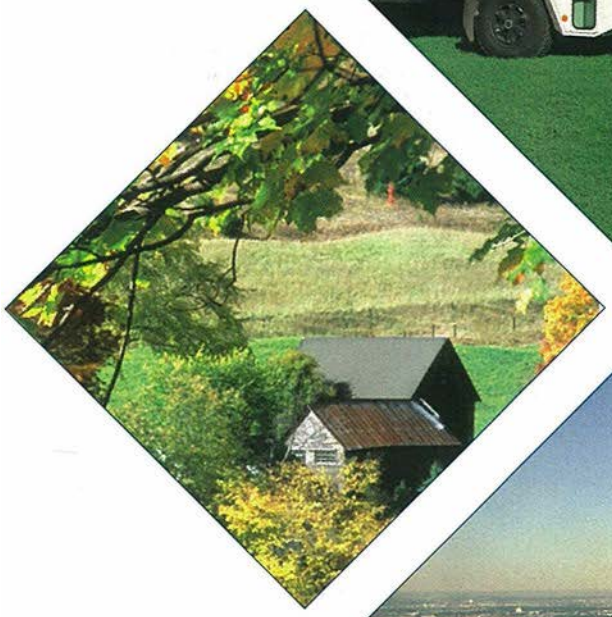

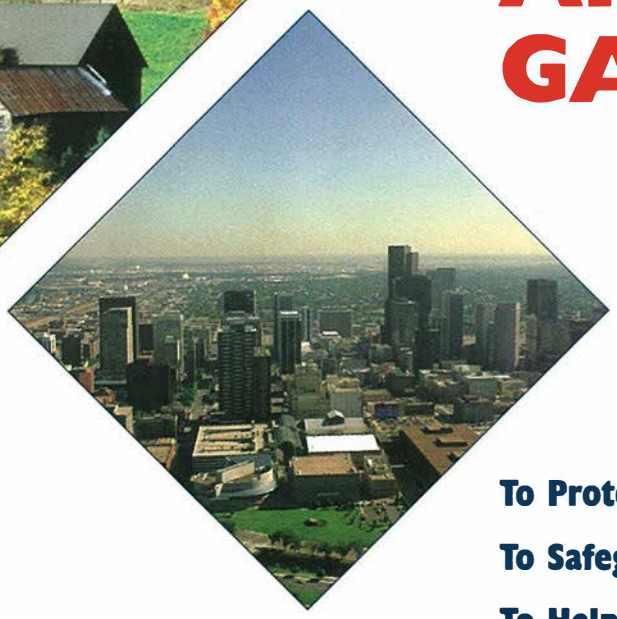

MANAGING AMERICA'S GARBAGE

To Protect the Environment

To Safeguard Public Health

To Help Create Strong Communities

March 1996

DRAFT FINAL REPORT

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THE GARBAGE CHALLENGE

Americans produced 207 million tons of garbage in 1993, according to the U.S. Environmental Protection Agency (EPA). The garbage included just about everything Americans used and threw away: glass containers, paper and plastic packaging, newspapers, broken toys, food scraps, steel cans, grass clippings, old televisions, worn-out appliances, office paper, textiles, cardboard boxes, tires, paper plates, plastic spoons, disposable diapers, aluminum cans, and more.

Americans didn't worry very much about all that trash. They simply filled up their trash cans and recycling bins and set them out for the local garbage collector. Few realized that each of us threw away about 4.4 pounds of garbage every day. Besides, that's not much, is it? Actually, it's more than 1,600 pounds a year and there are 260 million of us doing it. What's more, public works managers must do something with all this trash.

Therein lies the challenge. A small city with 100,000 people must dispose of more than 1,500 tons of municipal solid waste (MSW) every week. A metropolitan area with 1 million inhabitants has to manage more than 15,000 tons of MSW. Throughout the nation, American waste management professionals handle more than six million tons of solid waste a week — about two million tons a week more than EPA's estimate, according to *BioCycle* magazine.

It turns out that there are about 100 million tons of industrial, agricultural, and construction wastes that aren't officially counted as MSW, but get managed with it anyway. When writers at *BioCycle* asked each state for information about the total amount of waste landfilled or recycled in 1993, they discovered that the amount of waste actually managed as MSW totaled 307 million tons! In 1994, it was 323 million tons. Remarkably, total waste generation was probably even higher. Because many companies manage their own nonhazardous wastes on site, these wastes were not counted as part of *BioCycle's* estimate.

The amount of solid waste produced each year has either doubled or tripled (depending on whose numbers you use) from 88 million tons in 1960 (See Figure 1). There are several reasons why this has happened. To begin with, 80 million more Americans throw things away today than discarded trash in 1960. We use more paper and plastic packaging now than ever before in history. The use of office paper has mushroomed in the wake of computers and copy machines. Disposable items (such as diapers and razors) are a big hit with consumers. And, people have more money to spend.

Municipal Solid Waste Generation in the United States, 1960-1995

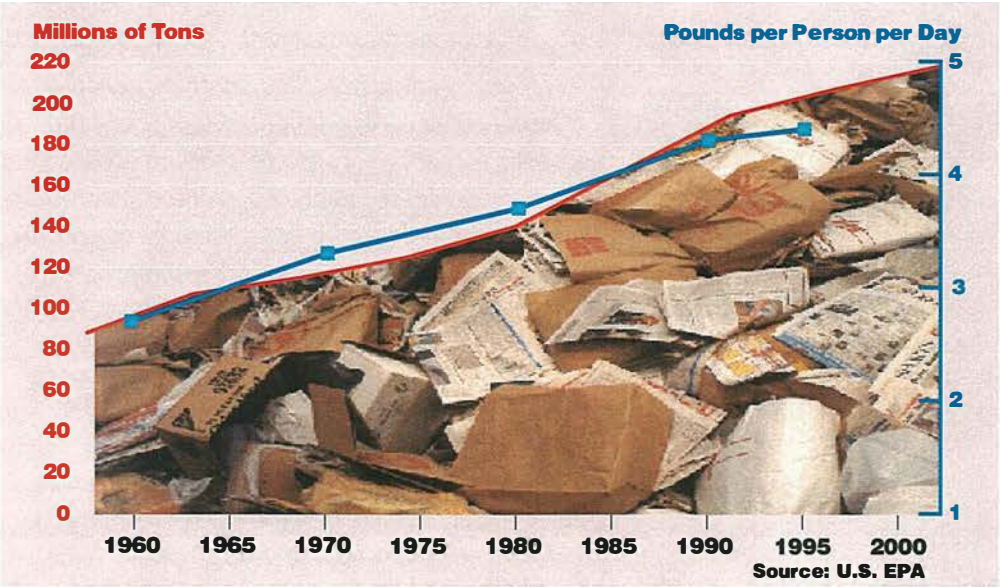


Figure 1.

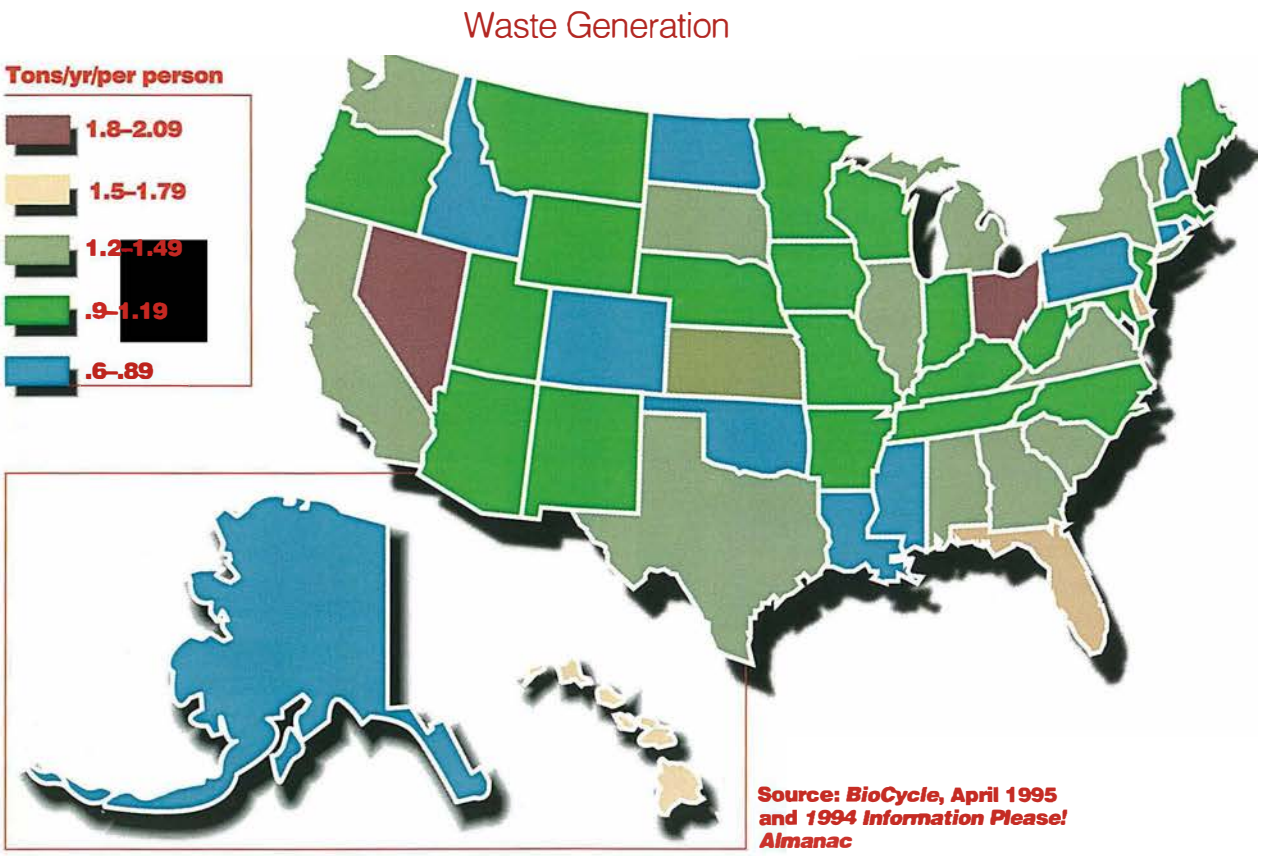


Figure 2.

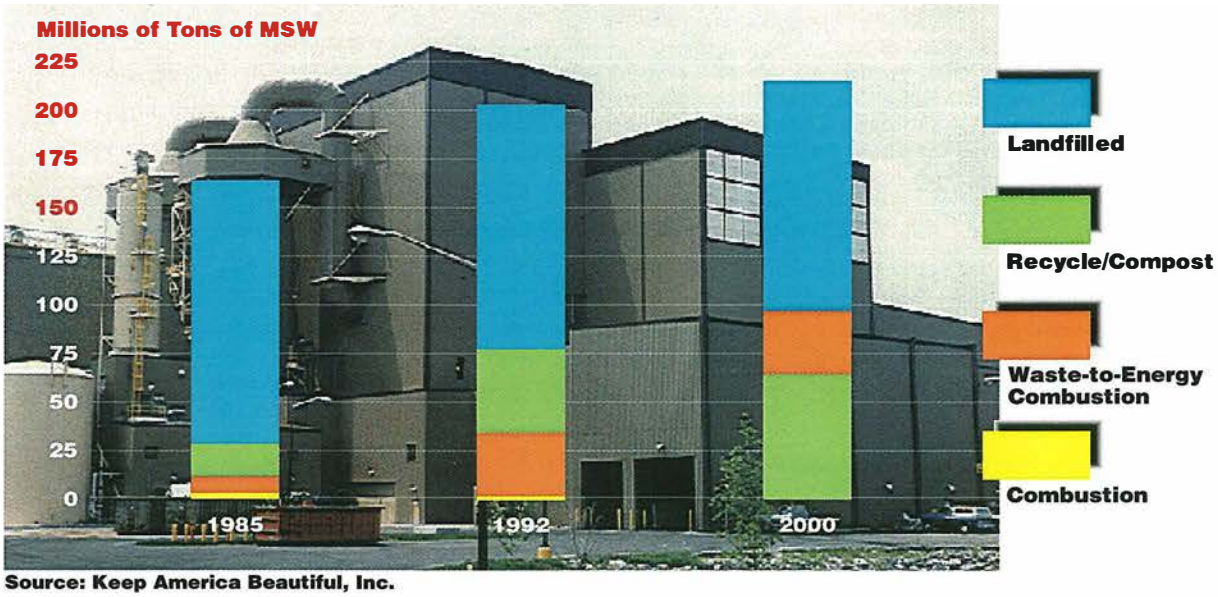
Taken together, these factors fueled a steady increase in the amount of solid waste generated in the United States. Per capita solid waste generation grew from 2.7 pounds per day in 1960 to today's record 4.4 pounds per day, according to EPA estimates. (*BioCycle's* numbers put per capita waste generation at more than 6.8 pounds per day!) But, there is a bright spot in this picture: Per capita waste generation is now holding steady; by 2000, it may even fall slightly. Figure 1 highlights these trends in U.S. solid waste generation.

Until just a few years ago, the economy determined how much garbage we threw away. Every time the economy flourished, Americans produced more trash. Per capita waste generation is finally leveling off because efforts to minimize wastes and encourage recycling have stopped the upward spiral. Reducing the garbage we throw away each year remains an elusive goal, however.

Figure 2 shows per capita waste generation for each state. However, there are no hard data on exactly what's being managed as MSW. There's no way to tell whether people in states with higher generation rates are really creating more waste than the rest of us. A good guess is that some states throw more industrial, construction, or agricultural wastes into MSW landfills than others. Unfortunately, guessing is the best that can be done, unless we as a society make it a priority to gather adequate information regarding the amounts and kinds of wastes Americans produce and manage as municipal solid waste.

The good news is that most solid waste is managed responsibly. Thanks to government regulation and improved technology, waste management professionals work to safeguard the public's health and prevent pollution as part of their jobs. Solid waste management no longer includes incinerators without emissions controls, ocean dumping, or city dumps teeming with vermin and leaching toxic chemicals into nearby wells and rivers. Even so, there are still problems to be solved in waste management: litter remains a chronic problem; some older landfills continue to threaten groundwater quality; landfills discharge methane, a potent greenhouse gas, into the atmosphere; and the environmental impacts of recycling have yet to be quantified or addressed.

MSW Management 1985-2000



Source: Keep America Beautiful, Inc.

Figure 3.

Figure 3 depicts changes in MSW management since 1985. Today's waste management systems work far better than those Americans relied upon in 1960. But, they are expensive.

Solid Waste Is Good Business

The U.S. solid waste industry has proven that it's possible to do right by the environment *and* make a profit. The nation's three largest solid waste companies offer garbage collection, waste hauling, and disposal services. This winning combination produced combined revenues for the firms in excess of $17 billion in 1994. More than 50 smaller companies, each with annual sales of millions of dollars, also provide waste management, disposal, and resource recovery services. Of these, about 30 specialize in the recovery or remanufacturing of wastes.

The nation paid private industry about $54.2 billion for managing America's trash in 1994. Figure 4 shows the sectors that profited from trash. Private MSW collection, transportation, and disposal cost America's cities $31 billion. Consulting engineering brought total private disposal costs to $32.25 billion. Resource recovery, now growing at a rate of 15.8% per year, brought in just under $15 billion in revenues. Equipment, instruments and computer systems accounted for the remainder.

