CHAPTER 17

SOLID WASTE MANAGEMENT AND DISPOSAL

As we use materials in our daily lives we generate waste. Much of that waste is sent to landfills. However, many materials that are no longer useful in their current form can be recycled for use in a different way. Most communities have recycling programs that reduce the amount of waste sent to landfills.

CHAPTER OUTLINE

OBJECTIVES

After reading this chapter, you should be able to:

- Explain why solid waste is a problem throughout the world.
- Understand that the management of municipal solid waste is directly affected by economics, changes in technology, and citizen awareness and involvement.
- Describe the various methods of waste disposal and the problems associated with each method.
- Understand the difficulties in developing new municipal landfills.
- Define the problems associated with incineration as a method of waste disposal.
- Describe some methods of source reduction.
- Describe composting and how it fits into solid waste disposal.
- List some benefits and drawbacks of recycling.

The following additional Case Study can be found on the book's website at www.mhhe.com/enger12e along with other interesting readings: "Recycling Is Big Business."

KINDS OF SOLID WASTE

The several kinds of waste produced by a technological society can be categorized in many ways. Some kinds of wastes are released into the air and water. Some are purposely released, while others are released accidentally. Many wastes that are purposely released are treated before their release. Wastes that are released into the water and air are discussed in chapters 15 and 16, respectively. There are wastes with particularly dangerous characteristics, such as nuclear wastes, medical wastes, industrial hazardous wastes, and household hazardous wastes. Chapter 10 deals with nuclear wastes, and chapter 18 considers hazardous waste issues. The focus of this chapter is solid waste.

Solid waste is generally made up of objects or particles that accumulate on the site where they are produced, as opposed to water- and airborne wastes that are carried away from the site of production. Solid wastes are typically categorized by the sector of the economy responsible for producing them, such as mining, agriculture, manufacturing, and municipalities.

We have very good information about those waste streams that are tightly regulated (hazardous wastes, municipal solid waste, medical wastes, nuclear wastes) but only general estimates for many of the other kinds of wastes, such as mining and agricultural waste.

Mining waste is generated in three primary ways. First, in most mining operations, large amounts of rock and soil need to be removed to get to the valuable ore. This waste material is generally left on the surface at the mine site. Second, milling operations use various technologies to extract the valuable material from the ore. These techniques vary from relatively simple grinding and sorting to sophisticated chemical separation processes. Regardless of the technique involved, once the valuable material is recovered, the remaining waste material, commonly known as tailings, must be disposed of. Solid materials are typically dumped on the land near the milling site, and liquid wastes are typically stored in ponds. It is difficult to get vegetation to grow on these piles of waste rock and tailings, so they are unsightly and remain exposed to rain and wind. Finally, the water that drains or is pumped from mines or that flows from piles of waste rock or tailings often contains hazardous materials (such as asbestos, arsenic, lead, and radioactive materials) or high amounts of acid that must be contained or treated—but often are not. In addition, failures of the earthen dams used to form waste ponds result in the release of contaminated water into local streams. Between 1993 and 2005, about 35 such failures occurred worldwide, seven of them in the United States.

It is difficult to get more than a rough estimate of the amount of mining waste produced, but the U.S. Environmental Protection Agency estimates that between 1 billion and 2 billion metric tons of mining waste are produced each year in the United States. Of the total waste produced, about 700 million to 800 million metric tons are considered hazardous.

Many types of mining operations require vast quantities of water for the extraction process. The quality of this water is degraded, so it is unsuitable for drinking, irrigation, or recreation. Since mining disturbs the natural vegetation in an area, water may carry soil particles into streams and cause erosion and siltation. Some mining operations, such as strip mining, rearrange the top layers of the soil, which lessens or eliminates its productivity for a long time. Strip mining has disturbed approximately 75,000 square kilometers (30,000 square miles) of U.S. land, an area equivalent to the state of Maine.

Agricultural waste is the second most common form of waste and includes waste from the raising of animals and the harvesting and processing of crops and trees. The amount of animal manure produced annually is estimated at about 1240 million metric tons. Other wastes associated with agriculture, such as waste from processing operations (peelings, seeds, straw, stems, sludge, and similar materials), might bring the total agricultural waste to about 1.5 billion metric tons per year. Since most agricultural waste is organic, approximately 90 percent is used as fertilizer or for other soil-enhancement activities. Other materials are burned as a source of energy, so little of this waste needs to be placed in landfills. However, when too much waste is produced in one place, there may not be enough farmland available to accept the agricultural waste without causing water pollution problems associated with runoff or groundwater contamination due to infiltration.

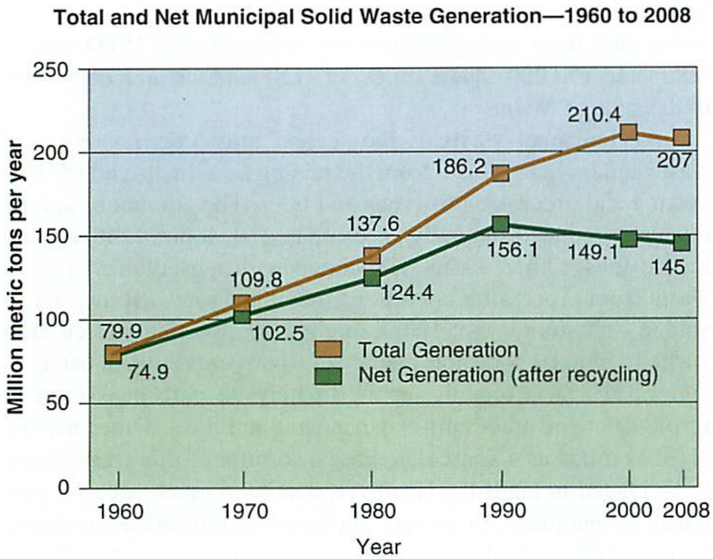
Industrial solid waste from sources other than mining is variously estimated to be between 200 million and 600 million metric tons of solid waste per year. It includes a wide variety of materials such as demolition waste, foundry sand, scraps from manufacturing processes, sludge, ash from combustion, and other similar materials. These materials are tested to determine if they are hazardous. If they are classified as hazardous waste, their disposal requires that they be placed in special hazardous waste landfills. Hazardous wastes are discussed in chapter 18. In addition to solid wastes, industries produce several billion metric tons of aquatic waste. See chapter 15 for a discussion of industrial use of water.

Municipal solid waste (MSW) consists of all the materials that people in a region no longer want because they are broken, spoiled, or have no further use. It includes waste from households, commercial establishments, institutions, and some industrial sources and amounts to about 210 million metric tons per year. Table 17.1 summarizes estimates of the quantity of various kinds of solid waste produced in the United States. The remainder of this chapter will focus on the generation and disposal of municipal solid waste.

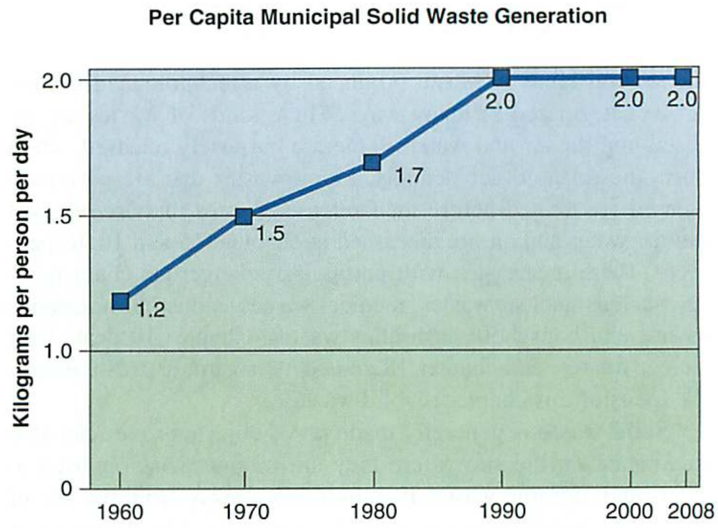
TABLE 17.1 Estimates of Solid Waste Produced per Year in the United States

Category of Waste	Amount of Waste (million metric tons)
Mining waste	1000–2000
Agricultural waste	1500
Industrial waste	200–600
Municipal solid waste	210

Source: Estimates from U.S. Environmental Protection Agency, U.S. Geological Survey, and U.S. Department of Agriculture.



(a)



(b)

FIGURE 17.1 **Municipal Solid Waste Generation Rates** The generation of municipal solid waste in the United States has increased steadily. However, because of increased recycling rates, the net production rates (after recyclables have been removed) has actually fallen since 1990 (a), and the per capita rate has stabilized (b).

Source: U.S. Environmental Protection Agency, Washington, D.C.

MUNICIPAL SOLID WASTE

Wherever people exist, waste disposal is a problem. Archaeologists are eager to find the middens, or waste heaps, of ancient civilizations. The kinds of articles discarded can tell us a great deal about the nature of the society that produced them. In modern society, many products are discarded when they are broken or worn out, while others have only a temporary use. Those that have only temporary uses make up the majority of solid waste.

