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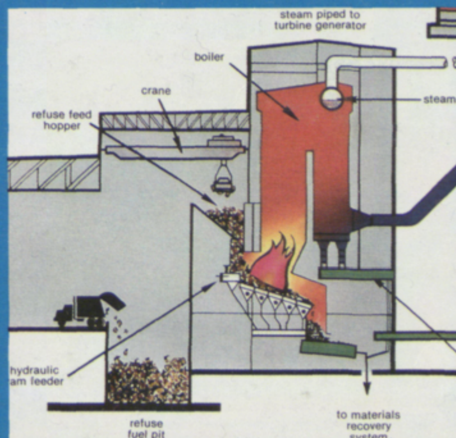

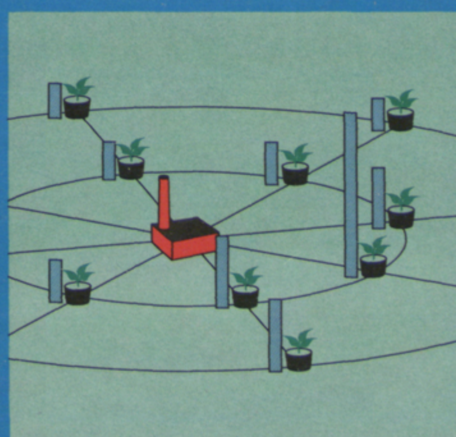

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SUMMER 1990

DEALING
WITH
WASTE


Coca-Cola
CLASSIC
diet Coke
Caffeine Free
PEPSI

IN THIS ISSUE

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Outside cover illustrations: The Cornell Waste Management Institute logo (at upper right) and illustrations pertaining to some of its components: recycling, combustion (see page 21), landfill disposal, and environmental concerns (see page 32).

The cover is printed on recycled paper.

Schuler

Harrison

Raymond

Gouldin

Ditz

Martin

DEALING WITH TRASH
Cornell's Program in Solid Waste Management

As dumps and landfills across the United States leak or reach capacity, the need for better facilities, new sites, and alternative means of disposal is mounting along with the garbage itself.

The Cornell Waste Management Institute (CWMI) was formed in 1987 to address the technical, environmental, socioeconomic, and community problems that are involved in the solid waste crisis. A sister organization, the New York State Solid Waste Combustion Institute (SWCI), was also created in 1987 as an independent entity located at Cornell. The university, with its ready access to the Cornell Cooperative Extension network and to facilities such as the Cornell National Supercomputer Facility, as well to faculty and staff expertise in many disciplines, has become an effective research, training, and extension center in solid waste management. Both institutes are directed by Professor Richard E. Schuler (who contributes the lead article in this issue).

CWMI, which is part of the university's Center for Environmental Research, receives administrative and staffing support from the university, but depends on outside funding for its programs. The largest single source of funds is the State of New York (through SWCI), which has budgeted $5 million over a three-and-one-half-year period for the Combustion Simulation Laboratory at Cornell, for incineration-related external research awards, and for applied research and outreach activities. SWCI, in turn, receives help from Cornell through CWMI; this is in the form of the services, staff, and facilities.

CORNELL WASTE MANAGEMENT INSTITUTE

Richard E. Schuler, Director
Frederick C. Gouldin, Director of the Combustion Simulation Laboratory
Ellen Z. Harrison, Associate Director
Steve Kulick, Research Coordinator
Daryl Ditz, Senior Extension Associate
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Major Outside Funding Sources:
New York State Solid Waste Combustion Institute (the State of New York)
New York State Energy Research and Development Authority
New York State Department of Environmental Conservation
New York State 4-H Foundation
National Science Foundation
Hewlett Foundation

CWMI promotes and conducts research and disseminates research results. Technical assistance and training programs throughout the state follow from the research and often utilize the Cornell Cooperative Extension county network. Regional workshops and tours of facilities are also arranged. To support the educational programs, the institute provides an array of educational resources (see the article in this issue by Ellen Z. Harrison).

CWMI also provides technical assistance, without charge, to communities that have concerns associated with the management of garbage disposal. Typical concerns are the compatibility of recycling and incineration, emerging waste-treatment technologies, the assessment of health risks, and the adequacy of environmental impact statements for waste-to-energy facilities.

In addition, members of CWMI participate in Cornell's instructional program. Last fall Schuler and Daryl Ditz (author of an article here) introduced an interdisciplinary course that addressed technical, economic, and policy issues in solid waste management.

SWIC sponsors research at the Combustion Simulation Laboratory at Cornell (see the article by the director, Frederick C. Gouldin, in this issue) and also at various universities in New York State through a competitive, peer-review process. Funding for the external projects amounts to more than $1.5 million. The two- or three-year projects that have been funded, and the investigators, are listed in the table. The awards are intended to improve the environmental and energy implications of combustion and digestion of solid wastes.