The actual cost of waste management was even higher. Many municipalities paid staff to collect, transport, and dispose of their trash rather than contracting with industry. Unfortunately, total costs for these services aren't readily available. It is possible to get a rough idea of the portion of municipal waste management provided by municipal staff and by industry from Table 1, however. The table is based upon a 1989 survey by the American Public Works Association.

Who performs waste management functions?

Function	Municipal Staff (%)	Contract (%)
Special Rubbish Collection	59	41
Landfill Operation	49	51
Transfer Station Operation	42	58
Residential Waste Collection	38	62
Recycling Collection	37	63
Commercial Waste Collection	27	73
Waste Combustor Operation	26	74
Recycling Processing	23	77

Source: American Public Works Association

Table 1.

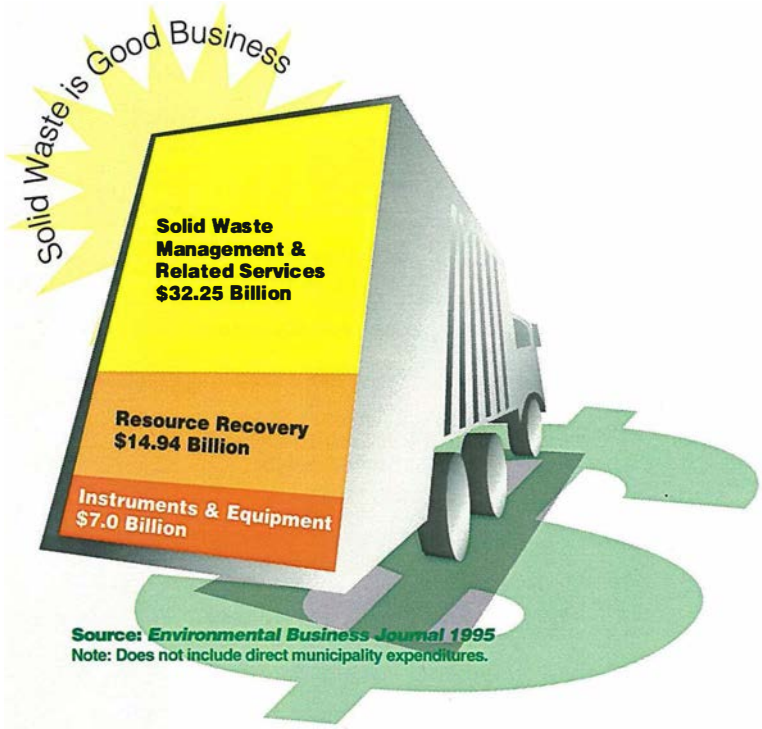


Figure 4.

Today, waste management is moving in a different direction than it did just a decade ago. In 1989, revenues from solid waste disposal were growing at 13% per year, rather than the current 5.4%. Modern, well-designed landfills and waste-to-energy plants were opening across the nation to replace open dumps and incinerators. Recycling was growing at just 4% per year. Seven years ago, the nation was concentrating on providing safer, more environmentally responsible solid waste disposal. In most cities, recycling was in its infancy. It was considered an expensive alternative to traditional waste management methods. Although Americans talked a lot about conserving resources and reducing waste, their behavior hadn't followed suit.

Today, Americans have had enough time to digest these ideas and bring them into reality. More than 40% of Americans have access to curbside recycling programs. Recycling's supporters include waste management professionals, industry, universities, politicians on both sides of the aisle, and ordinary people from all walks of life. Supported by the steady growth of waste diversion programs, market prices for recovered materials rose in 1994.

The emphasis on resource recovery has helped people to see their wastes as resources for materials and energy. Leaders from the public and private sectors are talking about making waste-management planning part of manufacturing, transportation, and other segments of the economy. In the past, public works managers simply scrambled to dispose of wastes as they appeared. Because there was no mechanism to help people make the connection between the production of goods and services and wastes, there was no easy solution for the waste problem once it got out of control. Instead, the nation had to resort to punitive measures designed to remedy years of environmental neglect.

Regulation of Solid Waste Management

Government regulation of solid waste management played a critical role in bringing waste management systems up to the standard we enjoy today. Even so, regulations promise far fewer benefits in the future. Regulations address only a small piece of what is a large and complex waste management system. They are a poor way to improve the whole system. For this reason, regulation is rapidly giving way to a new paradigm that envisions an enduring economic system that values both the environment and industrial growth. In such a system, pollution prevention, waste minimization, and recycling would be orchestrated by a prosperous, environmentally conscious business community.

In a sense, the regulations themselves sowed the seeds for this emerging "green" business community. A multibillion-dollar industry grew up to produce the technologies required to correct specific problems such as air emissions and groundwater pollution. Regulated industries discovered that taking care of the environment made them more, not less, profitable. And, American industry as a whole recognized that conserving materials and energy not only produced fewer wastes, it also increased profit margins.

Even as industry is recognizing the benefits of protecting the environment, regulations are beginning to create real barriers to further growth. A good example exists within the waste-to-energy industry. In late 1995, the government issued additional restrictions on emissions of dioxin, a cancer-causing chemical that has other deleterious health impacts. However, the regulation targeted emissions from waste-to-energy plants and ignored other larger dioxin sources.

Concise History of Federal Municipal Solid Waste Management Program

1963	**Clean Air Act**, which allocates $95 million to air pollution control.
1965	**The Solid Waste Disposal Act** (enacted as Title 2 of the Clean Air Act amendments) recognizes refuse disposal as a national problem, launches a federal MSW research and development program, and sets up grants to states and municipalities for new disposal programs. The Public Health Service and the Bureau of Mines are given enforcement responsibility for the law.
1969	**National Environmental Policy Act** creates the Council of Environmental Quality, with responsibility for national policy on waste generation and disposal.
1970	The nation celebrates the first **Earth Day** on April 22.
	The Environmental Protection Agency established. The agency brings together environmental divisions from the Public Health Service, the Departments of Agriculture and Interior, and other federal agencies. Since 1970, EPA has provided information on solid waste management and sponsored research on MSW collection, disposal, and recycling.
	The **Clean Air Act** grants the federal government broad regulatory powers to protect and enhance air quality. The law will have tremendous impact on incinerator operations.
	The **Resource Recovery Act** amends the Solid Waste Disposal Act, shifting emphasis in the federal program from disposal to resource recovery. It gives federal jurisdiction over hazardous wastes. It will help municipalities improve landfill practices.
1972	The **Marine Protection Research and Sanctuaries Act** attempts to curtail ocean dumping, but will meet with little success.
	The **Water Pollution Control Act** creates a program to protect and enhance the nation's ground and surface waters. It will impact most waste management methods, including landfilling, composting, recycling, and energy recovery.
1974	The **Energy Reorganization Act** mandates the formation of the Nuclear Regulatory Commission and the Energy Research and Development Administration (ERDA), whose mission is to develop domestic energy resources.
	The **Non-Nuclear Research and Development Act** mandates federal research on the productive use of wastes.
	The **Solar Energy Research, Development and Demonstration Act** mandates the establishment of a **Solar Energy Research Institute** (now the **National Renewable Energy Laboratory**) to accelerate the development of solar energy technologies, including waste-to-energy conversion.
1975	The newly chartered **Energy Research and Development Administration** assumes responsibility for the nation's renewable energy R&D, including energy recovery from municipal solid waste.
1976	The **Resource Conservation and Recovery Act (RCRA)** establishes a federal involvement in solid waste management and emphasizes aid to states and municipalities in resource recovery and planning. This law divides waste into two categories, hazardous and nonhazardous. It directs EPA to develop criteria for distinguishing sanitary landfills from open dumps.
1977	Congress creates the **U.S. Department of Energy (DOE)** to broaden federal control over energy, including energy from waste. DOE delegates responsibility to managing MSW programs to **Argonne National Laboratory** until 1986, when responsibility is consolidated at NREL.
1980	**Energy Security Act** directs DOE to prepare a plan for developing systems to recover energy from wastes.
	The **Comprehensive Environmental Response, Compensation and Liability Act (CERCLA),** aka Superfund, provides funding and federal enforcement for cleaning up hazardous waste sites. Numerous older landfills will be declared Superfund sites.
1984	The **Hazardous and Solid Waste Amendments to RCRA (HSWA)** direct EPA to revise regulations for MSW landfills.

1988	The **Ocean Dumping Ban Act** mandates the end of ocean dumping.
1989	EPA publishes ***The Solid Waste Dilemma: An Agenda for Action*** which outlines a strategy for addressing the nation's solid waste management issues.
1989-1991	Federal agencies implement programs to reduce waste production, recycle, and purchase recycled materials.
1990	The **Clean Air Act Amendments** mandate that EPA develop stricter regulations for landfills and waste-to-energy facilities.
1991	EPA promulgates comprehensive air emissions standards for new municipal waste combustors.
	EPA promulgates regulations for MSW landfills, created in accordance with Subtitle D of RCRA. The regulations set forth minimum standards for landfill location, design, operations, groundwater monitoring and protection, closure and postclosure care, and financial assurance.
1992	The **Energy Policy Act** continues support for energy recovery technologies, including the recovery of methane from solid waste and the development of refuse-derived fuel for co-firing with coal in industry and utility boilers.
1995	The **Bridge to a Sustainable Future**, developed by the President's National Science and Technology Council, articulates an environmental technology strategy. The strategy includes using MSW management in creating sustainable communities.
	EPA promulgates stringent air emissions standards for waste combustors. The regulations ensure that waste-to-energy facilities are among the cleanest power sources in the nation.

The waste-to-energy industry had already reduced its dioxin emissions by more than 100-fold since the early 1980s. As a result, municipal waste combustors currently contribute less than 3% of the total amount of dioxin emitted from known sources throughout the United States in a year. Once implemented, the new regulation will reduce the waste-to-energy industry's contribution to about 1%, according to H. Gregor Rigo in *Solid Waste Technologies*.

By narrowly focusing on dioxin emissions from the waste-to-energy industry, the regulation ignores the industry's ability to produce electricity with fewer emissions than coal, to reduce greenhouse gas emissions from landfills, to recover energy from wastes, and to reduce the volume of solid waste by as much as 90%. The cost of complying with the regulation threatens to slow the growth of an industry that contributes significant overall environmental benefits. The potential benefit from the proposed regulation is only a small reduction in the amount of a single pollutant in the air. Because waste combustion will only be responsible for 1% of the dioxin added to the air, about 99% of the dioxin (contributed by other sources) will still be there.

In addition to protecting the environment, regulations have fostered an adversarial climate among industry, government, and nongovernmental organizations. During the past 10 years, various groups have tried to control an inflexible system that viewed environmental protection in black-and-white terms and, more often than not, stifled innovation. The antagonism has undermined trust and reduced opportunities for experimentation and innovation. More workable and creative regulatory mechanisms would support the waste management industry in developing more environmentally sustainable materials management methods and in participating in collaborative planning at the local, state and federal levels.

The solid waste industry recognizes that environmental regulation may have reached the point of diminishing returns. But, less regulation doesn't mean the solid waste industry plans to reject environmental principles that the American people hold dear. Rather, it means that environmental protection will remain part and parcel of the waste management business in America — because caring for the environment is good business.

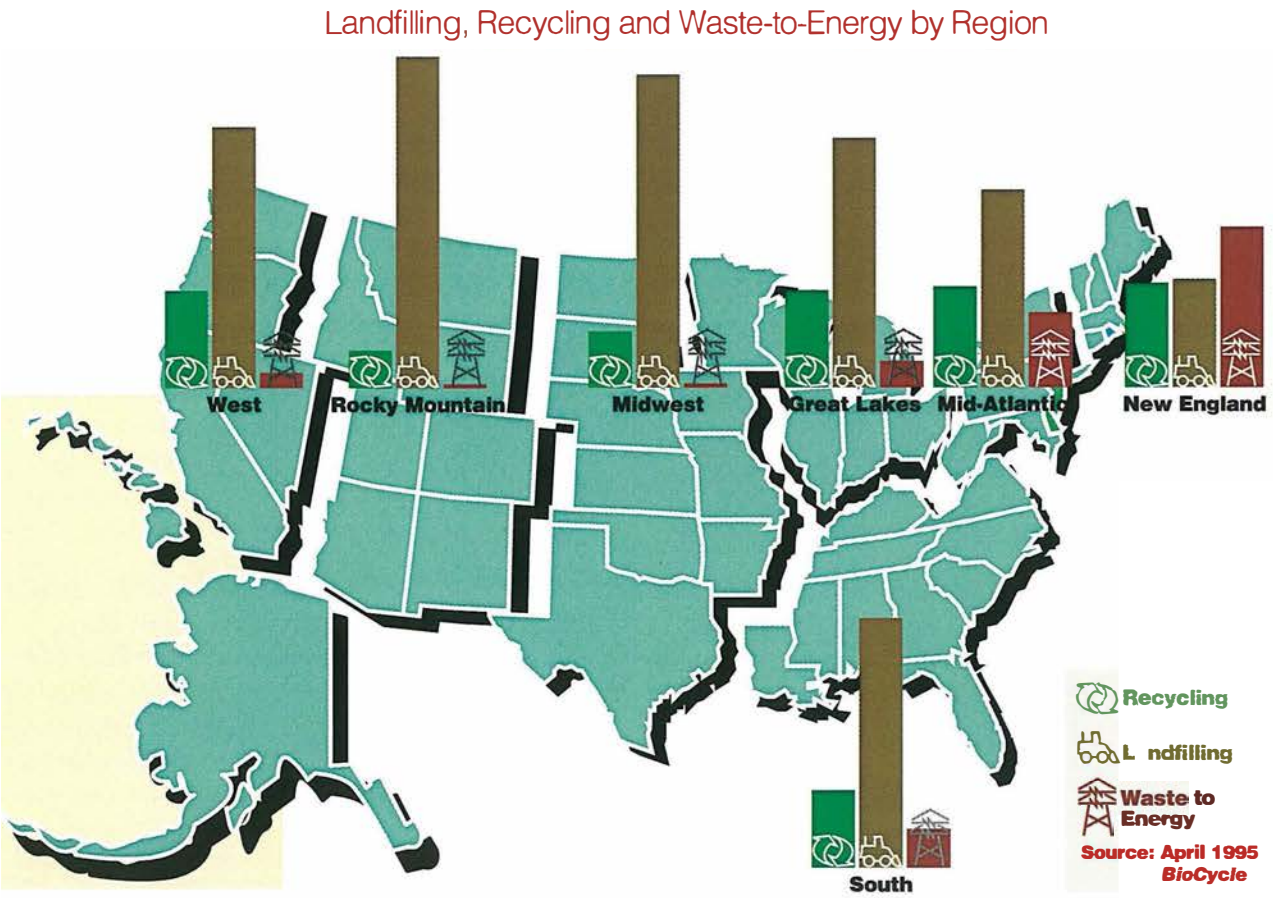


Figure 5.

Managing Garbage

There are three ways to manage garbage: Recycle it, combust it, or bury it in a landfill. Figure 5 shows how these methods stack up in different regions of the country.

Throughout history, the preferred method for dealing with garbage has been to dump it — on the floor, in the street, or in decidedly unsanitary open dumps. Burning and recycling have also been practiced since prehistoric times. Although today's solid waste management technologies are more sophisticated than ever before, the three basic methods remain the same. At present, about 62% of America's trash (approximately 130 million tons, according to EPA) is buried in sanitary landfills. In 1960, the same percentage of solid waste ended up in the city dump, but there were only about 55 million tons of it.