The United States produces about 210 million metric tons of municipal solid waste each year. This equates to about 2 kilograms (4.4 pounds) of trash per person per day, or 0.73 metric tons per person per year. The amount of municipal solid waste has more than doubled since 1960, and the per capita rate has increased by nearly 70 percent in that same time, although per capita rates began to stabilize about 1990. When recycling is included, the net waste produced has actually fallen since 1990. (See figure 17.1.)

Nations with high standards of living and productivity tend to have more municipal solid waste per person than less-developed countries. (See figure 17.2.) The United States and Canada, therefore, are world leaders in waste production. Large metropolitan areas have the greatest difficulty dealing with their solid waste because of the large volume and the challenge of finding suitable landfill sites near the city. For example, Toronto, Canada, has no local landfill for its waste. As a result, Toronto developed an ambitious plan to divert 100 percent of its solid waste from landfills by 2011. By 2004, it had met its intermediate target and was diverting about 40 percent. Toronto has a long-term contract with a landfill site in Michigan to dispose of its remaining solid waste (about 4000 metric tons per day) at a cost of about US $40 per metric ton. In response to public

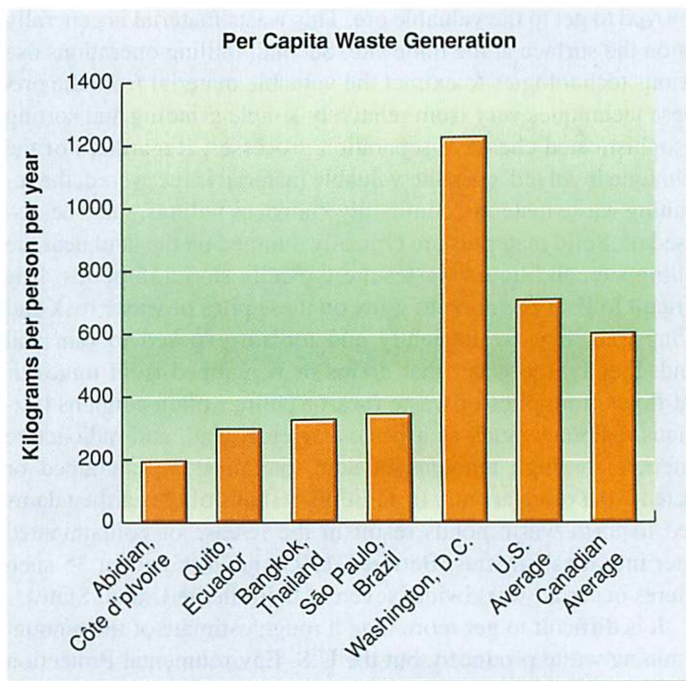


FIGURE 17.2 **Waste Generation and Lifestyle** The waste generation rates of people are directly related to their economic condition. People in richer countries produce more garbage than those in poorer countries.

Source: Data from *World Resources* 1996–2006, and U.S. Environmental Protection Agency.

Going Green

Garbage Goes Green

Nearly 400 municipal solid waste (MSW) landfills in the United States recover and combust landfill gas to generate heat or electricity. Landfill gas is generated during the natural process of bacterial decomposition of organic material contained in MSW landfills. A number of factors influence the quantity of gas that a MSW landfill generates and the components of that gas. These factors include, but are not limited to, the types and age of the waste buried in the landfill, the quantity and types of organic compounds in the waste, and the moisture content and temperature of the waste. Temperature and moisture levels are influenced by the surrounding climate.

Landfill gas can be an asset when it is used as a source of energy to create electricity or heat. It is classified as a medium-Btu gas with a heating value of 350 to 600 Btu per cubic foot—approximately one-half that of natural gas. Landfill gas can often be used in place of conventional fossil fuels in certain applications. It is a reliable source of energy because it is generated 24 hours a day, seven days a week. By using landfill gas to produce energy, landfills can significantly reduce their emissions of methane and avoid the need to generate energy from fossil fuels, thus reducing emissions of carbon dioxide, sulfur dioxide, nitrogen oxides, and other pollutants from fossil fuel combustion.

Landfill gas recovery projects provide a highly effective means of reducing overall greenhouse gas emissions from landfills. By using the otherwise wasted methane contained in the collected landfill gas to generate electricity or directly as a fuel, fossil fuels such as oil and coal are displaced. This displacement of fossil fuels is an environmental benefit, the magnitude of which would depend on the actual amount of electricity generated or landfill gas used. Some of the places making the best use of landfill gas include:

Jackson County, NC—Gas from a closed landfill warms a greenhouse where the county grows plants for public landscaping.

Sonoma County, CA—Landfill gas is compressed to natural gas and used to fuel the county's 45 public buses.

Columbus, OH—Compressed natural gas runs the landfill's 26 trash trucks.

Greer, SC—The plant that makes the BMW Roadster powers its paint shop with landfill gas.

concern, the Michigan legislature has enacted several laws that restrict the nature of the waste that can be imported into the state.

In March 2001, New York City closed its Fresh Kills Landfill on Staten Island. (It was reopened for a time following the September 11, 2001, terrorist attack to serve as a place to take the debris from the World Trade Center so that it could be processed.) Before its closure, it was the largest landfill in the world and received about 12,600 metric tons of trash each day. Today, New York City is exporting all of its solid waste to landfills in other parts of New York State, Pennsylvania, Virginia, and other states. In contrast to Toronto, which diverts about 40 percent of its waste, New York City diverts less than 20 percent of its waste.

Archaeologists rely on the waste of past societies to tell them about the nature of the culture and lifestyle of ancient civilizations. In the same way today, our municipal solid waste is a reflection of our society. Figure 17.3 shows how the composition of our trash has changed since 1960. Notice particularly the increase in the amount of paper and plastic and the effect that recycling has had on the amount of glass in the trash. In the United States, the two most common items in the waste stream are paper products and yard waste, and other significant segments are wood, metal, glass, plastics, and food waste. (See figure 17.4.) An analysis of the composition of our waste will present us with possible approaches to reducing the amount of waste we generate.

Methods of Waste Disposal

From prehistory through the present day, the favored means of disposal was simply to dump solid wastes outside of the city or village limits. Frequently, these dumps were in wetlands adjacent to a river or lake. To minimize the volume of the waste, the dump was often burned. Unfortunately, this method is still being used in remote or sparsely populated areas in the world. (See figure 17.5.)

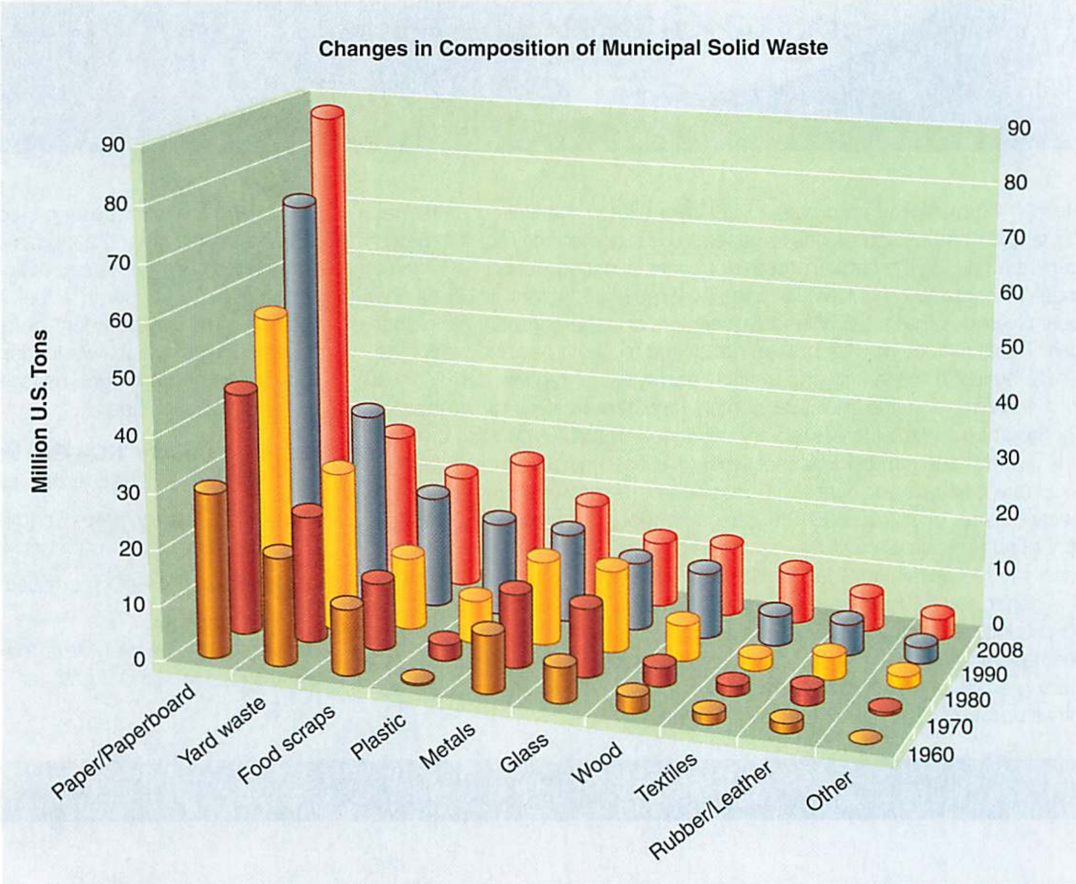
As better waste-disposal technologies were developed and as values changed, more emphasis was placed on the environment and quality of life. Dumping and open burning of wastes is no longer an acceptable practice from an environmental or health perspective. While the technology of waste disposal has evolved during the past several decades, our options are still limited. Realistically, there are no ways of dealing with waste that have not been known for many thousands of years. Essentially, five techniques are used: (1) landfills, (2) incineration, (3) composting, (4) source reduction, and (5) recycling.