A combustion research working group has been established by SWIC to bring together representatives of the universities, where much of the research is conducted, and representatives of industries that might benefit from the research. People from government, industry, and other universities are also involved in SWCI as members of its executive committee and its technical advisory committee.

Research, education, and community outreach: these are the functions of the sister institutes. The activities, Schuler said, "greatly enhance the ability of the state's policymakers to provide economically sound and environmentally safe solutions to the solid waste crisis." And because "solutions must be forged by an alliance between legislators and citizens," the institutes provide a wide array of resources for local officials, solid waste specialists, schools, environmental groups, and the public in general.

Some of the programs are described in the articles in this issue. Further information is available from the Cornell Waste Management Institute, 470 Hollister Hall, Ithaca, NY 14853; 607/255–7535.

CURRENT RESEARCH PROJECTS
A Selected List

Development of a Plant Biomonitoring System for Air Toxics. Research jointly conducted by staff from the Cornell Waste Management Institute (CWMI), the Boyce Thompson Institute for Plant Research (at Cornell), and the Ecosystems Research Center (at Cornell).

Cost and Emissions Impacts of Retrofit at Solid Waste Incinerators in New York State. An analysis of economic and environmental implications of new regulations.

Local Options to Encourage Waste Reduction. An analysis of laws and programs that can reduce the amount of solid waste.

Role of Host-Community Benefits in Siting Waste Facilities. A statewide survey and policy analysis carried out by CWMI, the Water Resources Institute (at Cornell), and faculty and staff members from the Cornell Departments of Communication and of Agricultural Economics.

The Tompkins County WastePlan© Project. An analysis of the economics of various recycling options, including the avoided costs of waste collection and disposal, using a new program for solid waste management planning.

Combustion Simulation Laboratory at Cornell. Development and evaluation of numerical simulation models; study of NO_x formation; analysis of pollution-control methods; study of combustion chamber flows. An experimental laboratory is under construction.

Changes in Attitudes and Behavior following Implementation of Volume Based Disposal Fees. Research jointly conducted by staff from CWMI, faculty members and students in Consumer Economics and Housing, and the Tompkins County Division of Solid Waste.

Solid Waste Combustion Institute: External Awards Program Projects

Mechanisms of PCDD/PCDF Formation in Incinerators. A U.S./Sweden collaborative study by Dr. Elmar R. Altwicker of Rensselaer Polytechnic Institute and Dr. Christopher Rappe of the University of Umea, Sweden.

Solid Waste Combustion Diagnostics: A study of the detection of chlorinated hydrocarbons in flue gases by Terrill A. Cool, Cornell professor of applied and engineering physics.

Characterization of Leachates from Municipal Incinerator Ash Materials. Research of Dr. Thomas Theis of Clarkson University.

Detection and Analysis of Waste Combustion Products by Analytical Spectroscopy—Spectral Signatures in the Presence of Overlapping Spectra. Research of George J. Wolga, Cornell professor of electrical engineering and of applied and engineering physics, and Frederick C. Gouldin, Cornell professor of mechanical and aerospace engineering.

Combustion of Chlorinated Ingredients of Municipal Solid Wastes. Research by C. Thomas Avedisian, Cornell professor of mechanical and aerospace engineering, in cooperation with the National Institute of Standards and Technology.

Oxidation Kinetics of Chlorinated Hydrocarbons at the Temperatures of Municipal Solid Waste Incineration. Research of Arthur Fontijn, professor of chemical engineering at Rensselaer Polytchnic Institute.

Analysis and Interpretation of Ash Data for Sampling Protocols. Research of Reza Khanbilvardi, professor of civil engineering at The City University of New York.

MUNICIPAL SOLID WASTE: CRISIS OR OPPORTUNITY?

by Richard E. Schuler

On this twentieth anniversary of Earth Year, pessimists can find much to vindicate their outlook: the worldwide emission of "greenhouse" gases is accelerating, global warming is upon us, and much of America is in the midst of a garbage crisis. But these are also the kinds of problems that stir the hearts of academics: they are challenging and multifaceted, and ultimately their solution will require better understanding of basic scientific and behavioral phenomena. As an example, at Cornell we have mounted—with substantial New York State support—a considerable effort to confront the nation's solid waste problem analytically, innovatively, and with regard for the welfare of people in their world.

The solid waste problem is hardly a recent phenomenon. Trash has been a product of all societies at all times, which is why archeologists infer much about ancient cultures by sifting through their wastes. But although the term "crisis" may be a bit hyperbolic, waste disposal as a public concern *is* recent. The increasing number of public debates about what to do with municipal solid waste in the United States is evidence of this.

A cause for some optimism is that the public discussion may afford us a unique opportunity for widespread consciousness-raising on environmental issues. While most people can avoid some environmental problems, everyone has to get rid of garbage—it's tough to avoid in an urbanized society—and as the trouble and cost of doing so increases, more attention will be given to issues of solid waste disposal.