Since 1965, the federal government has sponsored programs to help states and municipalities safely and responsibly dispose of garbage.The development of new technologies was a high priority. Researchers studied waste-to-energy conversion systems, refuse-derived fuels, landfill gas extraction and energy conversion, landfill designs, composting, materials separation, and recycling. Many different agencies have sponsored MSW research, including the U.S. Public Health Service, the Bureau of Mines, the National Institute of Standards and Technology, EPA, and the U.S. Department of Energy (DOE).

From its inception, EPA has regulated hazardous wastes, waste combustors, and landfills. The regulations pushed industry to develop disposal methods that protected public health and the environment. During the past two decades, EPA and DOE evaluated waste-to-energy systems, encouraged recycling, and developed concepts for integrated waste management. At the same time, federal monies assisted states with solid waste planning and in establishing agencies to oversee solid waste management.

The impact of these initiatives has been far reaching. In 1960, Americans recycled less than

SWANA/PIX03617

About 62% of America's trash is buried in sanitary landfills.

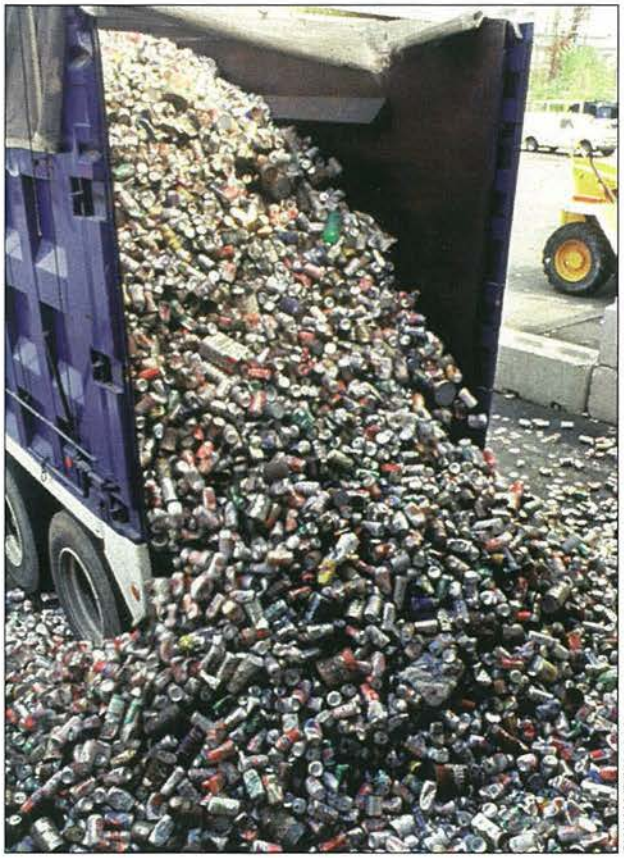
Part II, *Waste Management Goals*, discusses the goals of solid waste management in the context of an historical overview of garbage management in the United States. The section highlights efforts by visionary public works managers a hundred years ago to introduce methods for safeguarding public health into urban waste management. It discusses events since 1965 that integrated the concept of environmental protection into waste disposal. Finally, it provides a road map for using responsible waste management planning to help create strong and healthy communities.

6 million tons of MSW, or about 7% of total solid waste generation. In 1993, they recycled and composted 22% of the nation's total MSW generation, a whopping 45 million tons! At the same time, manufacturers developed methods for making lighter-weight glass, paper, plastic products, and packaging, thereby reducing the amount of waste. Open dumps closed for good, replaced by landfills designed to protect ground and surface waters. Ocean dumping of wastes stopped. Municipal incinerators were shut down and replaced by modern waste-to-energy plants with stringent air emissions controls. The old-style incinerators had been responsible for about 18% of the black smoke hanging over America's cities, according to historian Martin Melosi.

Despite these accomplishments, the current system could still be better. The nation's growing population and its relative affluence continue to foster waste generation. Municipalities need new technologies and analytical methods for recovering energy and materials from solid waste. Manufacturers and consumers need assistance in reducing the amount of waste they create.

Managing America's Garbage was written to describe the federal role since 1965 in developing better ways to manage the nation's trash. It highlights accepted waste management technologies that can meet America's future needs. It also explains how solid waste management in the 21st century can be specifically tailored to each community to minimize waste creation and maximize resource recovery.

Part III, *Technologies and Methods*, describes the evolution of key municipal solid waste management technologies and methods, including source reduction, recycling, composting, waste-to-energy conversion, and landfilling. It highlights research activities directed toward more efficient and lower cost waste management.



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The percentage of bottles, paper, cans, and other materials that are recycled has jumped from about 7% in 1960 to 22% in 1993.

WASTE MANAGEMENT GOALS

From colonial times until the mid-1800s, America's city dwellers disposed of their garbage by throwing it into the streets. Cities were small during most of this period. The country was blessed with abundant land and natural resources, which helped keep the environment clean in spite of our ancestors' habits. However, major sanitation problems developed when the nation's cities grew larger after the Civil War. Organized sanitation efforts sprung up to remedy the filthy conditions responsible for frequent and often devastating epidemics. Since the mid-to-late 1800s, the primary goal of managing garbage has been to safeguard the public's health. Pioneering efforts to recover useful materials and energy from trash also began in the 1800s.

During the 1960s, Americans began to realize that pollution threatened the environment upon which they depended for sustenance. Many poor waste management methods were subsequently eliminated, allowing the environment to recover from years of neglect. Since 1965, the goal of protecting the environment has been second only to that of safeguarding public health.

Today, with better technologies and a deeper understanding of how to prevent environmental pollution, waste management has a third goal: to help create strong communities. Unlike earlier goals, this objective cannot be met by waste management professionals alone. The health of America's cities in the 21st century will depend on how well they can integrate waste management, pollution prevention, industrial growth, and community services. Cities will thrive only if they can create an enduring economic system that conserves its material and energy resources, according to the National Environmental Technology Strategy.

Safeguarding Public Health

For centuries, carelessly discarded garbage was a source of disease. It contaminated water supplies and served as a breeding ground for flies, rats, and other disease-carrying vermin. Dysentery, bubonic plague, cholera, and typhoid fever are examples of serious illnesses spread by the appalling, unsanitary conditions that existed in many U.S. cities until the early part of this century.

Because horses were used for transportation and pigs scavenged food wastes tossed into the streets, unpaved town thoroughfares were rife with manure. Rainstorms turned this mess into a sea of slime. On hot summer days, cities reeked from open air markets, rotting garbage, animal wastes, and leaking privy vaults in the basements of tenements. If there were any kind of sewer system, raw sewage passing under the streets to the nearest river or ocean contributed to the normal stench of daily life. Dust and soot were pervasive. As cities grew larger, sanitary conditions steadily worsened. Disease became widespread, particularly in crowded areas.

"I believe the regulatory system should devote just as much effort to assisting the regulated community as to enforcement."

– H. Lanier Hickman, Jr., Solid Waste Association of North America

SWANA/PIX03620

Americans have come to realize that pollution, like this old dump, threatens our existence. The goal of protecting the environment is second only to that of safeguarding public health.

SWANA/PIX03622

Open dumping, like this scene of white goods in wetlands in New Hampshire, came under fire in the 1970s. Poorly managed open dumps have been closed as people realized that garbage needs to be carefully managed.

When public works managers in the 19th century made the connection between the mounds of filth in city streets and burgeoning public health problems, modern municipal waste management began. In 1895, Colonel George E. Waring, Jr. was appointed New York City's Street Cleaning Commissioner. Known as "the Apostle of Cleanliness," Waring employed 2,000 uniformed workers to clear the streets of garbage and manure. Wastes were sent to dumps, incinerators, or into the East River. (Despite Waring's innovative street-cleaning methods, a substantial fraction of turn-of-the-century New York City's trash was managed by loading it onto garbage scows and throwing it into the river, often within a few feet of where slum dwellers were bathing.)

In the early 20th century, public works managers in other cities followed Waring's lead and initiated refuse management systems. As a result, sanitary conditions in the nation's cities improved. Even so, the link between poor waste management and disease continued to elicit public concern.

Since 1900, incineration, open dumping, and landfilling have all come under fire. For example, Americans had bad experiences with polluting garbage incinerators from 1900 through the mid-1980s. Smoke, foul odors, and blowing ash bothered city dwellers. Poorly managed city dumps also emitted foul odors and frequently caught fire, polluting the air. One such fire, at Washington, D.C.'s Kenilworth dump in 1968, engulfed three small children, killing one of them. The incident evoked public outcry, forcing the dump to close and inspiring Congress to put a stop to open dumping. During the 1970s and 1980s, poorly managed hazardous wastes perpetuated fears that garbage threatened the public's health and safety. In 1986, for example, 184 landfills were recommended for the Superfund National Priorities List. All but two of them had accepted hazardous industrial wastes along with municipal trash.

Even though incinerators now have emission controls, open dumps have been closed, and toxic wastes are handled safely and responsibly, Americans continue to view garbage as an external threat rather than the logical consequence of their lifestyle. This attitude adds to the challenge of municipal solid waste management and fosters a crisis mentality with respect to garbage. People find it difficult to make the connection between their own behavior as consumers and the challenges the nation faces in disposing of hundreds of millions of tons of garbage.

Americans have typically dealt with garbage by ignoring it for as long as possible. Eventually, problems that might easily have been solved with consistent attention "suddenly" escalated into a "garbage crisis." The crisis then mobilized citizens and government officials to take "action" until people felt sufficiently reassured to forget about garbage again. Americans have repeatedly learned and forgotten three important lessons: (1) Waste management improves to the degree that the nation invests in better analytical methods and more efficient technologies. (2) Better technologies and methods come from ongoing research and development, including long-range basic research. (3) Public health suffers if municipal waste management fails to use the best available technologies and methods.

Protecting the Environment

For more than two centuries, Americans took the environment for granted. It appeared to be a limitless reservoir of raw materials and an unlimited repository for wastes. The latter assumption came under fire in the years following World War II. The nation grew more affluent and its population expanded. The composition and amount of garbage began to change. A burgeoning packaging industry revolutionized the distribution and marketing of meats, fruits, and vegetables, creating new packaging wastes. At the same time, food wastes plummeted. Consumers were easily enticed by television advertising and attractive packaging to purchase convenient, disposable products such as paper plates, cups, and tableware; diapers; razors; and nonreturnable bottles.

People got rid of most of this extra trash by setting it out for the trash collector, who saw to it that the trash was burned in a municipal incinerator or deposited in the town dump. Homeowners, particularly in the west, burned wastepaper in homemade incinerators. Americans also threw pop cans, candy wrappers, and cigarette butts out the windows of their automobiles. As more and more people threw away more and more trash, several problems became apparent: garbage incinerators made a noticeable contribution to air pollution, dumps became an eyesore and a hazard to health, and litter piled up along the nation's highways.

The first national campaign against litter occurred in the 1950s. Overnight, "litterbug" became a household word. Since then, national organizations such as Keep America Beautiful, Inc., have urged individuals, civic organizations, and communities to take responsibility for reducing litter. By the middle of the 1960s, however, it was clear that litter was just a small part of the problem the nation faced in managing its garbage.

In 1965, President Johnson recommended that the federal government help states in solving pressing waste disposal problems. Soon afterwards, Congress passed the Solid Waste Disposal Act, as Title 2 of the amendments to the 1963 Clean Air Act. The Public Health Service, the Bureau of Solid Waste Management, and the Bureau of Mines were given responsibility for enforcing for the new law.

"The country has had a garbage crisis every 15 to 30 years since 1875. I've gone through three of them so far."

– Harvey Alter, U.S. Chamber of Commerce

The Solid Waste Disposal Act recognized that garbage disposal was a national problem. It launched a federal research program to develop better disposal technologies. The law also set up grants to states and municipalities for solid waste programs. In 1965, there were no state solid waste agencies, and only five states even had employees responsible for solid waste management. The federal grant money laid the foundation for state solid waste agencies across the nation.

In 1966, the Bureau of Mines began a research program to develop a process for reclaiming metals

Once it was common to just throw garbage into the streets between homes and tenements like this one. As cities grew larger, sanitary conditions steadily worsened. Disease became widespread, particularly in crowded areas.

SWANA/PIX03619

Fires at open dumps were once a common sight, but modern practices have all but eliminated this scene.

and glass from incinerator ash. The Public Health Service launched a research program the same year to investigate public health issues related to composting, incineration, materials separation and recovery, landfill design and operation, disease transmission from waste, and other related topics. The agency also established graduate-level fellowships at five universities for Master's students in environmental sciences or engineering wishing to specialize in solid waste. The graduate programs led to a new professionalism in solid waste management.

The Public Health Service launched its "Mission 5000" in 1966. The program had a goal of closing 5,000 open dumps across the country within six years. At the time, nearly 20,000 small community dumps dotted the landscape. Except for occasional fires set to create more space and reduce the vermin problem, most of these dumps received no attention, let alone management. The majority were located close to cities and towns, but sufficiently out of the way to avoid offending local citizens. Little care was taken in the design of such facilities.

Many of them were situated on river banks. Such a location created an open dump in perpetuity: periodic flooding washed the contents downstream whether or not the dump continued to accept new garbage. The Public Health Service's goal was to close the dumps whose locations were particularly poor and upgrade the design and operations of those that remained open.

By 1970, most Americans were aware of the environmental problems associated with waste disposal. Public health officials implicated air pollution as a major factor in deaths from emphysema and chronic bronchitis. The smoke emanating from old-style municipal incinerators (without emissions controls) helped convince people that air pollution was a serious problem. To make matters worse, scientists began warning the public that environmental problems were only likely to worsen as the nation's economy and population both continued to grow. Public concern in response to these developments was channeled into action on April 22, 1970, with the celebration of the nation's first Earth Day.

Paradoxically, sanitation services during the 1970s remained about the same as they had been for most of the 20th century. Street cleaning, refuse collection, and waste disposal were standard services. Only about 6% of the dumps in the United States met even the minimum requirements for a sanitary landfill. There were also tens of thousands of unregulated, unauthorized dumps in use throughout the country. During the 1970s, incineration continued its decline in popularity. Municipalities increasingly relied upon land disposal for solid waste.

Before major changes could occur in solid waste management, public attention shifted to hazardous wastes. In 1978, residents of Love Canal (near Niagara Falls, New York) were evacuated from their homes, which had been built over an abandoned toxic-chemical waste dump. Residents recounted horror stories of unexplained illnesses and birth defects. Subsequent evacuations of other communities occurred over the next few years. The nation reeled from the impacts of its laissez-faire attitude toward the disposal of hazardous wastes. Fears of toxic chemicals revived in 1984, when a chemical spill at the Union Carbide plant in Bhopal, India, claimed 3,500 lives. As a result of such well-publicized occurrences, concerns about solid waste management stayed on the back burner for nearly a decade.

MSW management returned to the limelight in 1987 when the infamous garbage barge, the Mobro 4000, sailed away from Long Island and failed to find anywhere to dump its load of garbage. Ironically, this well-known symbol of the "garbage crisis" had nothing to do with declining numbers of landfills and

rising costs for waste disposal, as widely believed. The barge was simply a get-rich-quick scheme gone awry when its captain failed to find any city along the East Coast willing to take New York's garbage for less money than he'd already been paid. The garbage barge eventually ended up in Islip, New York, where its journey began.