Landfills

Landfills have historically been the primary method of waste disposal because this method is the cheapest and most convenient, and because the threat of groundwater contamination was not initially recognized. As we have recognized some of the problems associated

FIGURE 17.3 The Changing Nature of Trash Paper products are the largest component of the waste stream. Changes in lifestyle and packaging have led to a change in the nature of trash. Note the increase in the amount of plastics in the waste stream. Most of what is currently disposed of could be recycled.

Source: Data from the U.S. Environmental Protection Agency.



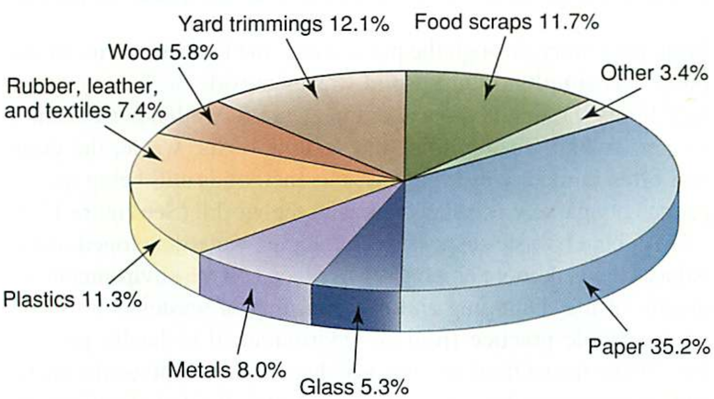


FIGURE 17.4 Composition of Trash in the United States (2008) Paper and yard waste are the most common materials disposed of, accounting for about 50 percent of the waste stream.

Source: Data from the U.S. Environmental Protection Agency.

with poorly designed landfills, efforts to reduce the amount of material placed in landfills have been substantial. Although the amount of waste has increased, composting and recycling have removed significant amounts of materials from the waste stream, and the amount of material entering landfills has declined. (See figure 17.6.) However, the landfill of today is far different from a simple hole in the ground into which garbage is dumped.

A modern **municipal solid waste landfill** is typically constructed above an impermeable clay layer that is lined with an impermeable membrane and includes mechanisms for dealing with liquid and gas materials generated by the contents of the landfill. Each day's deposit of fresh garbage is covered with a layer of soil to prevent it from blowing around and to discourage animals from scavenging for food. The selection of landfill sites is based on an understanding of local geologic conditions such as the presence of a suitable clay base, groundwater geology, and soil type. In addition, it is important to address local citizens' concerns. Once the site is selected, extensive construction activities are necessary to prepare it for use. New landfills have complex bottom layers to trap contaminant-laden water, called **leachate,** leaking through the buried trash. The water that leaches through the site must be collected and treated. In addition, monitoring systems are necessary to detect methane gas production and groundwater contamination. In some cases, methane produced by decomposing waste is collected and used to produce heat or to generate electricity. As a result of the technology involved, new landfills are becoming increasingly more complex and expensive. They currently cost up to $1 million per hectare ($400,000 per acre) to prepare. (See figure 17.7.)

Today, about 55 percent of the municipal solid waste from the United States and about 80 percent of Canadian municipal solid waste goes into landfills. The number of landfills is declining. In 1988, there were about 8000 landfills, and in 2008, there were

Water Connections

Landfills' Impact on Water

Although landfills are an indispensable part of our society, they may present long-term threats to groundwater and surface waters that are hydrologically connected. In the United States, federal standards to protect groundwater quality were implemented in 1991 and required some landfills to use plastic liners and collect and treat leachate. However, many disposal sites were either exempted from these rules or grandfathered (excused from the rules owing to previous usage).

There is an increasing belief among solid waste experts that unless further steps are taken to detoxify landfilled materials, today's society will be placing a burden on upcoming generations to address future landfill impacts.

The precipitation that falls into a landfill, coupled with any disposed liquid waste, results in the extraction of the water-soluble compounds and particulate matter of the waste, and the subsequent formation of leachate. The creation of leachate, sometimes called "garbage soup," presents a major threat to the current and future quality of groundwater.

It is for this reason that new landfills are required to have two or more liners and leachate collection systems above and between liners. Liners can be made of highly compacted clay and/or plastic that is nonpermeable. Landfills should also be strategically located well above the water table in a soil with a low permeability so as to help prevent further seepage of the leachate. These soils usually have a very high clay content.

FIGURE 17.5 **Burning Landfills** In the past, it was common practice to burn the waste in landfills to reduce the volume. Waste is still being burned in sparsely populated areas in North America and other parts of the world.

about 1625 active sanitary landfills. (See figure 17.8.) The number of landfills has decreased for two reasons. Many small, poorly run landfills have been closed because they were not meeting regulations. Others have closed because they reached their capacity. The overall capacity, however, has remained relatively constant because new landfills are much larger than the old ones.

A prolonged public debate over how to replace lost landfill capacity is developing where population density is high and available land is scarce. Selecting sites for new landfills in locations such as Toronto, New York, and Los Angeles is extremely difficult because of (1) the difficulty in finding a geologically suitable site and (2) local opposition, which is commonly referred to as the

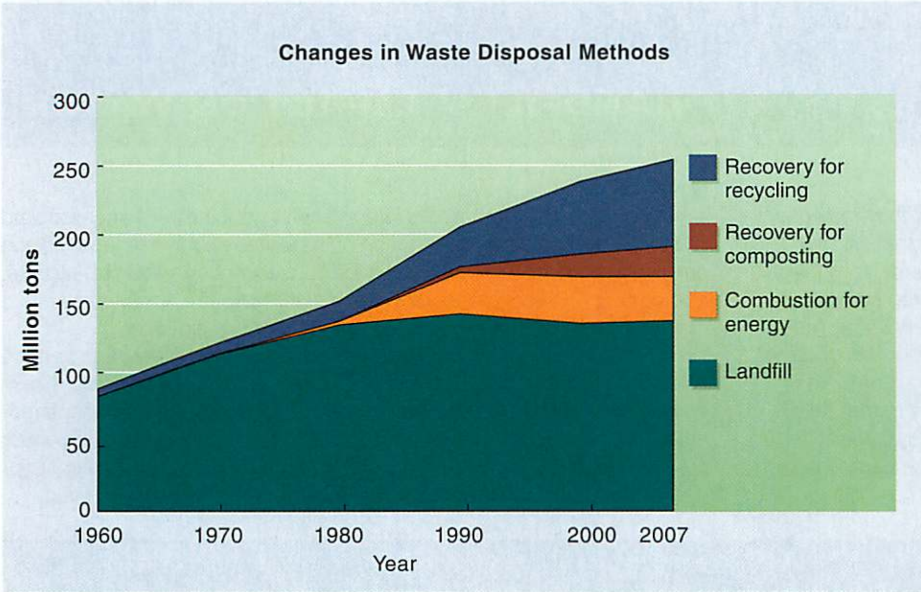


FIGURE 17.6 **Changes in Waste Disposal Methods** The landfill is still the primary method of waste disposal. Historically, landfills have been the cheapest means of disposal, but this may not be the case in the future. Notice that recycling and composting have grown over the past decade, while the amount of waste going to landfills has declined somewhat.
Source: Data from the U.S. Environmental Protection Agency.

