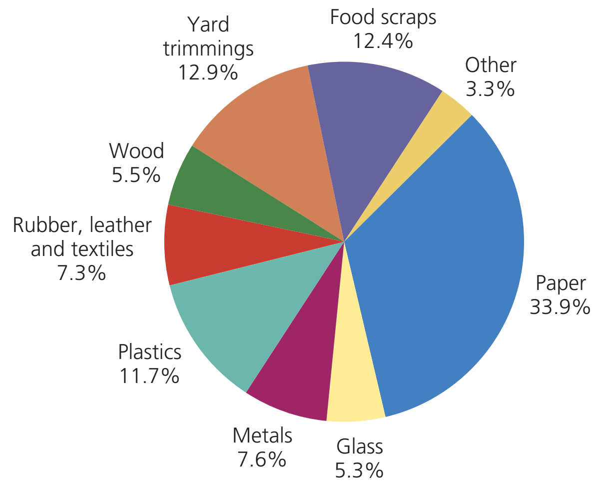
9. Congratulations! You are in charge of the world. List the three most important components of your strategy for dealing with **(a)** solid waste and **(b)** hazardous waste.

10. List two questions you would like to have answered as a result of reading this chapter.

Note: See Supplement 13 (p. S78) for a list of Projects related to this chapter.

ECOLOGICAL FOOTPRINT ANALYSIS

This pie chart diagram from an EPA report shows the typical composition of U.S. municipal solid waste (MSW) in 2006.



Source: U.S. Environmental Protection Agency, 2008, **www.epa.gov/epaoswer/non-hw/muncpl/pubs/msw06.pdf**

1. The average daily municipal solid waste production per person in the United States in 2006 was 2.10 kilograms (4.60 pounds). Use the data in the figure above to understand what makes up the annual MSW ecological footprint for a typical American. For each category in the pie chart, calculate the total weight in kilograms (and pounds) generated in 2006 by the average American. (*Note:* 1 kilogram = 2.20 pounds)

LEARNING ONLINE

Log on to the Student Companion Site for this book at **academic.cengage.com/biology/miller**, and choose Chapter 21 for many study aids and ideas for further reading and research. These include flash cards, practice quizzing, Weblinks, information on Green Careers, and InfoTrac® College Edition articles.

AP* Review Questions for Chapter 21

1. Recycling aluminum (Al) cans saves 95% of the energy needed to produce new aluminum cans from raw materials. How many Al cans can be made out of recycled Al with the same amount of energy that it takes to make one Al can out of new material?
(A) 1
(B) 2
(C) 5
(D) 10
(E) 20

2. E-waste (electronic waste) is often labeled as recyclable material and sent to undeveloped countries where workers recover a small amount of valuable metals from the waste. The remainder is then burned or dumped in landfills where it releases toxic pollutants such as dioxins. This is frequently used as a means of bypassing the
(A) Clean Air Act
(B) Kyoto Protocol
(C) International Basel Convention
(D) Resource Conservation and Recovery Act
(E) Non-Proliferation Treaty

3. One method to remove contaminants such as Cesium-137 from surface soil would be
(A) to use phytoremediation that allows a plant's roots to absorb toxins by rhizofiltration.
(B) to use a plasma arc torch to incinerate the toxins in situ.
(C) to create a surface impoundment with a liner.
(D) to spray the surface with a genetically engineered bacteria that breaks down cesium.
(E) to burn and replace the soil.

4. One of the primary concerns of the 12 POPs (persistant organic pollutants) such as dioxins or PCBs is that they
(A) are soluble in water and cause large-scale problems.
(B) can be concentrated in the fatty tissues of organism.
(C) are rarely found but very toxic.
(D) quickly breakdown into other, more harmful pollutants.
(E) are only found in plants and disrupt photosynthesis.

5. The majority of solid waste generated in the United States is in what form?
(A) Toxic waste
(B) Industrial solid waste
(C) Municipal solid waste
(D) Radioactive waste
(E) Electronic waste

6. Which of the activities below is a form of integrated waste reduction?
(A) Burying MSW in a landfill
(B) Incinerating MSW to produce electricity
(C) Shipping e-waste to China for disposal
(D) Separating out and composting yard waste
(E) Dumping non-toxic waste offshore in the oceans

7. Which of the activities below is **NOT** an aspect of the popular phrase, "reduce, reuse, recycle?"
(A) E-mailing or texting in place of using conventional paper mail
(B) Reading newspapers or magazines online
(C) Buying products in bulk form whenever possible
(D) Utilizing plastic in place of paper bags
(E) Donating or selling used items

8. One of the major disadvantages of recycling goods is that
(A) it may cost more than burying trash in areas with ample space.
(B) it increases profits for landfill operators.
(C) it helps to protect biodiversity.
(D) it is an important part of the economy.
(E) it saves energy and reduces mineral demand.

9. When you are in an area that restricts the type of plastics that can be recycled, why should you remove plastic caps from bottles when you go to recycle them?
(A) A small amount of other plastics can contaminate and make useless recycled plastic.
(B) It is impossible to remove plastic caps from bottles before recycling.
(C) Plastic bottle caps cost too much to dispose of after their removal.
(D) The coloring of bottle caps makes them difficult to recycle.
(E) Bottles with their caps on cannot be recycled and are thrown away.

10. Many environmental scientists advocate that the best and cheapest way to deal with solid waste is to
(A) truck the waste to landfills and bury it.
(B) reduce the amount produced in the first place.
(C) incinerate the waste to generate electricity.
(D) establish grass-roots organizations advocating for fewer landfills.
(E) pass more laws and treaties with tighter controls on emissions of pollutants.