The misperception of a garbage crisis grew out of successful state and federal efforts to shut down thousands of small, poorly designed landfills. Since there were now fewer landfills, spaced further apart, the cost of disposal began to rise. The crisis mentality was magnified by both the environmental movement and the waste management industry. The perception of a crisis allowed the former to drum up support for recycling and the latter to profit from higher waste disposal fees even as it was building larger and more modern landfills.

"Our nation's future strength will in large part be built on the viability of our nation's communities. we must make choices today that increase the…desirability of our cities, towns, and rural areas if we are to preserve our natural environment and build a strong domestic economy."

– Bridge to a Sustainable Future, a National Environmental Technology Strategy

There was no garbage crisis in 1987. The reality was that municipal garbage disposal methods were much improved. By 1988, the number of U.S. landfills declined to about 8,000, with open dumping all but eliminated. (The number would fall to less than 3,400 by 1994.) Newer, larger sanitary landfills replaced older facilities. The new landfills not only safeguarded public health, they also protected the environment.

By 1988, only a few large incinerators were still in operation. In their place, more than 100 waste-to-energy combustion facilities had come on line. Drop-off programs and curbside recycling programs had sprung up across the country. As a result, the percentage of trash recycled had almost doubled, rising from 7% in 1965 to 13%. Municipal composting of yard wastes had appeared in a few locations.

Even so, the public continued to view garbage as a threat.

Environmental groups voiced concerns about the health impacts of emissions from waste-to-energy facilities. They worried whether energy recovery might be competing with recycling. At the time, recycling was being touted as a panacea for waste management.

An additional concern surfaced: scientists warned the public that carbon dioxide, methane, and other greenhouse gases were accumulating in the atmosphere in sufficient quantities to pose a threat to the stability of global climates. Researchers speculated that a buildup of greenhouse gases could lead to a worldwide warming trend, beginning early in the 21st century. This new threat focused the attention of waste management professionals on landfill disposal. Landfills generate methane, typically for decades, and landfills release methane gradually into the atmosphere.

Many larger landfills and some smaller landfills recover methane. Once a landfill has a collection system in place, it can recover 75% or more of the gas generated, but less than 5% of landfills have collection systems.

P. Shepherd/PIX03626

Municipal garbage disposal methods in the late 1980s were much improved. Newer, larger sanitary landfills replaced older facilities.

The possibility of a global climate change began to change the way people thought about waste disposal. Environmental protection suddenly became more complicated than adding emissions controls to incinerators, liners to landfills, or closing dumps. Rather, it appeared to demand change in the fundamental ways in which people obtained energy, food, fiber, shelter, and consumer goods. People began to realize they needed to work in concert with the planet to provide for their needs, use material and energy resources more efficiently, and generate less waste. The high energy and materials requirements of today's industrial societies may seriously impact environmental quality over the long run. The new thinking is expected to impact solid waste management during the next several decades.

Helping Create Strong Communities

Since 1980, the nation has managed solid wastes to protect public health and the environment. The next 25 years should see new technologies appear in the wake of environmental policies promoting innovation, systems engineering, strategic planning, and industrial ecology. Industrial ecology studies ways to reduce the flow of energy, materials, and wastes through industrial systems to minimize the impact of human activity on natural systems. As the nation seeks long-term economic growth that both creates jobs and sustains the quality of our natural environment, public works managers will face new challenges.

The President's National Science and Technology Council provided a road map of these challenges in April 1995. The Council's National Environmental Strategy discussed the continuing need to remediate past environmental damage. It also offered a framework for shifting from waste management to pollution prevention and the more efficient use of resources. The Strategy envisioned the creation of communities where "wastes" are not only minimized, but also used and reused as resources. Material and energy resources would no longer be treated as commodities to be squandered; rather, they would be conserved and used efficiently. As part of the strategy, America's communities would adopt advanced municipal waste management methods in the future. The methods include

- Waste management that anticipates and prevents environmental pollution rather than relying on methods created solely to address a specific problem or regulation,
- Waste disposal strategies that are fully integrated with manufacturing, agriculture, energy, transportation, and other community operations and services,
- Sufficient materials and energy recycling to relegate landfilling to a minor role in MSW management,
- Waste disposal systems that incorporate scientific advances in computing, genetics, biotechnology, and modeling, and
- Individualized and integrated waste disposal systems designed for each community's particular needs.

Tomorrow's communities will rely on both natural and man-made physical systems to support the well-being of all members of the community, including future generations. Individuals, industry, labor, communities, nongovernmental organizations, and local, state, and federal governments will all need to work together to design tomorrow's infrastructures. Nevertheless, the task of integrating solid waste management with all facets of community operation will fall primarily on waste management professionals.

P. Shepherd/PIX03628

An experiment in New Jersey uses ash from a waste-to-energy facility to demonstrate how the ash can be used in paving projects.

However, they will have help from other stakeholders in the federal municipal solid waste program, national waste management industry associations, state agencies, local officials, and interested citizens.

Warren Gretz, NREL/PIX00085

Cities, both large and small, need new technologies and analytical methods for recovering energy and materials from solid waste.

To create an enduring economic base and ensure environmentally sustainable development, Americans will need to generate 40% to 50% less waste, consume 30% to 40% less energy, and use 20% to 25% fewer materials per unit of gross domestic product. The National Environmental Technology Strategy recommended that the nation meet this goal by 2020. The implementation of advanced materials management systems as part of national and local "healthy community" initiatives will be a prerequisite for meeting these goals.

As a means of meeting these goals, the Strategy suggests replacing the regulation of specific waste streams with flexible standards based upon the performance of the most advanced commercial technologies. To ensure accountability, the performance-based standards would include independent audits to ensure that the standards were being met or surpassed. Such verification would enhance the competitiveness of the nation's solid waste technologies in global markets. This type of integrated systems approach would allow industry to develop the most cost-effective technologies for complying with the standards.

According to the Strategy, regulatory flexibility will foster innovation in waste management technologies. In contrast, the more rigid regulatory policies of the past, which mandated control of specific pollutants, often impeded technological development. Technologies capable of meeting regulatory standards were adopted regardless of whether industry could have come up with better performing, lower cost solutions. To avoid this problem in the future, the Strategy proposes cooperation among the public and private sectors in developing affordable, innovative technologies for reducing wastes and lowering energy and materials use.

It is not yet clear whether Congress, federal agencies, and the American public will endorse a vision of technology-based, environmentally sustainable development. Assuming that they do, it is crucial that future environmental regulation and technology development occurs within separate, independent agencies. Separating regulatory policy setting from technology development sets the stage for credible research and development. And, it fosters the development of flexible, performance-based standards necessary for innovation in solid waste technology.

Integrated Waste Management

In every community, Americans can make more efficient use of resources and choose disposal methods that have less impact on the environment. Individual methods can be combined into large and efficient integrated waste management systems designed to use natural resources efficiently and prevent pollution. Eventually, waste management could be fully integrated with manufacturing, agriculture, energy, transportation, and other community services.

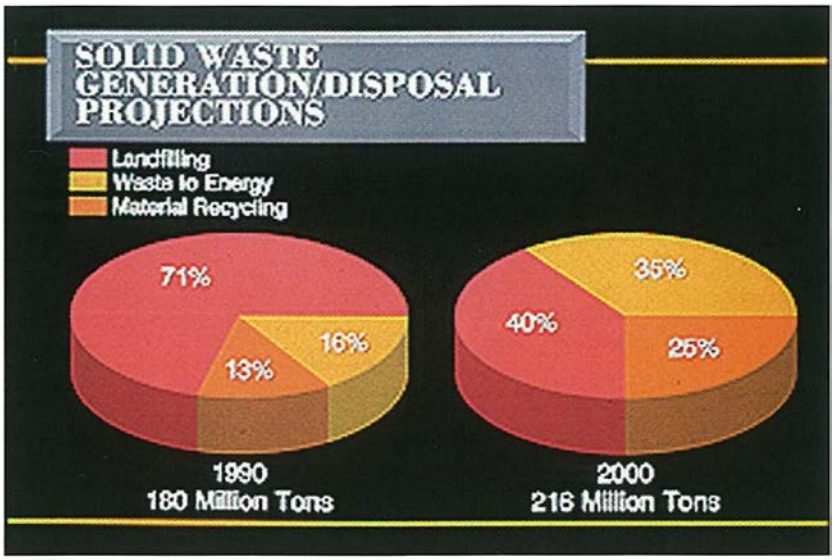
Thousands of cities and towns already practice some form of integrated waste management, which includes coordination, planning, and public education, in addition to waste collection, transport, and disposal. The key feature of integrated waste management is its systems perspective; just because a community happens to use more than one disposal method doesn't necessarily mean it has an integrated system.

In an integrated approach, each municipality selects disposal options that meet its needs, then coordinates waste management for maximum efficiency, low cost, and acceptable environmental impacts. With such a strategy, cities in sparsely populated western states might emphasize landfilling and limit recycling. Unless there were remanufacturing facilities nearby, recycling might not make sense environmentally or economically. In contrast, a large urban metroplex might encourage remanufacturing industries, build a large waste-to-energy combustion plant, and minimize landfilling. In general, integrated waste management systems are designed to enable communities to manage their wastes in the most efficient, environmentally sound, and economical fashion possible.

The Federal Role in Solid Waste Management

Today's solid waste management methods need refinement to support environmentally sustainable economic development. Unfortunately, waste management professionals often cannot find the information they need to make decisions fostering improved waste management. Too often, a strong opinion based on emotion, not on facts, is the deciding factor because objective information is not available. In the past, federal MSW research focused on the development of one technology, or on the solution to a specific problem, rather than taking a systems approach to waste management.

As a result, there are many holes in the basic information available about waste management technologies. Waste-to-energy combustion is the only technology that has been extensively tested (because of regulatory requirements). Other waste management methods, including landfilling, composting, and recycling, have undergone far less scrutiny regarding their efficiency and environmental impacts.



SWANA

Between the years of 1990 and 2000 landfilling as a method of garbage disposal is expected to decline in favor of waste-to-energy and materials recovery.

Since 1970, landfilling research focused on sanitary landfill design and the containment of toxic liquids produced inside the landfill. Recently, researchers have begun detailed studies of landfill gas emissions and recovery. Because landfills are enormously complex chemical and biological systems, they remain poorly understood. Important and necessary steps to prevent water pollution also slow the internal biological processing that occurs naturally in a landfill. This processing used to take about 30 years; modern sanitary landfills may take 100 years or longer to reach stability. Until they reach stability, landfills release methane to the atmosphere, con

tributing to greenhouse warming. To make matters worse, the plastics, wastepaper, food wastes, yard trimmings, and textiles in a landfill are wasted materials and energy that could have been recovered.

The United States and other nations have made a commitment to protecting the world's climatic stability. Americans also want to conserve the nation's material and energy resources. Consequently, the nation cannot continue to ignore the long-term environmental impacts of our major waste disposal technology.

As our population continues to grow, the nation will need to implement the most efficient waste disposal methods available. In the future, landfilling may not prove to be economical—just as some types of recycling may not be environmentally benign. The problem now is that we simply do not have all the information we need about current waste management technologies to adequately plan for the future.

To remedy this situation, EPA and DOE began a study in 1994 to gather detailed information regarding recycling, composting, MSW combustion, and landfilling. Researchers planned to evaluate paper, glass, metals, and plastics in terms of their materials and energy requirements, environmental impacts, and costs. The analysis will cover the entire life cycle, from the acquisition of raw materials through manufacturing, use, reuse, and waste management. Within three years, the agencies plan to assemble a database on emissions, resource and energy consumption, and representative costs of all operations involved in solid waste management. They also plan to gather data on obtaining raw materials, manufacturing (and remanufacturing), consumer use, reuse, and waste generation patterns. In a similar effort to understand public works from a systems perspective, the American Public Works Association plans a detailed cost study in 1996 of municipal services, including waste management.

"Waste management professionals continually tell us they need credible information on the various methods used for MSW management. How do they perform? What are their costs? How do they affect the environment? How do you evaluate them?"

– Carlton Wiles,
National Renewable
Energy Laboratory

Once such studies become available to municipal officials, long-term planning for waste management can begin in earnest. In the meantime, researchers will continue to develop new technologies for making alcohol fuels from wastepaper, for digesting municipal wastes in the absence of oxygen, and for recycling ash from waste combustors.

During the coming decades, we must use energy and materials more efficiently to produce goods and services and curb excessive waste generation. Waste management systems that emphasize the recycling of materials and production of energy will play a significant role — provided innovative, low-cost waste management technologies become available. How to accomplish this is a matter of some debate.

Government regulation can drive innovation, but the resulting technologies are often very expensive. To make matters worse, innovation may grind to a halt once regulatory standards are met. Alternatively, private industry can take responsibility for developing new, cost-effective technologies — with or without regulatory incentives. This strategy works well for technologies near commercialization.

However, long-term technology development is a high-risk proposition for industry. Few, if any, companies can afford to undertake the development of next-generation technologies, which don't pay off commercially for many years. Nevertheless, the nation's future competitiveness depends on such efforts. So does environmentally sustainable development.

Public/private partnerships are often the best way to foster the development of next-generation technologies. Working together, the public and private sectors can enhance the solid waste management systems, analytical methods, databases, and information systems needed by communities to meet tomorrow's challenges.

Fortunately, most time-honored methods of waste disposal are now illegal. Smoky incinerators, vermin-infested city dumps, and widespread littering have yielded to modem technologies for keeping America clean. When a municipality collects garbage from its citizens, sanitary engineers get rid of it safely and economically.

Depending on the city, garbage disposal may include recycling, composting, energy recovery, and landfilling. By the time the waste management professionals get involved, it's already too late for source reduction or reuse. Waste minimization has to occur long before people set their trash out for the garbage collector. Because they have such great potential for reducing the volume of solid waste, source reduction and reuse are essential to effective solid waste management

"Source reduction absolutely makes sense. Why? Three-quarters of the cost to manage MSW is in collecting it. There is absolutely no reason to produce waste to recycle it or use it as a fuel if you don't have to make it at all."

– Donald K. Walter,
former Municipal Solid Waste Program Manager, U.S. Department of Energy

Waste Minimization

The best way to keep garbage out of a municipal solid waste management system is to produce less of it. There are many ways to do this, but some work better than others. It's a matter of balancing convenience, cost, and impact on the environment. For example, the following suggestions for reducing garbage have met with only limited success: use cloth grocery bags, pass up prepared meals, pass up quick-cleaning home-care products, buy bulk foods, and avoid disposable diapers, razors, dishes, and so forth.

Lists like this one have several problems. To begin with, waste minimization is often in the eye of the beholder rather an objective reality. Whether or not an idea is good for the environment often boils down to personal values and assumptions.

Take the controversy over cloth diapers, for example. Two studies of cloth versus disposable diapers came up with opposite conclusions about which alternative is better for the environment. So what do we know for sure? Washing cloth diapers at home uses lots of energy and creates wastewater that must be treated to avoid pollution. Disposable diapers create lots of trash, but have less impact on water quality. To further complicate the picture, commercial diaper services use less energy and produce less waste water per diaper than does washing them at home. Many consumers don't worry about any of this. They opt for the disposables because they're convenient and affordable.

People who come up with ideas for reducing garbage cannot afford to ignore consumer attitudes. In most American households, all the adults work. Where are busy people going to find the time and energy to put labor-intensive suggestions to work? In terms of trash, convenience has a price that most Americans are more than happy to pay. This fact is central to understanding why the nation creates so much municipal solid waste.