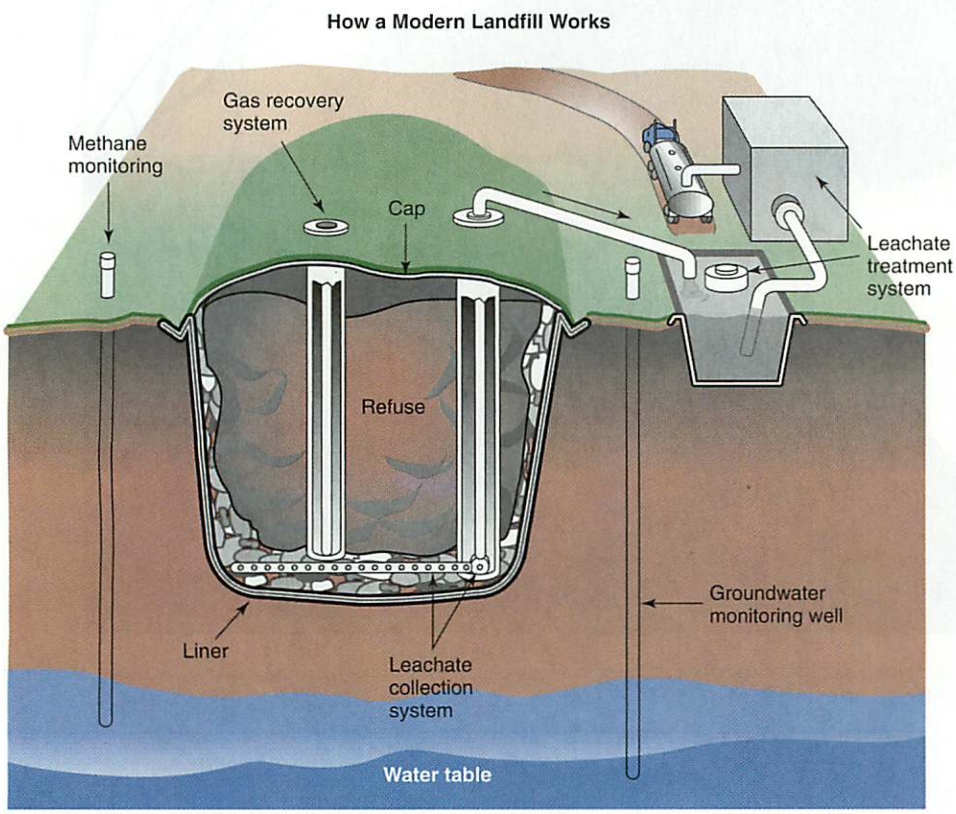


FIGURE 17.7 **A Well-Designed Modern Landfill** A modern sanitary landfill is far different from a simple hole in the ground filled with trash. A modern landfill is a self-contained unit that is separated from the soil by impermeable membranes and sealed when filled. Methane gas and groundwater are continuously monitored to ensure that wastes are not escaping to the air or the groundwater.
Source: National Solid Waste Management Association.

NIMBY, or "not-in-my-backyard," syndrome. Resistance by the public comes from concern over groundwater contamination, rodents and other vectors of disease, odors, and truck traffic. Public officials look for alternatives to landfills to avoid controversy over landfill site selection. Although sites must be chosen for new landfills, politicians are often unwilling to take strong positions that might alienate their constituents.

Japan and many Western European countries have already moved away from landfills as the primary method of waste disposal because of land scarcities and related environmental concerns. Switzerland and Japan dispose of less than 15 percent of their waste in landfills, compared to 55 percent in the United States. Instead, recycling and incineration are the primary methods. (See figure 17.9.) In addition, the energy produced by incineration can be used for electric generation or heating.

INCINERATION

Incineration is the process of burning refuse in a controlled manner. Today, about 15 percent of the municipal solid waste in the United States is incinerated; Canada incinerates about 8 percent. While some incinerators are used just to burn trash, most are designed to capture the heat, which is then used to make steam to produce electricity. The production of electricity partially offsets the cost of disposal. There are about 125 combustors with energy recovery in the United States, with the capacity to burn up to 96,000 metric tons of MSW per day. Most incineration facilities burn unprocessed municipal solid waste. This is often referred to as **mass burn** technology. About one-fourth of the incinerators use refuse-derived fuel—collected refuse that has been processed into pellets prior to combustion. This is particularly useful with certain kinds of materials, such as tires.

Incinerators drastically reduce the amount of municipal solid waste—up to 90 percent by volume and 75 percent by weight. Primary risks of incineration, however, involve air quality problems and the toxicity and disposal of the ash.

Modern incinerators have many pollution control devices that trap nearly all of the pollutants produced. However, tiny amounts of pollutants are released into the

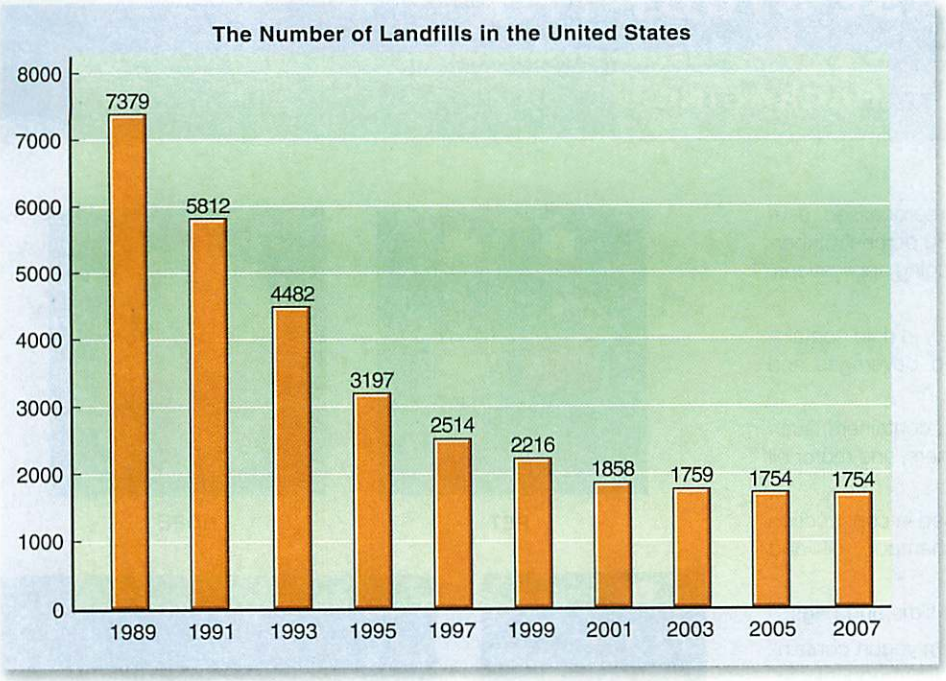


FIGURE 17.8 Reducing the Number of Landfills The number of landfills in the United States is declining because they are filling up or because some have been closed because their design and operation do not meet environmental standards.
Source: Data from the U.S. Environmental Protection Agency.

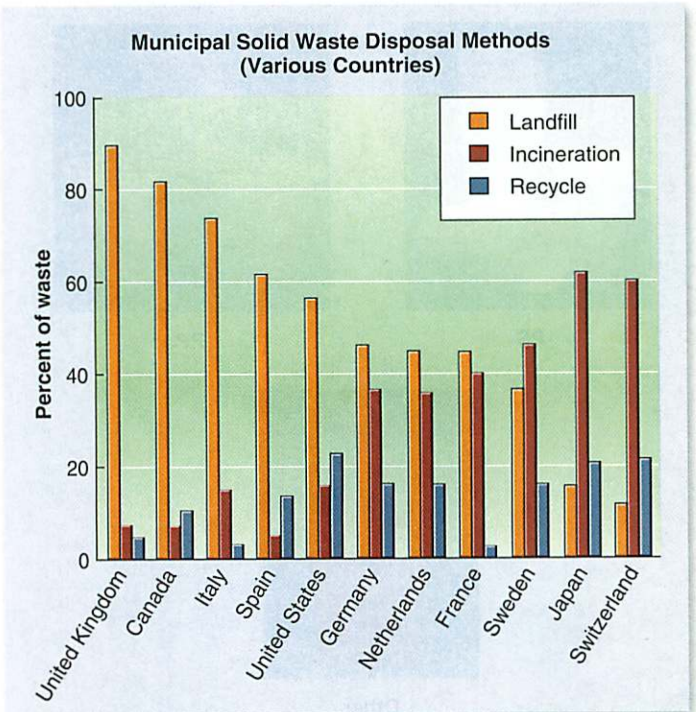


FIGURE 17.9 Disposal Methods Used in Various Countries Many countries have difficulty finding adequate space for landfills. Therefore, they rely on other technologies, such as incineration and recycling, to reduce the amount of waste that must be placed in a landfill.
Source: Data from the U.S. Environmental Protection Agency.

atmosphere, including certain metals, acid gases, and classes of chemicals known as dioxins and furans, which have been implicated in birth defects and several kinds of cancer. The long-term risks from the emissions are still a subject of debate.

Ash from incineration is also an important issue. Small concentrations of heavy metals are present in both the fly ash captured from exhaust stacks and the bottom ash collected from these facilities. Because the ash contains lead, cadmium, mercury, and arsenic in varying concentrations from such items as batteries, lighting fixtures, and pigments, the ash is tested to determine if it should be designated as a hazardous waste. This is a concern because the toxic substances are more concentrated in the ash than in the original garbage and can seep into groundwater from poorly sealed landfills. In nearly all cases, the ash is not designated as hazardous and can be placed in a landfill or used as aggregate for roads and other purposes.

The cost of the land and construction for new incinerators are also major concerns facing many communities. Incinerator construction is often a municipality's single largest bond issue. Incinerator construction costs in North America in 2000 ranged from $45 million to $350 million, and the costs are not likely to decline.