The good news is that we can cut down on waste without too much trouble. Wasting less food is one way to make less garbage. About 9% of the garbage Americans set out every week is edible food that is spoiled or otherwise unwanted. Americans have already made a lot of progress in curbing food wastes — thanks to packaging, which keeps food fresh longer, but there's still room for improvement. Another easy way to reduce waste is to use a mulching lawn mower instead of collecting and discarding grass clippings. Americans could also make a noticeable dent in paper wastes if somebody could figure out how to curb unsolicited direct mailings, preferably without violating the First Amendment or shutting down the postal service.

Some strategies for minimizing wastes take almost no effort at all. Consumer choice is a good example. Retailers now offer laundry detergents, dishwashing detergents, floor-care products, and toothpastes that use less packaging. Although the toothpaste inside a shrink-wrapped tube is just the same as in a tube sold in a box, many consumers select the boxed product out of habit. Since consumers continue to buy them, manufacturers continue to make them — and the trash piles up.

Detergent manufacturers reduce packaging by removing water and fillers from their products. However, they've discovered that consumers don't always buy the smaller packages. Shoppers assume that they are getting less product for their money. Usually, the opposite is true. In 1995, for example, *Consumer Reports* magazine rated one such dish-washing detergent as its best buy. Consumer education is crucial for making source reduction efforts pay off.

American Plastics Council/PIX03623

Food packaging has become more convenient for consumers, and has reduced food waste. However, packaging has created a whole new category of waste.

Even without consumer feedback, manufacturers have a strong impetus to make products lighter, thinner, and more durable. Such endeavors, collectively known as lightweighting, save money on raw materials. They may also save on transportation costs. The savings translate into higher profits. Nowhere is this more apparent than in the computer industry. A hand-held microprocessor now has the power of a 1970-vintage computer that filled a small room. That's a roomful less waste when that microprocessor becomes obsolete. Some computer firms also sell factory-reconditioned items such as computers, printers, and toner cartridges along with new products, further reducing waste.

The plastics industry has made important strides in lightweighting containers. For example, a plastic, 2-liter soda bottle that weighed 68 grams in 1977, weighed only 51 grams in 1991. That's 25% less material. Plastic milk jugs weighed about 98 grams each in 1977. They weighed 60 grams in 1991, almost 40% less. Lightweighting has helped keep the percentage of plastics discarded in landfills nearly constant (at about 10%) for the past 25 years.

There is a limit to how far lightweighting can go in reducing wastes, however. Less material makes containers less durable. Anyone old enough to remember when beer and pop bottles were routinely recycled knows how hard it was to break one of those old, heavy bottles. Today's lighter glass containers aren't strong enough to be used over and over.

Many manufacturers help minimize wastes by recycling production wastes. Paper mills, corrugated board suppliers, aluminum sheet manufacturers, steel makers, and glass bottle producers are some of the industries that recycle manufacturing wastes rather than discard them. Paper trimmings go right back into the pulper; iron spilled when ingots are poured goes right back into the blast furnace; broken glass gets remelted and reformed; and metal wastes recycle continuously back through the manufacturing process.

The automobile and waste management industries also send large amounts of scrap metal back to the steel industry for recycling. Steel left over after car door panels are stamped out gets recycled. The "holes" for door handles, latches, mirrors, and so forth go back to the steel maker, not into a landfill. The nation's solid waste combustion plants recover more than 620,000 tons of scrap metal for recycling each year. As a result of efforts like these, between 66% and 68% of the steel produced each year in the United States is made from recycled scrap metal, according to the Steel Recycling Institute.

The high cost of raw materials is encouraging American industry to develop even more innovative methods for minimizing wastes.

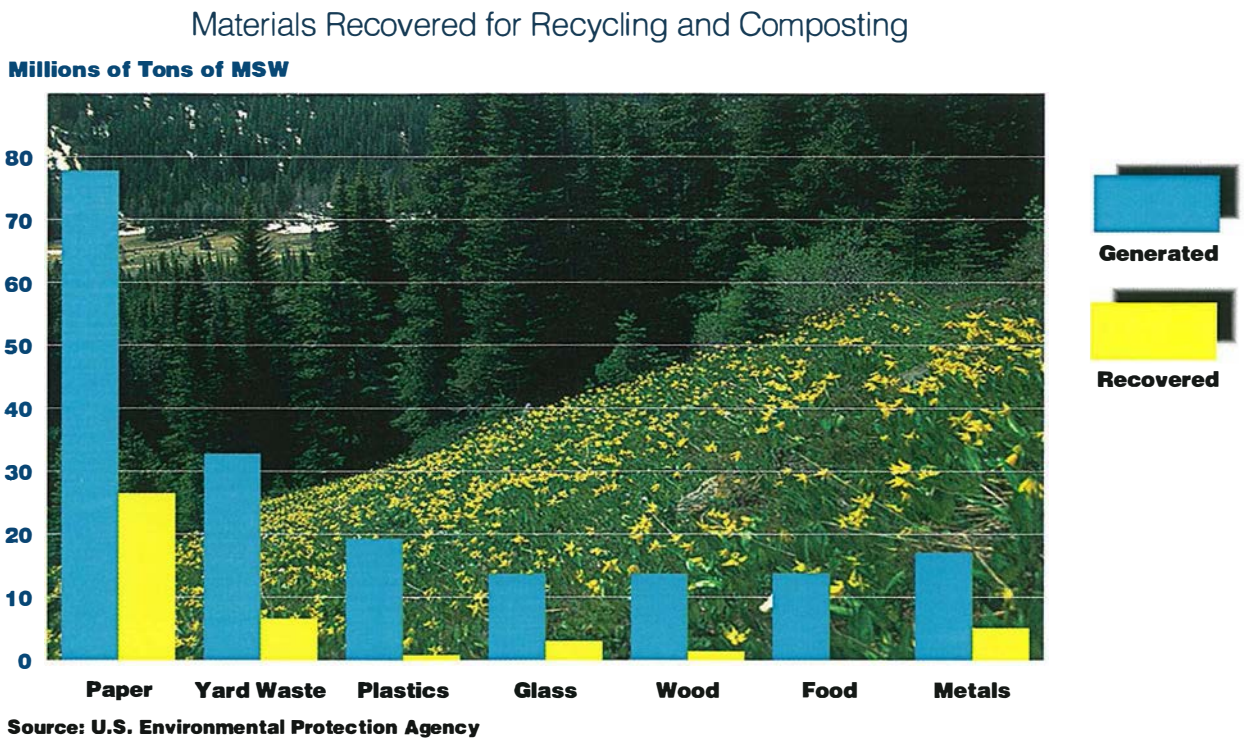


Figure 6.

Reuse and Recycling

Reuse and recycling date back to ancient times. Of necessity, preindustrial societies reused and recycled materials. Raw materials were often difficult to obtain. Skilled artisans spent too many hours making tools, weapons, jewelry, and household items to just throw them away.

During the 18th and 19th centuries in the United States, ragpickers were the cornerstone of an efficient and lucrative recycling system. They collected used paper and cloth rags for sale to Eastern paper mills. The mills combined fibers from these materials with virgin wood pulp to make paper. Ragpickers earned about $350 (in 1989 dollars) per ton of rags—more than two and a half times the average price for old newspaper in 1995.

Ragpickers also collected other items for resale. For most of this century, their modern descendants have collected, processed, and exported millions of tons of old newspaper, cardboard, and scrap metal from old cars and used appliances. The scrap industry flourished long before the current recycling era. With the exception of a small scrap industry, however, America's commitment to recycling has been an on-again, off-again affair. Some interesting highlights in the nation's recycling history include:

- *Chicago's rendering plants, which operated during the 1850s.* City street cleaners gathered dead animals and brought them to a rendering plant, which made grease for the Windy City's cable cars.
- *Making boxboard from old newspapers.* Since 1905, grayish-brown boxboard containers such as cereal boxes and the rollers inside toilet paper or paper towels have been made using a simple remanufacturing process. The process consists of dumping wastepaper into a pulper, which is essentially a huge Waring blender. Wires used to wrap the paper bales get tangled around themselves and are removed out of the center of the pulper. Waxed paper, heavily printed cardboard, and other materials that don't pulp readily get trapped in the wires and are removed along with them as waste. The paper fibers left behind in the pulper are processed and dried to make boxboard.
- *Recycling during World War II.* Newspaper, tin cans, fat (a source of glycerine needed to make explosives), aluminum, and tin foil were collected and reused as part of the war effort.
- *Using recycled cardboard to make car headliners.* Car headliners are the material between the metal roof of the car and the fabric on the inside that make the

roof soft to the touch. They were (and still are) made from recycled cardboard. During the 1950s, there were so few markets for recycled cardboard that its price could be used to estimate the number of new cars manufactured each year.

Today, reuse is distinguished from recycling. Reuse means exactly what it says. Instead of being discarded, an item continues to serve a purpose, often for someone other than its original owner. Reuse occurs whenever someone cleans a plastic yogurt container and uses it to store leftovers. More often, reuse takes place as a result of garage sales, second-hand stores, charitable donations, and scavenging.

Recycling happens when discards are collected and made into new products. If glass bottles collected in curbside collection and drop-off programs are used to make new glass containers or paving material, they have been recycled. If they are deposited in a landfill, they have not been recycled. Recycling is a three-step process: collection, remanufacturing, and use. Figure 6 compares the amount of waste generated in 1993 with the amount of material recovered for recycling. As shown in the figure, composting is counted as a form of recycling because yard-waste compost is a commercial product. As shown in Figure 7, commercial institutions are the largest source of recovered materials, followed by private residences.

The seeds for the modem era in recycling were sown by the 1970 Resource Recovery Act. The act shifted the emphasis of the federal MSW program from disposal to recycling. During the 1970s, government agencies evaluated recycling with the help of the National Center for Resource Recovery, a private Washington, D.C.-based research organization, whose mission was to promote resource recovery. Recycling blossomed during the late 1980s amidst unfounded fears that the nation was running out of landfill space.

At the time, recycling seemed to be the ideal waste management solution. Many people believed that recycling was, without exception, good for the environment. Environmental publications proclaimed that there were few, if any, practical limits to achieving recycling rates of 50% or higher. Most important, curbside recycling was convenient and it didn't demand that Americans change their normal consumption habits.

Recycling captured the imagination of the nation's citizens and public works managers. Together, recycling and composting are now second only to landfilling for managing garbage. Recycling enjoys support from governmental agencies, environmental groups, and the American public. Between 1985 and 1995, recycling and composting from solid waste increased from about 10% to 23%.

The EPA projects that 30% of MSW could be recycled by the year 2000. For this to happen, however, several things must occur, according to a 1994 study by Keep America Beautiful, Inc. Commercial recycling must increase significantly, the number of curbside recycling programs must double, and the diversion and composting of yard wastes must count toward overall recycling goals. Yard-waste composting is responsible for much of the recent increase in the nation's recycling rate.

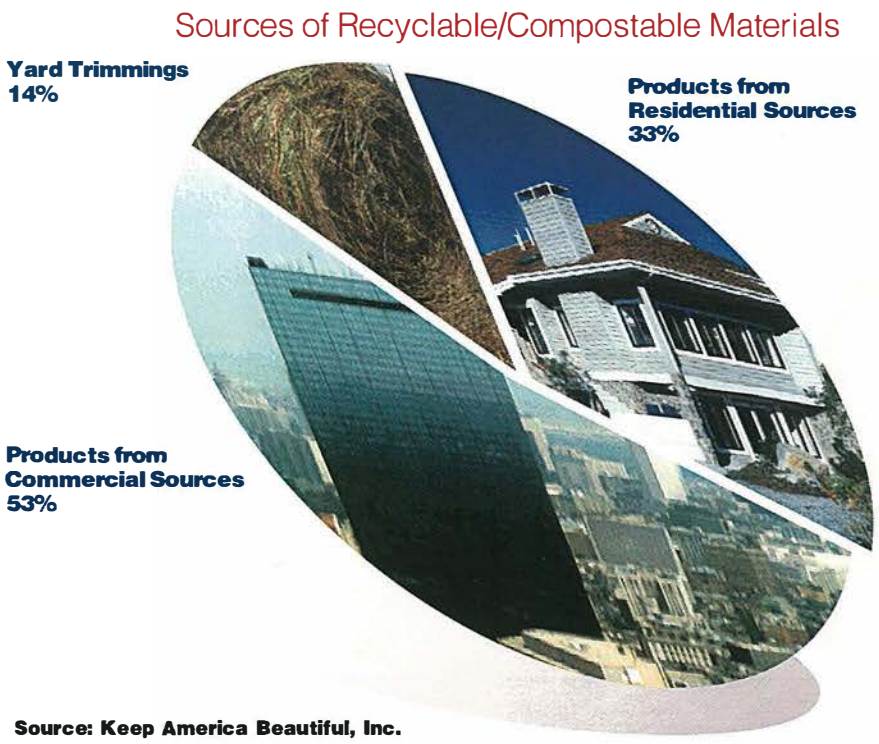


Figure 7. Residential MSW includes wastes from single and multifamily residences.

The study concluded that it would require more than source reduction, recycling, and composting to achieve national waste diversion rates greater than 35%. In a similar study, the city of Chicago discovered that the best recycling rate it could hope to achieve would be about 38%. Higher recycling rates are likely to increase waste management costs in most communities. Whether municipalities will be willing or able to handle the higher costs is not known.

It appears there are indeed practical limits to achieving recycling rates of 50% or higher. The poor quality of many discards, scrap prices, market availability, and high costs all limit recovery rates. Even when market prices for recovered materials are high, recycling often costs more than sending garbage to a landfill. Curbside recycling is the most convenient method for recovering materials from private residences. It is also the most expensive, because of collection costs.

To achieve the modest recycling rates envisioned by Keep America Beautiful, Inc., more than six out of every 10 Americans will need a curbside recycling program. And, as more recyclable materials become available, new remanufacturing facilities and larger markets for recycled products will be required. As these adjustments take place, scrap market prices may vary considerably.

NREL/PIX00331

The environmental effects of recycling depend on how far wastes are transported. If newsprint is shipped by truck more than a few hundred miles for recycling, there may be an energy and cost penalty.

Because the industry is growing so rapidly, researchers are beginning to look at recycling's impact on the environment. They're discovering that recycling isn't always the best choice. In 1994, Argonne National Laboratory analysts concluded that the environmental impact of recycling depends upon how far, and by what means, wastes are transported. For instance, if newsprint is shipped by truck more than a few hundred miles for remanufacturing, fossil fuels are spent to recycle a renewable resource. This means the air gets more polluted in order to reduce the requirement for harvesting trees. Since most paper is now made from plantation trees rather than from forests, this may not be a wise choice. Fast-growing plantation trees do not just provide pulp for paper, they also remove carbon dioxide from the air.

The Argonne study also found that recycling office paper saves less energy than recycling newspapers. That's because the chemical processes that produce quality papers also make them difficult and costly to recycle. In addition, there are no studies of the impacts of pollution resulting from paper remanufacturing. It often makes more sense environmentally to burn quality wastepaper for energy than it does to recycle it, according to Don Walter, who managed the MSW program at DOE for more than 19 years.