Incineration is also more costly than landfills in most situations. As long as landfills are available, they will have a cost advantage. When cities are unable to dispose of their trash locally in a landfill and must begin to transport the trash to distant sites, incinerators become more cost effective. The U.S. Environmental Protection Agency has not looked favorably on the construction of new waste-to-energy facilities and has encouraged recycling and source reduction as more effective ways to reduce the solid waste problem. Critics have argued that cities and towns have impeded waste reduction and recycling efforts by putting a priority on incinerators and committing resources to them. Proponents of incineration have been known to oppose source reduction. They argue that incinerators need large amounts of municipal solid waste to operate and that reducing the amount of waste generated makes incineration impractical. Many communities that have opposed incineration say that they support a vigorous waste-reduction and recycling effort.

Producing Mulch and Compost

Mulch is organic material that is used to cover the soil. It is often used to protect areas where the soil is disturbed or to control the growth of unwanted vegetation in certain kinds of plantings. Typically, large branches, bark, and other organic materials are chopped or shredded into smaller pieces. Mulches can be sorted by the size of the pieces and can be colored for decorative purposes. Since mulch is organic matter, it eventually breaks down and becomes part of the soil.

CASE STUDY 17.1

RESINS USED IN CONSUMER PACKAGING

Thermoplastics are plastics that can be remelted and reprocessed, usually with only minor changes in their properties. About 30 percent of thermoplastic resins produced are used in consumer packaging applications. The most commonly used resins are the following:

1. Polyethylene terephthalate (PET) is used extensively in rigid containers, particularly beverage bottles for carbonated beverages and medicine containers.
2. High-density polyethylene (HDPE) is used for rigid containers, such as milk and water jugs, household-product containers, and motor oil bottles.
3. Polyvinyl chloride (PVC) is a tough plastic often used in construction and plumbing. It is also used in some food, shampoo, oil, and household-product containers.
4. Low-density polyethylene (LDPE) is often used in films and bags.
5. Polypropylene (PP) is used in a variety of areas, from yogurt containers to battery cases to disposable diaper linings. It is frequently interchanged for polyethylene or polystyrene.
6. Polystyrene (PS) is used in foam cups, trays, and food containers. In its rigid form, it is used in plastic cutlery.
7. Other. These usually contain layers of different kinds of resins and are most commonly used for squeezable bottles (for example, for ketchup).

Currently, HDPE and PET are the two most commonly recycled resins because containers made of these resins are typically recovered by municipal recycling programs. Other plastics are less frequently accepted. Most of the recycled LDPE is from commercial establishments that receive large numbers of shipments wrapped in LDPE.

Recycling Rates for Plastic Resins Used in Packaging

Type of Plastic Resin	Percent Recycled (2007)
High-density polyethylene (HDPE)	25.6%
Polyethylene terephthalate (PET)	20.7%
Polypropylene (PP)	3.9%
Low-density polyethylene (LDPE) films	3–4%
Polyvinyl chloride (PVC)	Less than 1%
Polystyrene (PS)	Less than 1%

Source: Data from American Plastics Council.

PET

HDPE

PVC

LDPE

PS

PP

Other

Composting is the process of allowing the natural process of decomposition to transform organic materials—anything from manure and corncobs to grass and soiled paper—into compost, a humuslike material with many environmental benefits. In nature, leaves and branches that fall to the forest floor form a rich, moist layer that protects the roots of plants and provides a habitat for worms, insects, and a host of bacteria, fungi, and other microorganisms.

In composting operations, proper management of air and moisture provides ideal conditions for these organisms to transform large quantities of organic material into compost in a few weeks. A good small-scale example is a backyard compost pile. Green materials (grass, kitchen vegetable scraps, and flower clippings) mixed with brown materials (twigs, dry leaves, and soiled paper towels) at a ratio of 1:3 provide a balance of nitrogen and carbon that helps microbes efficiently decompose these materials.

Large-scale municipal composting uses the same principles of organic decomposition to process large volumes of organic materials. Composting facilities of various sizes and technological sophistication accept materials such as yard trimmings, food scraps, biosolids from sewage treatment plants, wood shavings, unrecyclable paper, and other organic materials. These materials undergo processing—shredding, turning, and mixing—and, depending on the materials, can be turned into compost in a period ranging from eight to 24 weeks. About 3800 composting facilities are in use in the United States. Roughly 62 percent of yard trimmings is converted into mulch or composted in the United States through municipal programs. (See figure 17.10.) Most municipal programs involve one of three composting methods: windrows, aerated piles, or enclosed vessels.

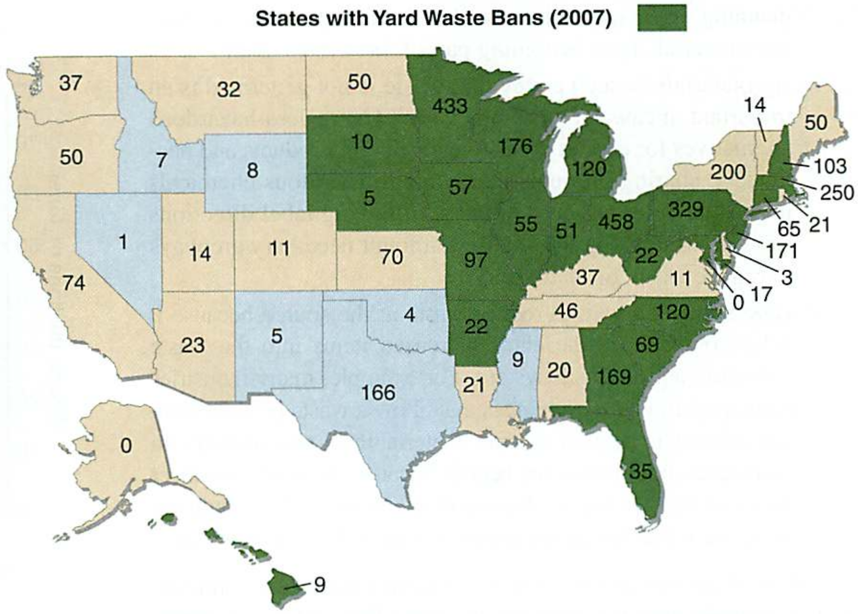


FIGURE 17.10 Diverting Yard Waste Through Composting Since yard waste is such an important segment of the solid waste stream, many states have passed laws that prohibit the deposition of yard waste in landfills. The states shown in green have laws that ban yard waste from going into a landfill. The states shaded blue have yard waste composting programs. This will extend the useful life of the landfill. To accommodate their citizens, many communities still collect yard waste but have instituted composting programs to deal with that waste. Even states that do not ban yard waste from landfills can extend the life of landfills by diverting yard waste to composting programs. The numbers on the map indicate the number of composting programs in each state.

Source: Data from the U.S. Environmental Protection Agency.

- *Windrow* systems involve placing the compostable materials into long piles or rows called windrows. Tractors with front-end loaders or other kinds of specialized machinery are used to turn the piles periodically. Turning mixes the different kinds of materials and aerates the mixture.
- *Aerated piles* are large piles of material that have air pumped through them (aeration) so that no mechanical turning or agitation is necessary. They also typically are covered with a layer of mature compost or other material to insulate the pile to keep it at an optimal temperature.
- *Enclosed vessels* can also be used to compost materials very rapidly (within days). However, these systems are much more technologically complex. In such systems, compostable material is fed into a drum, silo, or other structure where the environmental conditions are closely controlled, and the material is mechanically aerated and mixed.

In addition to keeping wastes from entering a landfill, composting has other significant benefits. The addition of compost to soil will improve it by making clay soils more porous or increasing the water-holding capacity of sandy soils. Nitrogen, potassium, iron, phosphorus, sulfur, and calcium are all common in compost and are beneficial to plant growth.

Source Reduction

Throughout the life cycle of a product—from extraction of raw materials, to transport to processing and manufacturing facilities, to manufacture and use—waste is generated. The simplest way to reduce waste is to prevent it from ever becoming waste in the first place. **Source reduction** is the practice of designing, manufacturing, purchasing, using, and reusing materials so that the amount of waste or its toxicity is reduced.

Design changes to soft drink bottles and milk jugs are good examples of source reduction. Since 1977, the weight of a 2-liter plastic soft drink bottle has been reduced from 68 grams (2.4 ounces) to 51 grams (1.8 ounces). That translates to 114 million kilograms (250 million pounds) of plastic per year that has been kept out of the waste stream. The weight of a plastic milk jug has been reduced 30 percent.

Manufacturing processes have been changed in many industries to reduce the amount of waste produced. One of the simplest ways to reduce waste is to pay careful attention to leaks, spills, and accidents during the manufacturing process. All of these incidents generate waste, and their prevention reduces the amount of raw material needed and the amount of waste generated.

Purchasing decisions can significantly reduce the amount of waste produced. In many cases, consumers and businesses can choose to purchase things that have reduced packaging waste. You can choose to purchase products in larger sizes so that the amount of waste produced is reduced. In addition, careful planning of the quantities purchased can prevent unused surplus materials from becoming part of the waste stream.

Using materials in such a way that waste is not generated is an important means of curbing waste. Using less-hazardous alternatives for certain items (e.g., cleaning products and pesticides), sharing products that contain hazardous chemicals instead of throwing out leftovers, following label directions carefully, and using the smallest amount necessary are ways to reduce waste or its toxicity.

Reusing items is a way to reduce waste at the source because it delays or prevents the entry of reused items into the waste collection and disposal system. For example, many industries participate in waste exchanges that allow a waste product from one industry to be used as a raw material in another industry. In such cases, both industries benefit because the waste producer does not need to pay to dispose of the waste and the industry using the waste has an inexpensive source of a raw material.

Most businesses and manufacturers have a strong economic incentive to make sure that they get the most from all the materials used in their operations. As regulations on the production of waste become more stringent, industries will need to become even more efficient. Most businesses also see the value in reducing waste disposal costs. Any activities that reduce the amount of waste produced reduce the cost of waste disposal, the amount of raw materials needed, and the amount of pollution generated. This economic incentive also works at the consumer level. In the United States, over 4000 communities have instituted "pay-as-you-throw" programs in which citizens pay for each can or bag of trash they set out for disposal rather than through the tax base or a flat fee. When these households reduce waste at the source, they dispose of less trash and pay lower trash bills.

Recycling

Recycling is one of the best environmental success stories of the late twentieth century. (See figure 17.11.) In the United States, recycling, including composting, diverted about 30 percent of the solid waste stream from landfills and incinerators in 2007, up from about 16 percent in 1990. Several kinds of programs have contributed to the increase in the recycling rate. Some benefits of recycling are resource conservation, pollutant reduction, energy savings, job creation, and reduced need for landfills and incinerators. However, incentives are needed to encourage people to participate in recycling programs. Several kinds of programs have been successful.

Container laws provide an economic incentive to recycle. (See the case study on Beverage Container Deposit-Refund Programs.) In October 1972, Oregon became the first state to enact a "bottle bill." The law required a deposit of two to five cents on all beverage containers that could be reused. It banned the sale of one-time-use beverage bottles and cans. One of the primary goals of the law was to reduce the amount of litter, and it worked. Within two years of when it went into effect, beverage-container litter decreased by about 49 percent.

Many argue that a national bottle bill is long overdue. A national bottle bill would reduce litter, save energy and money, and create jobs. It would also help to conserve natural resources. But the lobbying efforts of the soft drink and brewing industries are very strong, and Congress currently has failed to pass a national container law.

Mandatory recycling laws provide a statutory incentive to recycle. Many states and cities have passed mandatory recycling laws.

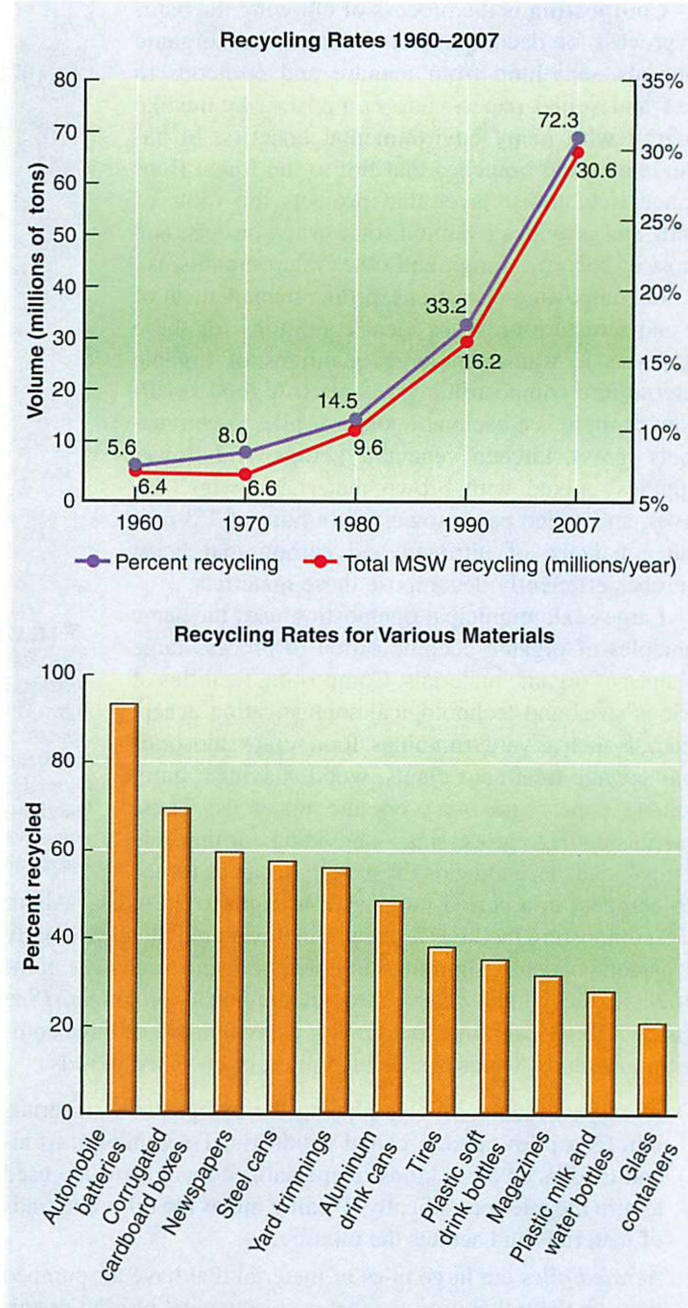


FIGURE 17.11 Recycling Percentage for Selected Materials (2005) and Recycling Rates from 1960–2007 Recycling rates for materials that have high value such as automobile batteries are extremely high. Other materials are more difficult to market. But recycling rates today are much higher than in the past as technology and markets have found uses for materials that once were considered valueless.

Source: Data from the U.S. Environmental Protection Agency, *Characterization of Municipal Solid Waste in the United States*, 2007.

CASE STUDY 17.2

BEVERAGE CONTAINER DEPOSIT-REFUND PROGRAMS

Container deposit-refund programs are among the original product stewardship programs. In a product stewardship program, the cost of the disposal or recycling of a product is included in the price of the product. Through legislation, a cash value in the form of a deposit is placed on the glass, aluminum, or plastic beverage container. With a cash value on each container, consumers have an incentive to return their containers for the redemption value regardless of where they are when they finish their beverages. If the containers are not returned then the cost of wasting has been paid by the consumer and can be used to cover the costs of proper collection and disposal of the container rather than passing this cost on to the public as a whole.

Deposit-refund laws are the most effective public or private recycling policies adopted over the past 30 years. The 11 states with bottle bills recycle more bottles and cans than the other 39 states combined and account for over 90 percent of the container recycling that occurs. Glass and other materials collected through deposit systems, unlike those collected through curbside recycling programs, are of a higher quality and are more marketable. The amount of the deposit also has an impact on the recovery rate. Michigan, the only state with a 10 cent deposit, also has the highest recovery rate: over 90 percent.

BEVERAGE CONTAINER WASTE IS A PROBLEM

In 2008, consumers in the United States failed to recycle an estimated 155 billion aluminum, glass, and plastic beverage containers. This is 33 percent more containers than were disposed of a decade ago. The problems associated with the disposal of these beverage containers are many:

- Glass, aluminum, and plastic containers disposed of in landfills and incinerators represent a loss of valuable resources and reduce employment opportunities in the domestic recycling industry.
- Disposal of these containers leads to increased greenhouse gas emissions and other forms of pollution when replacement containers are manufactured.
- Manufacturing aluminum cans from used cans requires only 4 percent of the energy compared to making new cans from bauxite ore.
- Beverage containers account for 40 percent of the total volume of litter on our roads and highways.

WHAT ARE THE CURRENT RECOVERY RATES?

Container recovery is down in the United States for aluminum and plastic containers even though the number of households with access to curbside recycling has increased 600 percent since the early 1990s.

- Aluminum recovery is down from a high of 65 percent in 1992 to 48 percent in 2008.
- Plastic bottle recovery is down from a high of 40 percent in 1995 to less than 20 percent in 2008.

WHAT IS CAUSING THIS DECLINE?

- More beverages are being consumed away from home, where consumers are less likely and less able to recycle.
- New types of beverages, including bottled waters and designer drinks, have been introduced into the market and are not accepted in some curbside or bottle bill programs. Of the 11 states with container deposits, only three states cover these new types of drinks and containers.
- In 2008, Chicago became the first major U.S. city to put a 5-cent tax on bottled water in an effort to encourage recycling and discourage consumption.

COMPARING OREGON AND WASHINGTON STATE'S CONTAINER DISPOSAL TONNAGES

In 1971, Oregon was the first state in the United States to pass a bottle bill. Oregon's bill requires that all beer, carbonated soft drink, and malt-based glass and aluminum beverage containers be returnable and have a minimum refund value. Oregon's 5-cent deposit begins with the distributor and is refunded to the customer when the empty container is returned. A current effort is underway in Oregon to raise the deposit to a dime to provide a better incentive to return the containers and to add the new drinks in plastic bottles to the deposit system.