If glass is shipped by truck more than 100 miles for remanufacturing, it takes more fossil fuels to recycle it than to make new glass from raw materials. (It's just not that complicated to make glass: mix together sand, minerals, and a source of carbon dioxide such as sea shells. Add a lot of energy, a reasonable manufacturing process, and — voilà.)

Recycling plastic containers saves energy. It also saves oil, the raw material from which plastic is made. Plastic can also serve as an energy-rich fuel in waste-to-energy combustion.

Aluminum is one material for which recycling usually makes sense. Regardless of how far aluminum is transported, recycling it saves significant amounts of energy, with a correspondingly lower impact on the environment.

There is no waste management method, including recycling, that does not generate some pollution. Each city should look at the waste management choices open to it and select those that provide positive

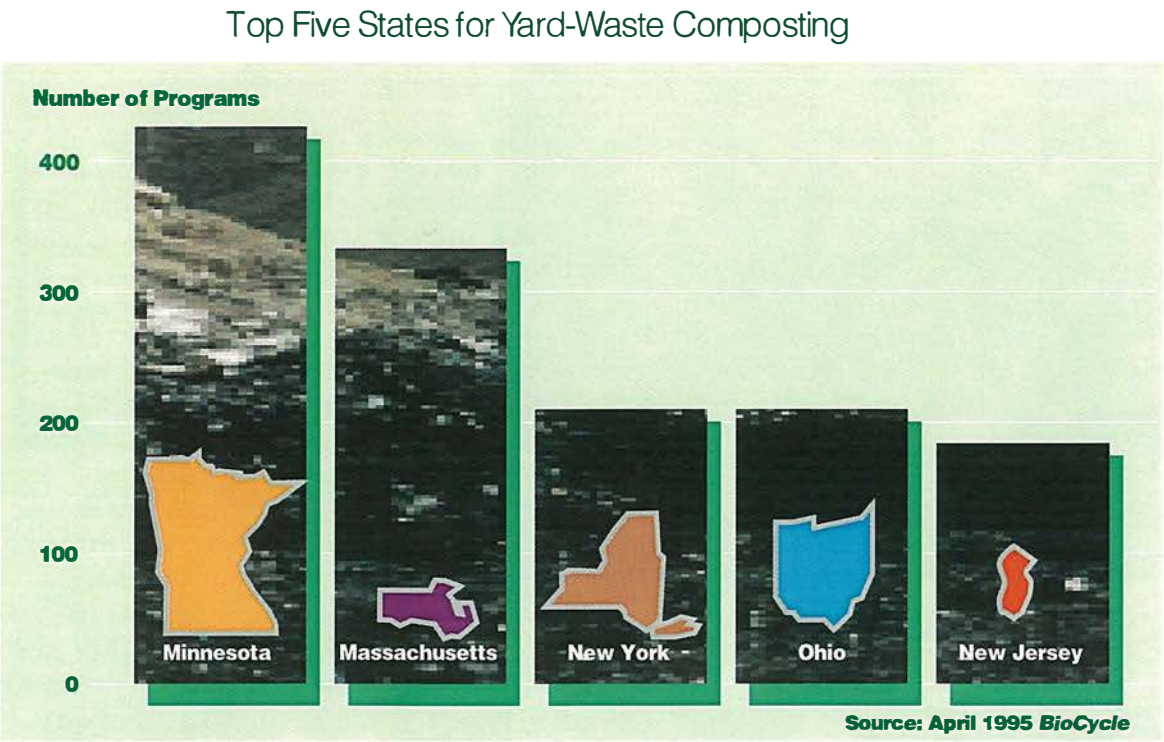


Figure 8.

benefits. In the Great Plains, for example, this might mean selecting waste-to-energy conversion in lieu of recycling paper if the nearest paper mill were hundreds of miles away. It might also mean crushing glass to use as landfill cover or in pavement rather than shipping it to another state to make new containers.

Today, waste management professionals are more realistic about what recycling can accomplish. Clearly, it is not going to reduce waste generation. Even though the recycling rate has risen steadily since 1988, EPA's estimate of the amount of waste going into landfills has remained constant at about 130 million tons per year. Recycling may have kept up with increased waste generation, but it has not made a dent in the total amount of garbage being buried each year.

The recycling industry is growing rapidly, however. As it grows, it is developing better processes for recycling different materials. Entrepreneurs are already building new remanufacturing plants in many cities. Waste exchanges such as *The Recyclers Exchange* have been set up on the World Wide Web. They provide a way for buyers, sellers, and traders interested in reusable or recyclable materials to initiate business contacts. The Chicago Board of Trade has set up a similar electronic marketplace for recyclable material such as office paper and corrugated cardboard. These developments are likely to make recycling more economical and may reduce its impact on the environment. For this reason, public works managers should regularly reevaluate the role of recycling in waste management.

Composting

Composting has been practiced for centuries. Farmers and gardeners do it by combining food wastes, paper, leaves, grass clippings, or cardboard with soil and a little water in an outdoor bin. With time, the mixture undergoes biological processing into a soil conditioner. Home-style composting schemes have been practiced in the suburbs throughout this century. Small composting systems work fairly well with a combination of food and yard wastes.

Today, there are more than 3,200 centralized composting and mulching programs across the United States. As shown in Figure 8, five states, led by Minnesota, have more than 40% of these programs, which divert yard wastes from landfills. Home composting is probably also helping to minimize landfilling of yard wastes, but there is no reliable method for determining how much. Direct composting of municipal wastes remains rare. Because it is more dif

NREL/PIX03678

Combustion ash, a byproduct of waste-to-energy plants, is tested for toxicity, and consistently it is not hazardous. It can be used in street paving projects.

ficult to control odors and destroy germs in mixed-waste composting systems, such systems require more sophisticated and costly technology.

Thus far, enthusiasm for composting as a waste diversion method has not been matched by a corresponding growth in markets for composted products. Compost is primarily a soil conditioner, not a fertilizer. Soil nutrients such as nitrogen are lost to the air during processing. And, because of low market demand, compost is expensive. With a market price of about $22.50 per ton, compost is worth more as a fuel in a waste-to-energy plant than as a soil enhancer.

Composting methods include community composting, land application, and mulching. In community composting, centralized facilities compost grass clippings with leaves or brush. The mixture of wet and dry material helps control moisture and temperature, yielding a higher quality product. Leaves may be piled on the ground during the fall without being composted. They function much like mulch during the winter, providing insulation and keeping soils moist. With the arrival of warmer weather, the leaves break down, conditioning the soil. Old Christmas trees, tree branches, and other woody yard trimmings may be chipped or shredded, then sold or distributed as mulch for landscaping and gardening. Mulching involves very little management and virtually no biological activity. It is relatively simple and inexpensive.

Energy Recovery

Garbage is an important energy resource. It's domestic, renewable, and there's plenty of it. Americans could get about 2% of the energy they use each year from solid waste, if energy recovery were a priority.

There are two basic strategies for recovering energy from wastes in the United States: combustion and biological processing. Biological methods use microorganisms to change wastes into high-energy products such as biogas or alcohol fuels. Combustion of wastes produces heat to warm water or make steam. Hot water and steam may be used directly for industrial processing or district heating. In most cases, however, steam is used with turbines to generate electricity.

Electricity is a particularly valuable form of energy. Electricity made from garbage displaces electricity made from coal, reducing the impact of power generation on the environment. As a result of government regulation, making electricity from garbage produces fewer emissions than making electricity from coal. Figure 9 compares coal, oil, natural gas, and municipal wastes in terms of the emissions produced in generating electricity.

Combustion

American cities have burned wastes to reduce their volume for more than a hundred years. The U.S. Army built the nation's first garbage incinerator on Governor's Island, New York, in 1885. Within two years, Wheeling, West Virginia, Allegheny, Pennsylvania, and Des Moines, Iowa, had also installed "crematories." Crematories borrowed heavily from European incinerator technology, which didn't work very well with American garbage. It was too wet to burn efficiently. Numerous cities discovered this problem the hard way — after building a new incinerator.

Even so, the use of incineration for waste disposal soared between 1910 and 1920, then leveled off until the late 1930s. Because of poor emissions control, incineration declined in popularity as competition

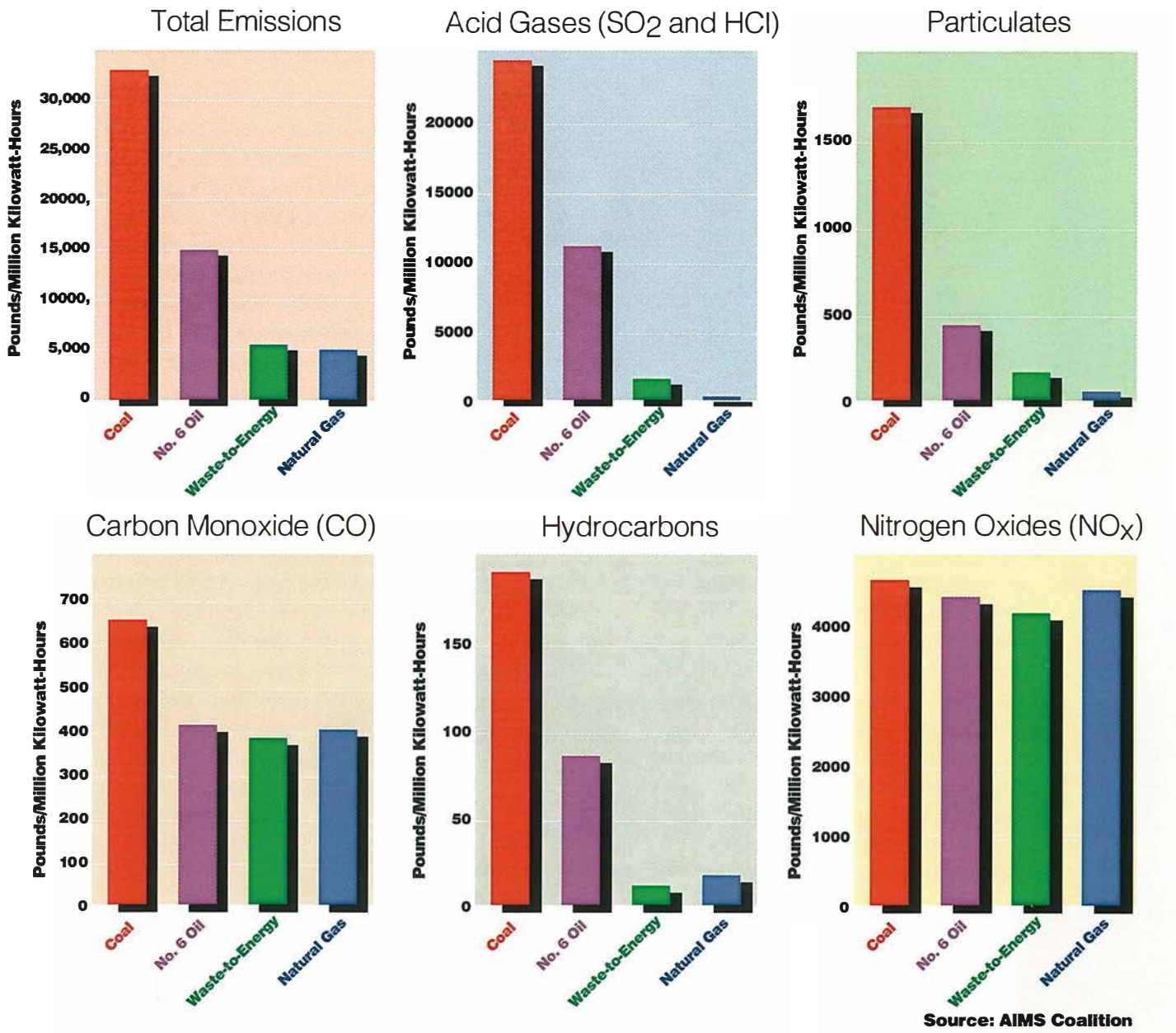
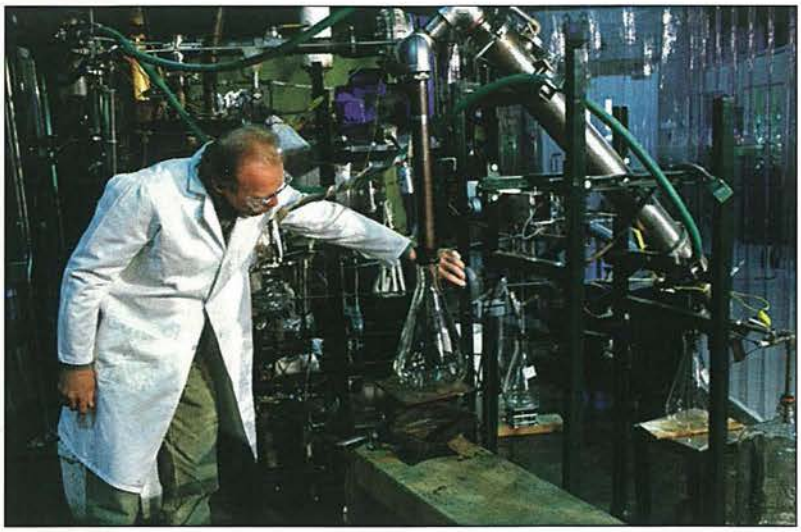


Figure 9.

from landfills increased. Between 1938 and 1966, the number of municipal incinerators fell from nearly 700 to about 265.

Early experiments with waste-to-energy didn't fare well, either. In 1905, New York City launched a project to combine a rubbish incinerator with an electric lighting plant. It was supposed to illuminate several city structures and the Williamsburg bridge, but little came of it. Before World War I, Milwaukee, Wisconsin, Minneapolis, Minnesota, Seattle, Washington, Rochester, New York, Miami, Florida, and Savannah, Georgia, operated waste-to-energy facilities, but without notable success.

Waste-to-energy's relatively high costs deterred significant development of the technology in the United States for many years. Incineration, ocean dumping, and landfilling were all less expensive modes of garbage disposal than energy conversion. Coal, oil, and natural gas were plentiful and much less expensive resources for producing steam or electricity than solid waste. These factors worked against the development of waste-to-energy technologies until the 1970s, when concerns about the environment and the nation's energy security led to interest in waste-to-energy conversion.



NREL/PIX03677

Innovative technologies such as pyrolysis produce gas and oils from waste by heating it.

When U.S. cities decided to invest in waste-to-energy technology, most selected designs were based upon European technology. Switzerland, Germany, and other European nations had actively developed waste combustion technologies since the 1920s. With less land, more expensive fossil fuels, and sizeable district heating requirements in many cities, these countries had greater incentives to develop waste-to-energy systems. By the time the United States was ready to explore waste-to-energy, the Europeans had already developed modern, efficient waste combustion plants.

"The modern municipal waste-to-energy plant is cleaner than the modern coal plant because EPA regulations say it will be. So from an environmental standpoint, we are better off with a waste-to-energy plant."

– Donald K. Walter, former Municipal Solid Waste Program Manager, U.S. Department of Energy

The U.S. Navy built the first modern U.S. waste-to-energy plants, which began operation at the Portsmouth and Norfolk, Virginia, Naval Stations in 1965 and 1970, respectively. Both facilities were designed for waste reduction and steam production.

The 1970 Clean Air Act opened the door to the development of a U.S. waste-to-energy industry. Open-burning dumps were banned. Old-style incinerators were forced to install costly pollution controls or shut down. In 1970, only about 160 incinerators remained in operation. As incineration declined, waste-to-energy conversion took its place. By 1975, four cities had modern waste-to-energy plants using European technology. Several U.S. companies acquired licenses to build plants based on European designs.

European-designed mass-burn facilities used water-wall furnaces. Originally developed for coal and adapted to solid waste, the huge furnaces were lined with water-filled tubes to capture the radiant heat of combustion. The "water-wall" design was more efficient than the fire box and boiler systems used in older facilities. Modern plants using this design can produce 600 kilowatt hours (kWh) to 700 kWh of electricity per ton of solid waste.

The 1973 energy crisis focused the nation's attention on the need for alternative domestic energy resources such as solid waste. Researchers began developing new fuels called refuse-derived fuels (RDF) made from waste. More than half a dozen different kinds were developed. The densest materials were developed to be burned with coal in a utility or industrial boiler. Researchers developed a series of techniques for making RDF. They were designed to separate non-combustible materials such as metal and glass from paper, plastics, food, textiles, and so forth. The techniques included shredding the waste to reduce particle size, separating metals and glass from mixed wastes with magnets or by hand, passing wastes through screens or a rotating drum known as a trommel to separate wastes by size, passing waste through air currents to separate light and heavy materials, and pelletization.

The Bureau of Mines pioneered RDF production as part of its research on materials recovery. Private industry, the EPA, and the National Center for Resource Recovery were also active in efforts to make RDF from municipal wastes. Union Electric's Meramec station in St. Louis, Missouri, was the first American utility to burn RDF with coal in a utility boiler. The pioneering project, which ended in 1975, led to several other large projects. The first of these, which came on line in 1975 in Ames, Iowa, operated for 20 years. The modern descendants of these plants

can extract up to 700 kWh of electricity per ton of processed solid waste.

The 1976 Resource Conservation and Recovery Act provided funds for the development of new waste disposal technologies by ERDA and DOE. Until the early 1980s, EPA and DOE supported industry in experimenting with innovative technologies such as pyrolysis, which produced gas and oils from waste by heating it. During the late 1970s, nearly two dozen pilot projects were built to demonstrate new technologies. In some cases, large plants were built before engineers understood basic processes well enough to scale them up successfully. Many demonstration projects proved to be expensive and unreliable in comparison with the mass-burn technology recently imported from Europe.

The fledgling waste-to-energy industry grew rapidly in the 1980s. The 1978 Public Utility Regulatory Policies Act (PURPA) set the stage for this growth. PURPA required that utilities purchase electricity from small power producers, including waste-to-energy plants. By guaranteeing a market, PURPA made it easier for new waste-to-energy projects to obtain financing. Shortly after PURPA was enacted, DOE and EPA funded feasibility studies of waste-to-energy facilities in dozens of cities.

During the 1980s, federal monies flowed to states, municipalities, and industry for planning and technology development. The lure of money brought new businesses into the waste industry, increasing competition. Approximately 46 new waste-to-energy facilities were built in the early 1980s. During this period, about 15 U.S. companies were marketing mass-burn systems, the majority based on European technology. The misperception that landfill space near cities was declining fueled industry growth during this time.

The 1986 Tax Reform Act accelerated the growth of the trash-to-energy business. The law "grandfathered" nearly 100 projects already in the planning stages or under construction, making them eligible for federal tax credits through the end of the decade. Otherwise, the tax credits would have expired in 1986. By 1989, 56 major new waste-to-energy facilities and 27 smaller plants had opened. The smaller plants processed less than 100 tons per day of waste to produce steam.

The expansion of the waste-to-energy industry slowed during the early 1990s. The favorable tax benefits disappeared. Competition developed with larger, modern landfills, forcing the industry to lower its prices. Industry growth was also hindered by the misperception that recycling could single-handedly solve the nation's waste disposal problems. Public officials postponed dozens of waste-to-energy projects in favor of recycling programs.

To make matters worse, the public's trust in municipal waste management declined to an all-time low. Repeated (mis)perceptions of garbage crises spawned widespread "Not-In-My-Backyard," or NIMBY, reactions. In many cities, residents opposed the siting of any type of waste disposal facility in their neighborhood. NIMBY attitudes took a particularly heavy toll on the waste-to-energy industry.

In May 1994, the Supreme Court (in C&A Carbone v. Town of Clarkstown) declared that "flow control" laws were unconstitutional. Flow control ordinances allowed municipalities to dictate which disposal sites would be used for wastes generated within their jurisdiction. Cities had traditionally used the laws to protect sizeable investments in waste-to-energy facilities, which require high volumes of waste to operate efficiently and be profitable. The lawsuit was instigated by a waste hauler who wanted the freedom to take his garbage to a less expensive landfill

NREL/PIX01003

Prior to the 1970s, waste-to-energy had little interest in major cities because coal, oil, and natural gas were plentiful and much less expensive resources for producing steam or electricity than solid waste.

Comparing the Emissions from Coal-Generated Electricity to the Emissions from Municipal Solid Waste Combustors

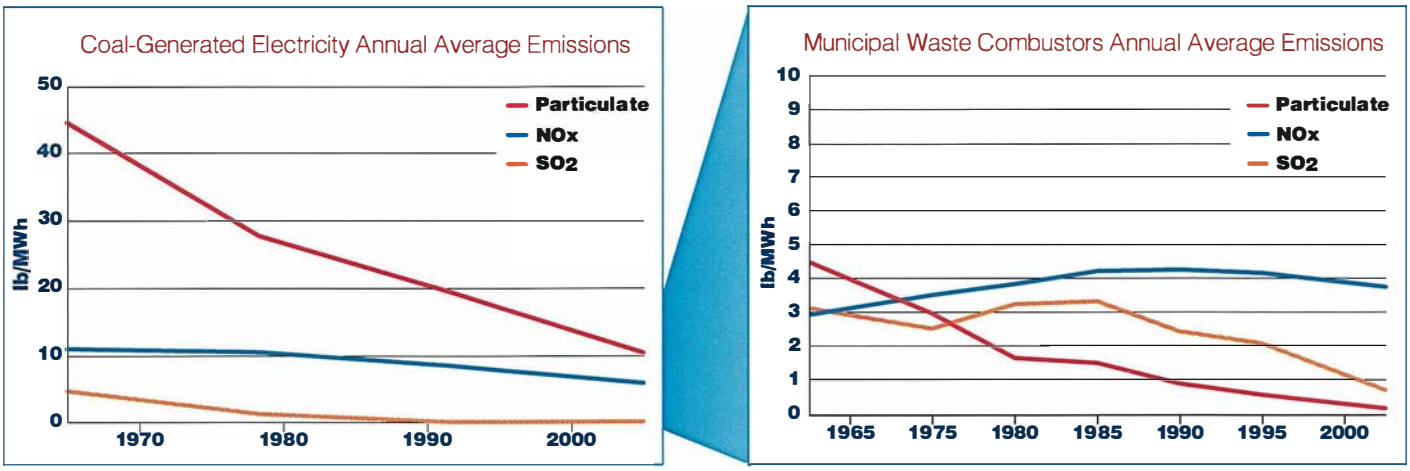


Figure 10. The emissions from municipal solid waste combustors are significantly less than emissions from coal-fired power plants. Note the differences in scales. Emissions from MSW plants are more heavily regulated than those from coal-fired plants.

rather than to a waste-to-energy plant. The Supreme Court decision appeared to be a major setback for both the waste-to-energy industry and cities relying on the technology for waste disposal.

Reaction to the law was swift: Solid waste projects went on hold across the country. Congress began debating new flow control legislation to protect municipal investments in waste-to-energy plants. Although Congress may eventually pass such legislation, this did not occur in 1995. In the meantime, haulers in other parts of the country sued for the right to deliver wastes to the least expensive site. Industry analysts raised concerns that the Supreme Court decision might lead to an increase in landfilling, currently the least expensive disposal option.

The waste-to-energy industry faced other challenges in 1994. In May, the Supreme Court ruled (in CBE v. City of Chicago) that waste-to-energy facilities must periodically prove that their combustion ash is not hazardous. Failure to pass toxicity tests meant that combustion ash would have had to be treated prior to disposal. However, two years of tests have shown it to be consistently nontoxic. Generally speaking, the ruling appeared to hold little import for the waste-to-energy industry.

In 1995, EPA issued more stringent emissions standards for new waste-to-energy facilities. The standards were endorsed by the Integrated Waste Services Association, which worked with EPA in developing the final version of the standards.

Even before the new standards were proposed, modem waste-to-energy facilities produced less air pollution than coal-fired power plants. By law, all waste-to-energy combustion units already had air pollution controls such as wet or dry scrubbers, baghouses, and electrostatic precipitators. Newer facilities also used dry scrubbers and baghouse filters in conjunction with advanced technologies to control the emission of acid gases. Figure 10 compares emissions from waste-to-energy plants with coal-fired electrical generation.

In spite of regulatory and other obstacles, 37 waste-to-energy facilities were built between 1990 and 1995. Today, more than 1,300 communities in 34 states recover energy from their wastes by burning them, according to the Integrated Waste Services Association. In 1995, the nation had a total of 148 waste combustors. Of these, 121 recovered energy using either mass-burn or RDF technologies. Waste-to-energy facilities processed nearly 100,000 tons of trash each day and generated enough electricity to power approximately 1.2 million homes.

Mass-burn technology dominated the waste-to-energy industry, both in terms of solid waste processed and in number of facilities. Nearly 70 facilities used the technology to process more than 70,000 tons of

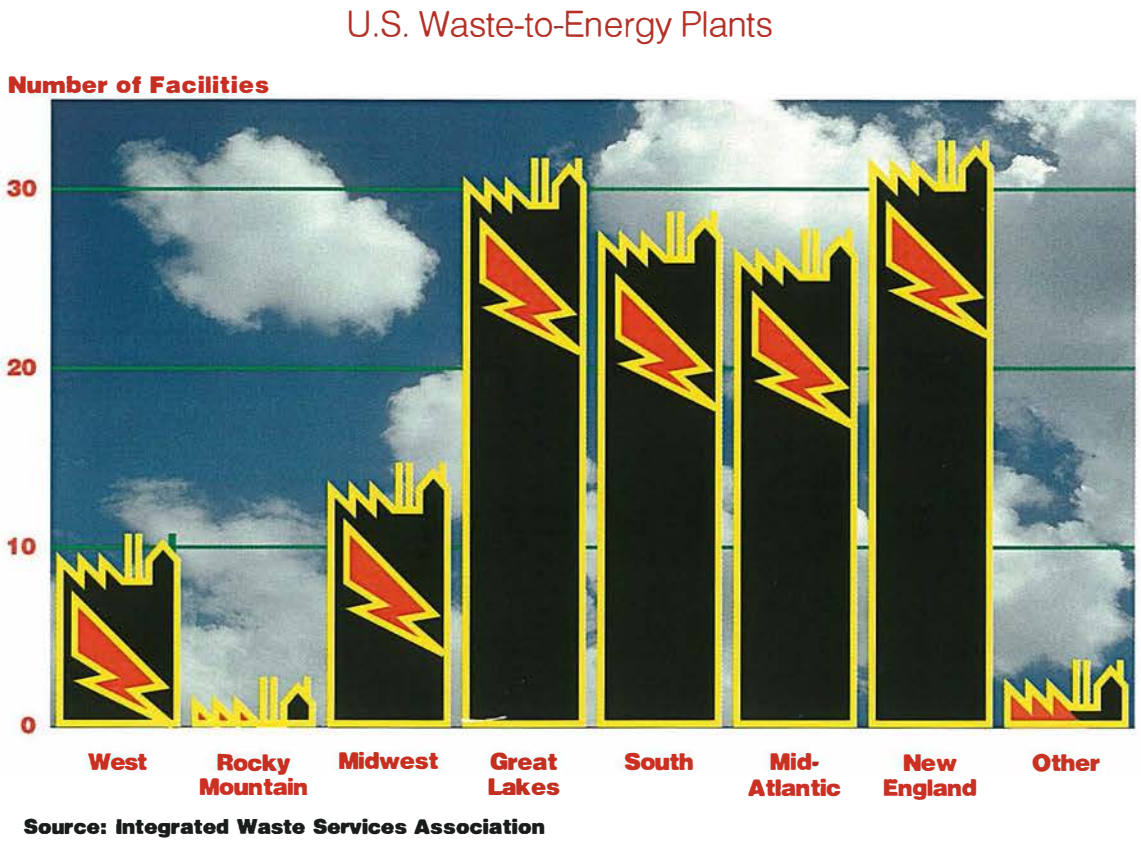


Figure 11.

trash each day. Refuse-derived-fuel plants handled about 26,000 tons of trash a day — slightly more than one-fourth of the solid waste recovered for energy. Small, modular units accounted for about 3% of the total.

Most waste-to-energy capacity was located in Florida, New England, and the Mid-Atlantic states. These densely populated areas have high rates of municipal waste generation and relatively little land suitable for landfilling. In such areas, energy recovery from solid waste is an essential part of integrated waste management. Figure 11 shows the number of waste-to-energy facilities by region.

Biological Processing

Microorganisms can recover energy from wastes. When researchers began investigating biological processing during the 1970s, they focused on using microbes to transform wastes into either alcohol fuel, a gasoline substitute, or an energy-rich "biogas." Biogas is 50% to 60% methane, the main ingredient in natural gas. It can used to produce heat or electricity.

Jerry Roy, Black & Veatch/PIX03682

On the island of American Samoa, a container ship is loaded with cans of tuna bound for California. The island is the site of a major tuna processing plant that produces waste that is high in fat, oil, and grease. NREL is exploring whether an anaerobic digestor can convert the waste into renewable energy on the island.

Anaerobic Digestion

When microbes decompose wastes in the absence of oxygen, the process is called anaerobic digestion. Anaerobic digestion can be a very efficient process under controlled conditions inside an air-tight vessel. Anaerobic digestion occurs in a haphazard and unpredictable fashion in landfills. Not surprisingly, anaerobic digestors produce two to four times as much methane in a few weeks as many landfills produce in a decade or more.

One early treatment for wastewater was to remove solid matter by letting it settle out in septic tanks, where the foul-smelling sludge was digested by anaerobic bacteria. In the early 1900s, Karl Imhoff developed an innovative digestor that eliminated problems with odors and produced a residue that could be burned, used as fertilizer, or landfilled. By the 1930s, half the U.S. wastewater treatment plants used his design.

The success of using anaerobic digestion for sewage sludge inspired researchers to evaluate the technique for solid waste disposal. The Public Health Service began studying anaerobic digestion of municipal wastes in 1969. Researchers wanted to learn how to convert as much solid waste as possible to biogas. At first, the project's goal was to reduce the volume of waste rather than to use the biogas for energy.

In the wake of the 1973 energy crisis, researchers began exploring ways to productively use the biogas from anaerobic digestion. The National Science Foundation's Research Applied to National Needs (RANN) program funded an industry project to build and operate an anaerobic digestor at the Pompano Beach, Florida, landfill. In 1976, ERDA took over the RANN project, passing it along to DOE in 1978. DOE operated the Pompano Beach digestor, which processed 50 to 100 tons of trash per day, between 1978 and 1985. The experience allowed researchers to better understand the process of anaerobic digestion and to define engineering requirements for a commercial-scale demonstration project.