A comparison was made between Washington and Oregon to see if there was a difference in the quantities of containers appearing in the garbage. The following data clearly show the impact of container deposits. As a percentage of the waste stream, Washington disposed of four times more aluminum cans and 2.5 times more glass bottles than Oregon. The percentages of plastic bottles are almost the same. Since only plastic soda bottles are a part of the Oregon system, it makes sense that they are similar to Washington numbers. The data show that Oregon residents throw away far fewer glass bottles and aluminum cans than Washingtonians.

Do you support beverage container deposit-refund programs? Should all beverage containers, including bottled water, be included in such programs? Who would be opposed to such laws? Why?

(See figure 17.12.) Some of these laws simply require that residents separate their recyclables from other trash. Other laws are aimed at particular products such as beverage containers and require that they be recycled. Some are aimed at businesses and require them to recycle certain kinds of materials such as cardboard or batteries. Finally, some laws forbid the disposal of certain kinds of materials in landfills. Therefore, the materials must be recycled or dealt with in some other way. For example, banning yard waste from landfills has resulted in extensive composting programs.

Those states and cities with mandatory recycling laws understandably have high recycling rates. For example, California mandated 50 percent diversion of waste through recycling and other

CAMPUS SUSTAINABILITY INITIATIVE

Recycling Partnership at Northern Arizona University

Through a partnership with the city of Flagstaff, Arizona, Northern Arizona University (NAU) has significantly reduced waste by increasing the amount of material that is recycled. Before the partnership began in 2005, NAU diverted an average of 4 tons of material per week from the landfill through its recycling program. The partnership with Flagstaff allows an average of 21 tons of recyclables to be diverted from the landfill. Thirteen percent of the city of Flagstaff's total recycled material now comes from NAU. By diverting 17 additional tons per week from the landfill, it is estimated that there is a reduction of greenhouse gas emissions by 1128 metric tons per year, the equivalent of removing 862 cars from Flagstaff streets. It is also estimated that 39,742 BTUs of energy are saved and waterborne wastes are reduced by 4.2 metric tons per year.

The NAU partnership with the city allowed the university to co-mingle its recyclables. The city hauls mixed recyclables from campus to an independent facility where workers separate them. Glass and food waste must still be separated; however, other recyclables need not be separated. The economic benefits of the new program are significant. A total of $100,000 was saved in the first year of the partnership primarily by reducing labor and landfill costs. The program also benefits the greater Flagstaff community by reducing air and water pollution. As an added bonus, the lifespan of the city landfill, which was scheduled to close in 2017, has been significantly extended. NAU's increased recycling efforts have contributed to keeping the landfill open an additional 23 years until 2040.

FIGURE 17.12 Mandatory Recycling Many states and cities have passed mandatory residential recycling laws.

means by 2001. Although many cities did not meet the goal, by 2004, the statewide recycling rate was 49 percent.

Curbside recycling provides a convenient way for people to recycle. In 1990, a thousand U.S. cities had curbside recycling programs. By 2008, the number had grown to about 11,000 cities. By 1999, mandatory recycling laws for all materials had been passed in 15 states. In Canada, Toronto, Mississauga, and the province of Ontario have comprehensive recycling programs.

Some large cities—such as Portland, Oregon; San Jose, California; Los Angeles, California; and Minneapolis, Minnesota—have achieved recycling rates of 50 percent or more. In general, these cities have curbside recycling and accept a wide variety of materials, including junk mail and cereal boxes. By contrast, cities that do not provide curbside recycling, such as El Paso, Texas, and Detroit, Michigan, have recycling rates of less than 10 percent.

Although environmentally concerned citizens have been pushing recycling for many years now, and curbside pickup is increasingly the norm, recycling rates in North America still remain low. In an effort to increase those rates, a former management consultant co-founded RecycleBank in 2004. RecycleBank is based on a simple idea that people want to recycle, but they just need a little push. So why not appeal to their pocketbook? RecycleBank works like this: Every family on a garbage route is issued a special container with a computer chip. When garbage trucks pick up the recycling, they weigh the container and record by weight how much each family is recycling. The more you recycle, the more RecycleBank points you earn, which can be redeemed for offers at merchants like CVS/pharmacy.

Since RecycleBank launched in Philadelphia in 2006, its formula has led to success everywhere it has gone—and it now operates through much of the Northeast United States. Recycling rates in one of the first Philadelphia neighborhoods that RecycleBank served rose from 7 percent to 90 percent in a matter of months and the total waste sent to landfills is down considerably. RecycleBank's success is not just the economic incentive—it is also a sense of accomplishment. Families can now track how much they recycle. Metrics do matter—measuring something is often the first step to encouraging better behavior.

In 2008, RecycleBank went after a new target: college campuses. Starting with a pilot program at New City's Columbia University, RecycleBank is putting special kiosks in cafeterias and dorms. Students get a RecycleBank card and take their recycling to the closest kiosk, where they swipe their card, weigh their recycling, and claim their points. RecycleBank is being actively pursued by venture capitalists and will likely expand in the years to come.

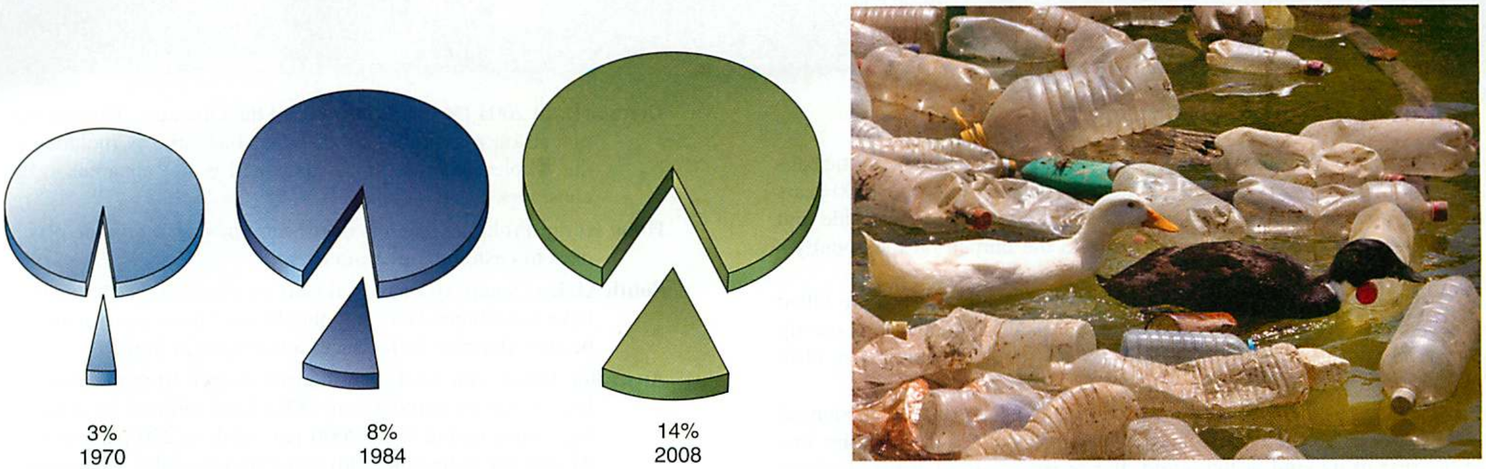


FIGURE 17.13 Increasing Amounts of Plastics in Trash Plastics are a growing component of municipal solid waste in North America. Increased recycling of plastics could reverse this trend. As the photo shows, many plastic bottles are not recycled or properly disposed of.
Source: Data from Franklin Associates, Ltd.

Recycling Concerns

Although recycling programs have successfully reduced the amount of material that needs to be trucked to a landfill or incinerated, there are many technical and economic problems associated with recycling. Technical questions are of particular concern when recycling plastics. (See figure 17.13.) While the plastics used in packaging are recyclable, the recycling technology differs from plastic to plastic. There are many different types of plastic polymers. Since each type has its own chemical makeup, different plastics cannot be recycled together. A milk container is likely to be high-density polyethylene (HDPE), while an egg container is polystyrene (PS), and a soft-drink bottle is polyethylene terephthalate (PET).

Plastic recycling is still a relatively new field. Industry is researching new technologies that promise to increase the quality of plastics produced from recycled materials and that will allow mixing of different plastics. Until such technology is developed, separation of different plastics before recycling will be necessary.

The economics of recycling are also a primary area of concern. The stepped-up commitment to recycling in many developed nations has produced a glut of certain materials on the market. Markets for collected materials fill up just like landfills. Unless the demand for recycled products keeps pace with the growing supply, recycling programs will face an uncertain future. The prices for selected recycled materials are listed in figure 17.14. Prices for materials can vary widely from year to year, depending on demand.

Markets for materials collected in recycling programs grew dramatically during the 1990s. The establishment of a recyclables exchange on the Chicago Board of Trade allows for consumers and producers of recyclable materials to participate in an efficient market so that it is less likely that recyclable materials will be left unclaimed.

The long-term success of recycling programs is also tied to other economic incentives, such as taxing issues and the development of and demand for products manufactured from recycled material. Government policies need to be readjusted to encourage recycling efforts. Such policies as subsidizing the building of roads for extracting timber, taxing forest land at low rates, or selling trees from federal lands at low prices artificially lower the cost of virgin forest materials compared to recycled materials. Such policies severely inhibit the cost-effectiveness of paper recycling. In addition, on an individual level, we can have an impact by purchasing products made from recycled materials. The demand for recycled products must grow if recycling is to succeed on a large scale.

Recycling Composite Prices

		1999	2008
Metal			
Ferrous ($/ton)	Used steel cans	71	335
Nonferrous (¢/lb.)	Aluminum cans	50	87
	Auto batteries	6	5
Plastic (¢/lb.)			
	Green PET	7	21
	Clear PET	6	22
	Mixed HDPE	9	19
Paper ($/ton)			
	Corrugated	92	96
	Newspaper	31	82
	High-grade office	93	167
	Computer laser	163	232
Glass ($/ton)			
	Clear	39	29
	Green	14	8
	Brown	24	17

FIGURE 17.14 Recycling Composite Prices Prices for materials can vary widely from year to year, depending on demand.
Source: Data from American Metal Market LLC, a division of Metal Bulletin Plc.

ISSUES & ANALYSIS

Paper or Plastic or Plastax?

Before 2002 Ireland's 3.9 million people were using 1.2 billion plastic bags per year. These bags were generally nonrecyclable, took 20 to 1000 years to break down in the environment, were littering the countryside and clogging storm drains, and were adding to the burden on the country's landfill sites.

Worldwide some 100,000 birds, whales, seals and turtles are killed as a result of suffocating on plastic bags. Ireland's population is mostly rural, and its waste disposal system is poorly funded, making it an ideal place for this kind of initiative.

The idea of the "plastax" or tax on plastic bags was first announced in 1999 and in 2002 the environment minister launched the program, one of the first of its kind in the world. For every bag used at the checkout counter of the supermarket a 15 euro cents (about 25 U.S. cents) surcharge was added. The revenue raised from this tax would be put toward a "green fund" for environmental projects such as recycling refrigerators and other large appliances.

In 2008, China banned free plastic bags from shops and supermarkets. The bags are also banned from all public transportation, including buses, trains, and planes and from airports and scenic locations. The Chinese were using 3 billion plastic bags every day, which accounted for 3 to 5 percent of the total weight of landfills. It is estimated that it took 37 million barrels of crude oil a year to make all the bags needed for China.

In the United States, which has less than one-quarter of China's 1.3 billion people, almost 100 billion plastic bags are thrown out each year. Over 12 million barrels of oil are needed to manufacture the bags, of which only a fraction make it to the recycling bin. It is estimated that if every one of New York City's 8 million people used one less grocery bag per year, it would reduce waste by about 220,000 pounds. In 2008, San Francisco became the first major U.S. city to ban petroleum-based plastic bags in large grocery stores and drugstore chains. Plastic bags had previously been banned in at least 30 remote Alaskan villages.

Other countries have enacted various controls or bans on plastic bags, including the following:

Bangladesh: Banned the manufacturing and distribution of plastic bags in 2003 after it was found that they were blocking drainage systems and had been a major problem during the 1988 and 1998 floods that submerged two-thirds of the country.

Denmark: In 2004 Denmark introduced the Greentax. This tax was placed on plastic bags and paper bags and is included in the wholesale price of the bags and is not apparent to the consumer.

Hong Kong: Prohibits retailers over a certain size to provide plastic bags to customers free of charge.

South Africa: South Africa passed a tax on plastic bags. Plastic bags have been dubbed the "national flower" because so many can be seen flapping from fences and caught in bushes.

Australia: IKEA—the retailer introduced its own 10 cent plastic bag levy. Since its introduction, IKEA have reduced their plastic bag consumption from 8000 per week to 250 per week—a 97 percent reduction. Aldi supermarkets—this supermarket chain charges for plastic bags and provides four options for customers to carry their goods. These are: 15 cent plastic bag; 69 cent cotton bag; $1.49 cooler bag; reused boxes (free); or no bag or own bag. The most common option chosen is the reused boxes, or for small purchases no bags.

India: In the Delhi Capital Territory, legislation makes the use of non-biodegradable plastic bags a punishable offense.

Mauritius: This nation has banned the import or local manufacture of non-degradable plastic bags, and has specified that only oxo-biodegradable can be considered degradable.

Malta: Malta charges a lower tax on bags made from degradable plastic.

Barbados: Barbados charges 60 percent import surtax on non-degradable plastic bags but only 15 percent on oxo-biodegradable plastic bags.

Japan: Almost any store you visit in Japan, from convenient stores to street vendors, will also net you a free plastic bag for your purchase. Although there are some supermarkets (like Kyoto Co-op) which charge for plastic bags, this is by no means the norm. Many supermarkets (like Izumiya) will give you extra points on your point-card if you bring your own bag.

- Do you think your community would support such a tax?
- Would you favor a tax on plastic bags?
- How would a ban on plastic bags alter your lifestyle?

SUMMARY

Municipal solid waste is managed by landfills, incineration, composting, waste reduction, and recycling. Landfills are the primary means of disposal; however, a contemporary landfill is significantly more complex and expensive than the simple holes in the ground of the past. The availability of suitable landfill land is also a problem in large metropolitan areas.

About 15 percent of the municipal solid waste in the United States is incinerated. While incineration does reduce the volume of municipal solid waste, the problems of ash disposal and air quality continue to be major concerns. There are several forms of composting that can keep organic wastes from entering a landfill.

The most fundamental way to reduce waste is to prevent it from ever becoming waste in the first place. Using less material in packaging, reusing items, and composting yard waste are all examples of source reduction. On an individual level, we can all attempt to reduce the amount of waste we generate.

About 30 percent of the waste generated in North America is handled through recycling. Recycling initiatives have grown rapidly in North America during the past several years. As a result, the markets for some recycled materials have become very volatile. Recycling of municipal solid waste will be successful only if markets exist for the recycled materials. Another problem in recycling is the current inability to mix various plastics.

Future management of municipal solid waste will be an integrated approach involving landfills, incineration, composting, source reduction, and recycling. The degree to which any option will be used will depend on economics, changes in technology, and citizen awareness and involvement.

THINKING GREEN

1. Buy things that last, keep them as long as possible, and have them repaired, if possible.
2. Buy things that are reusable or recyclable, and be sure to reuse and recycle them.
3. Use plastic or metal lunch boxes and metal or plastic garbage containers without throwaway plastic liners.
4. Use rechargeable batteries.
5. Skip the bag when you buy only a quart of milk, a loaf of bread, or anything you can carry with your hands.
6. Recycle all newspaper, glass, and aluminum, and any other items accepted for recycling in your community.
7. Reduce the amount of junk mail you get. This can be accomplished by writing to Mail Preference Service, Attn: Dept: 13885751, Direct Marketing Association, P.O. Box 282, Carmel, NY 10512. Ask that your name not be sold to large mailing-list companies. You may also register on-line by going to the website. Type Mail Preference Service into your browser. Of the junk mail you do receive, recycle as much of the paper as possible.
8. Push for mandatory trash separation and recycling programs in your community and schools.
9. Compost your yard and food wastes, and pressure local officials to set up a community composting program.

WHAT'S YOUR TAKE?

The growth of recycling programs has been pushed in part by municipalities' need to reduce waste and by the satisfaction people feel in taking the responsibility to recycle. These two forces have driven recycling's rise in spite of the fact that it has often not been financially profitable. In fact, many of the increasingly popular municipal recycling programs are run at an economic loss. Formulate an argument that justifies the continuation of a community recycling program that currently operates at a loss.

REVIEW QUESTIONS

1. How is lifestyle related to the quantity of municipal solid waste generated?
2. What conditions favor incineration over landfills?
3. Describe some of the problems associated with modern landfills.
4. What are four concerns associated with incineration?
5. Describe examples of source reduction.
6. Describe the importance of recycling household solid wastes.
7. Name several strategies that would help to encourage the growth of recycling.
8. Describe the various types of composting and the role of composting in solid waste management.

Critical Thinking Questions

1. How can you help solve the solid waste problem?
2. Given that you have only so much time, should you spend your time acting locally, as a recycling coordinator, for example, or advocating for larger political and economic changes at the national level, changes that would solve the waste problems? Why? Or should you do nothing? Why?
3. How does your school or city deal with solid waste? Can solid waste production be limited at your institution or city? How? What barriers exist that might make it difficult to limit solid waste production?
4. It is possible to have a high standard of living, as in North America and Western Europe, and not produce large amounts of solid waste. How?
5. Incineration of solid waste is controversial. Do you support solid waste incineration in general? Would you support an incineration facility in your neighborhood?