After 1985, DOE supported additional studies of anaerobic digestion. As part of this effort, the National Renewable Energy Laboratory (NREL) developed a high-solids digestor for methane production. The digestor uses microbes that occur naturally in wastes to transform garbage and other wastes into a methane-rich biogas and compost. In developing the new digestor, NREL researchers created a technology that combined techniques for sewage treatment with backyard composting.

The high-solids digestor produces more biogas, at a lower cost, than conventional digestors. It uses less water and processes as much solid waste in a day as ordinary reactors 20 times its size. For these reasons, the new technology's economic prospects appears bright.

The digestor works best when trash is mixed with oily food wastes such as tuna sludge. This feature is a

NREL/PIX03679

The National Renewable Energy Laboratory has a high-solids disgestor for methane production. The digestor uses microbes that occur naturally in wastes to transform garbage and other wastes into methane-rich biogas and compost.

key selling point. Fat, oil, and grease are common wastes in the food industry, and their disposal is difficult. A pilot plant using the new technology began operation in California in early 1996. It processes refuse-derived fuel mixed with tuna sludge from a local cannery.

Information on pilot plant operation will permit the design of commercial systems for islands and other communities that must manage both food and municipal solid wastes. On the island of Tutuila in American Samoa, for example, there are two large tuna canneries. Together, they produce about 200,000 gallons a day of tuna sludge. The island also has insufficient landfill capacity to manage its residents' garbage. NREL's high-solids digestor offers a good solution for both of these waste problems. The digestor could also provide the island with biogas to fuel electrical power generation and compost to enhance its impoverished volcanic soil.

Landfill Gas Recovery for Energy

Over time, microorganisms inside landfills break down food and yard wastes, paper, textiles, and similar wastes. In the process, they create a biogas composed of methane, carbon dioxide, and trace amounts of other gases. Landfills eventually emit these gases to the atmosphere. Pockets of methane can also accumulate inside a landfill, causing fires or explosions. For this reason, larger landfills are now required to collect landfill gas.

During the 1970s, researchers discovered that it was relatively easy to collect at least some of the biogas produced in a landfill. Sink pipes into any landfill and gas comes out. Depending upon the sophistication of the piping system, the pipes will collect between 30% and 85% of the gases generated by the waste. In the majority of landfills, collected gases are flared.

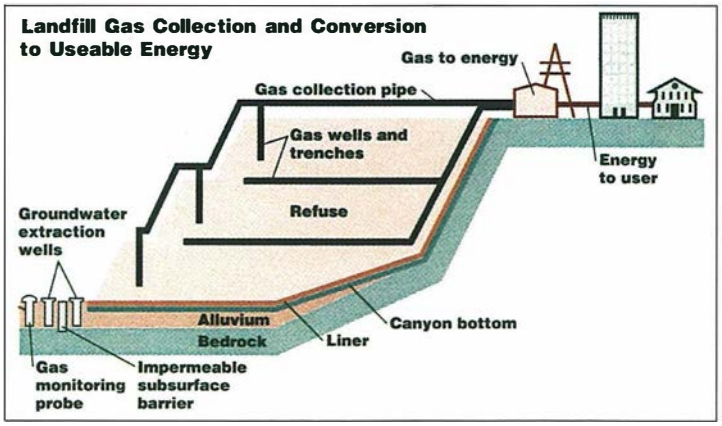
Also during the mid-1970s, ERDA and EPA worked with California utilities and private industry on gas recovery from landfills in Palo Alto and Mountain View. The agencies discovered that the biggest technical challenge in recovering energy from landfill gas was in cleaning the gas, removing water from it, and enriching the methane fraction. Cleaned and conditioned landfill gas can be sold as a substitute for natural gas, burned to produce heat, or used to operate gas turbines to produce electricity.

Less than 5% of the nation's 3,558 landfills operate landfill-gas-to-energy plants. The nation's 200 largest landfills, with capacities in excess of 1,000 tons per day, are the most likely to include energy recovery facilities. The quantity of gas generated by them is sufficient to justify the expense of producing electricity, process heat, or pipeline-quality gas.

Alcohol Fuels from MSW

Like alcoholic beverages, alcohol fuels can be produced by fermenting plant materials with yeast or other microorganisms. The microscopic creatures live off carbohydrates like starch and cellulose in biomass, producing alcohol as a by-product. Military scientists studied the process at the Army Quartermaster Laboratories in Natick, Massachusetts, after World War II. The project was initiated to understand why U.S. soldiers' cotton clothing had rotted so quickly in the South Pacific.

The cause turned out to be an alcohol-producing bacterium that fed on cotton. The discovery of the new microorganism meant that researchers could develop methods for making alcohol fuels from biomass, including solid waste. Like cotton and other biomass, municipal waste contains a lot of cellulose. Cellulose is a major constituent of wastepaper, textiles, yard wastes, and even some foods. Animals, and most microbes, including yeast, cannot digest cellulose, however. Therefore, traditional methods for making alcoholic beverages from starch would not work with cellulose.



NREL

Efforts to develop the technology to make alcohol fuels took off following the 1973 energy crisis. The goal was to develop renewable transportation fuels from solid waste and energy crops. (Energy crops are fast-growing trees and grasses grown specifically for energy use.) Using techniques from microbiology and genetic engineering, NREL researchers developed a method for converting cellulose, which comprises about 71% of solid waste, into alcohol fuel.

Making alcohol fuel from municipal waste begins with the collection and delivery of wastes to a materials recovery facility. There, glass, metals, plastics, and other materials unsuitable for ethanol production are removed. As soon as cellulose-rich materials are relatively free of contaminants, they undergo a mechanical milling process to reduce their size and make fermentation work better. Up to this point, the process is similar to making refuse-derived fuels.

"In our research with Amoco to make alcohol fuel from MSW, we used newsprint, old corrugated cardboard, white office paper, and magazines mixed together in similar proportions to what's found in a landfill. We chose this mixture because most paper is destined for a landfill, is easy to obtain, and low in cost — and we don't want to compete with recycling."

– George P. Philippidis, National Renewable Energy Laboratory

Next, the method uses both chemicals and enzymes to break down cellulose into sugars, which are fermented into alcohol by yeast and bacteria present in the reaction mixture. After fermentation, the "beer" containing the alcohol is removed for distillation to pure ethanol. The enzymes, bacteria, and yeast are recovered and recycled back through the fermentation system. Residue is removed and used as a boiler fuel to provide energy for fuel production.

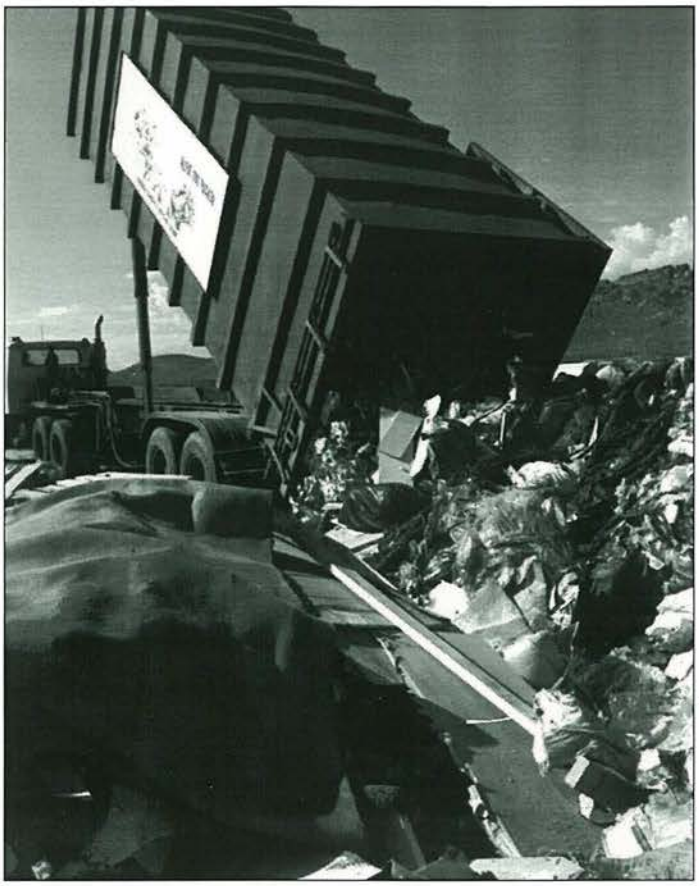
To test its fuel production system, NREL built a pilot plant to process a dry ton per day of biomass into alcohol. One project under way at the facility in 1995 was a six-year cooperative research and development agreement between the Laboratory and Amoco Corporation. Amoco wanted to develop a process to economically transform wastepaper and yard trimmings into alcohol fuel.

Landfilling

Open dumping is the world's oldest method for getting rid of garbage. It is also the most problematic. As practiced in American cities until the 1970s, it was unsightly, foul smelling, and dangerous. It encouraged flies, rats, and other vermin. In 1972, more than 14,000 municipalities had open dumps. Many allowed the burning of wastes in them, whether this occurred by accident or deliberately. To make matters worse, there were as many as 10 unauthorized dumps for every legal municipal dump. Despite obvious drawbacks to this disposal method, it took the nation a long time to find an alternative. It took even longer to figure out that sanitary landfilling could also seriously threaten environmental quality.

The British developed sanitary landfilling during the 1920s, calling it "controlled tipping." At first, the method consisted of covering newly deposited wastes with a layer of soil each day. New York City and Fresno, California, built the first American sanitary landfills in the 1930s. The Public Health Service endorsed sanitary landfilling in 1940 for its ability to protect the public health by controlling rats and mosquitos in swamps and marshes. Unfortunately, Americans were unaware that landfills could also contaminate groundwater and destroy wetlands.The conventional wisdom was that landfills should be sited in ravines, swamps, and abandoned sand and gravel pits. They were supposed to be covered with sand rather than clay to discourage rats from burrowing.

The U.S. Army Corps of Engineers experimented with sanitary landfilling during World War II. The Corps evaluated the method's ability to protect the health of soldiers stationed at American bases during the war. The Army's success with landfilling encouraged several cities to adopt the technique after the war. Unfortunately, public health officials had little understanding of either the causes of or remedies for pollution.



NREL/PIX03684

Landfilling is still the preferred way for most cities and towns to get rid of their garbage.

A 1954 study of the Riverside, California, landfill concluded that sanitary landfilling would not pollute groundwater so long as the landfill itself was not in contact with groundwater. This conclusion was the basis for U.S. landfill design for nearly 20 years. Unfortunately, the conclusion was valid only for a semi-arid region with relatively impermeable soils such as Southern California.

Public works officials continued to believe sanitary landfilling protected land and water from pollution — even when evidence of contamination began to surface during the 1960s. A 1961 report from the American Society of Civil Engineers enthusiastically endorsed sanitary landfilling. The report also discussed and dismissed a minority opinion that groundwater pollution was occurring in 20% to 50% of sanitary landfills. With benefit of hindsight, it is clear that this estimate was low.

In the mid-1960s, the practice of building residential or commercial structures on top of closed landfills came into question. In 1966, row houses built just seven years earlier had to be demolished when an unstable landfill beneath the houses caused floors to tilt and walls to crack.Within a few years, landfill gas explosions in Richmond, Virginia, and Commerce City, Colorado, created additional concerns regarding the wisdom of building housing developments over old landfills.

Environmental publications were openly critical of sanitary landfilling by the early 1970s. They argued that landfills not only contaminated groundwater, but also produced noxious fumes and explosive concentrations of methane gas. Curiously, a 1971 EPA report entitled "Sanitary Landfill Facts" continued to endorse the long-standing idea that pollution from sanitary landfills was rare. It did, however, recommend siting landfills well away from streams, lakes, wells, and other water supplies. Within a few years, public officials finally realized that groundwater was far more vulnerable to landfill pollution than they had been taught.

Meanwhile, public opposition to new landfills had grown increasingly strident. New landfills had to be sited in distant locations, giving rise to increased transportation costs. By 1975, it had become impossible to site a landfill in a swamp or other wetland area — the very areas once considered ideal for landfilling.

"The United States is land rich. That means it's easy to put wastes in a landfill where they're out of sight, out of mind."

– Robert Landreth,
U.S. Environmental Protection Agency

A single misconception was responsible for the decades of groundwater pollution caused by sanitary landfilling. Public officials believed that the ground beneath the earth's surface had nearly a limitless capacity to absorb and filter even the most toxic chemicals. This myth was dispelled by advances in analytical chemistry in the mid-1970s. Sensitive new

SWANA/PIX03625

During the 1970s, sanitation services remained about the same as they had been for most of the 20th century. In this photograph, taken in the 1970s, a worker unloads wooden pallets for burial at a sanitary landfill .

tests showed unequivocally that many of the nation's aquifers were contaminated with toxic and carcinogenic chemical compounds. These were the same compounds that were ubiquitous in the liquid formed inside a sanitary landfill.

The liquid, called leachate, is created when water percolates through wastes, extracting toxic chemicals from industrial wastes, household chemicals, and sewage sludge buried along with solid waste. Many chemicals present in leachate moved freely into groundwater systems and persisted there for years. The chemicals passed freely through the permeable soils recommended for landfilling during the 1960s and 1970s. Once this was understood, landfill designs incorporated leachate detection, collection, and removal systems. The nation's prolonged ignorance of the consequences of indiscriminate, unregulated waste disposal on land was finally over. However, recriminations and finger-pointing continued for another decade.

By the late 1980s, improved landfill technologies and methods were widely used. By the early 1990s, EPA codified this new knowledge into a stringent set of regulations under Subtitle D of RCRA. Today, landfills must be sited away from aquifers, rivers, lakes, and oceans and lined with dense clay and, in some cases, a flexible membrane (plastic) sheet. They must be designed to keep moisture from flowing into or out from the landfill. They must be operated to minimize the formation of leachate, and collect and treat leachate that does form as wastewater. Groundwater near the landfill must be monitored for contamination. Methane gas must be collected and vented or flared. Landfill operators must cover new wastes each day with soil to eliminate odors and control vermin. After closure, the landfill must be sealed with a clay cap or flexible-membrane liner. Closed landfills should be developed for other uses such as a park or golf course.

These features help prevent landfills from polluting nearby land and water. But, that's all they do. Researchers need to learn much more about what happens inside a landfill before newer, more advanced designs can be developed. It is not even clear whether the basic design, which prevents water from entering and keeps liquid inside the landfill to a minimum, is the best solution to the pollution problem. At present, landfill design is dictated by regulation, not scientific consensus.

Landfill regulation and efforts to contain costs led to the creation of huge regional landfills, which accept wastes from many cities. In many cases, the landfills accepted wastes from other counties and even other states. Wastes were often transported long distances for disposal, where they were conveniently out of sight and readily forgotten by the public. As a result, there has been little public interest regarding the environmental impacts of long-distance waste transport and the generation of greenhouse gases inside landfills.

In contrast, European nations are taking major steps to reduce landfilling. Several nations have curtailed landfilling of food, paper, textile, and other wastes that undergo biological processing, creating methane and leachate. The restrictions are expected to lead to significant increases in the number of waste-to-energy combustion plants and in biological waste management such as composting. Solid waste professionals in the United States are closely monitoring these developments.

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The Future of Waste Management

Ideally, advances in waste management systems will come out of a broad scientific and technical understanding of the environment, rather than from simply responding to regulations. There is much to be gained from in-depth analyses of the role of waste generation in maintaining a healthy economy and from collaboration on waste management at the local, state, and national levels. The waste management industry and federal, state, and local governments all have roles to play in developing improved waste management technologies and methods for the 21st century.

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