If we can educate the majority of Americans to appreciate that what they get rid of is in some way related to what they buy, how it's packaged, the way in which it is distributed, how it is marketed and manufactured, and, as a very first step, what products are produced to begin with, public sensitivity to a whole stream of environmental interconnections might be increased. The slender but complex threads of cause and environmental effect will begin to come clear when consumers stop thinking of themselves as merely the passive victims of pollution by greedy industrialists, but rather as part of a problem they can do something about.

That is the optimistic side of a garbage-disposal crisis: it offers visible evidence of an issue that is linked not only to the environmental consequences of collecting, hauling, and disposing of trash, but also indirectly to pollutants generated along the path of each product's production, packaging, distribution, and use.

FACING UP TO PROBLEMS OF MUNICIPAL SOLID WASTE

But back to garbage! The ultimate ecologically balanced solution can be summarized as "ashes to ashes; dust to dust"; eventually our wastes must be returned to Earth in forms that are at least as diffuse in concentration and as nontoxic in composition as the original raw materials. Only when the *rate* of dispersion and return equals the *rate* of extraction will society have reached a sustainable equilibrium in terms of not poisoning itself and not constructing a landscape of solid waste.

Currently the average American produces a ton of municipal waste each year. In New York State alone that is the equivalent of filling one hundred football stadiums per year with compacted trash to the top of the grandstands. Garbage trucks lined up bumper-to-bumper on a four-lane highway stretching around the earth would

"The slender but complex threads of cause and environmental effect will begin to come clear when consumers stop thinking of themselves as merely the passive victims of pollution by greedy industrialists, but rather as part of a problem they can do something about."

be needed to load the trash Americans produce every year.

A problem is that in modern sanitary landfills, the wastes do not deteriorate rapidly because those landfills are designed as hermetically sealed cups to prevent toxic materials from leaking out. Little air can get into the compacted mass and biological deterioration occurs very slowly. Therefore, the actual rate of return of wastes to Earth is slower by at least a factor of twenty than the rate at which wastes are generated and dumped. No wonder our landfills are filling up and we need to look further afield for new sites! These landfill conditions explain why the anthropologist William Rathje, who has been digging up samples from landfills around the country, has uncovered thirty-year-old newspapers that are readable and carrots that are still orange under a dark outer crust.

In the United States we are fortunate that there is still a tremendous amount of land on which it is technologically possible to construct safe, modern, sanitary landfills. Unfortunately, the number of available sites close to our nation's population centers is declining. As we try to haul our solid wastes to new, more remote locations, not only do the transportation costs mount, but often so does the ire of residents who don't want to provide the dumping ground for other people's garbage.

The net result is that the total cost of collection, transport, and disposal is beginning to exceed $500 per household per year in our largest metropolitan areas. That amount would attract as much attention as bills for other utilities do, except for the fact that in most cities the cost of garbage collection and disposal is buried in general-purpose taxes. No wonder, then, that the amount of garbage each American generates has been increasing at 2 to 3 percent per year. I wonder how rapidly our use of electricity would be growing today if there were no charge for service.

There is, however, an important reason why trash collection has been provided "free" in large cities: we have a collective interest in ensuring that solid wastes are regularly removed from buildings and streets for sanitary, public-health, and esthetic reasons. For many Americans the only true solid waste crisis arises when the collectors are on strike and the garbage piles up on the curb.

LANDFILLING, INCINERATION, AND OTHER DISPOSAL METHODS

Landfilling isn't the only way of disposing of trash. Many communities have used incineration for decades and most modern incinerators in the United States, as well as many throughout Europe, use the heat that is released by the combustion to provide steam for nearby industries, to furnish space heating for community buildings, or to generate electricity.

Of course, there are problems, often similar to those faced by managers of sewage-treatment plants. A major concern is that the chemical composition of our wastes is becoming more and more diverse, raising the risk that toxic materials will ultimately be released into the environment. What is curious is that we place the burden of removing toxic materials on the operators of waste-disposal facilities, rather than on the producers who introduce the potentially toxic materials into their products to begin with. In between are the consumers, who have been accessories to the environmental damage for one important reason: they haven't had to pay directly for getting rid of those materials.

Regardless of where the responsibility

"The only certain way of reducing the burdens of waste on society is to produce less of it."

should lie, the fact is that a well-run modern incinerator with acid-gas scrubbing and particulate-removal equipment installed on the exhaust can do a remarkably good job of removing most of the toxic compounds in the waste stream. Of course, the fly ash in the stack (and also the bottom ash) must still be disposed of; approximately 20 percent of the original municipal solid waste volume must be shipped to a landfill in the form of ash.

The other major potential problem with incineration is that if the combustion process is not thorough, new compounds—in particular, highly toxic chlorinated hydrocarbons such as dioxins and furans—can escape destruction or can be formed during incineration. The exact way in which these compounds are formed is not completely understood, however. In fact, there is much about the fundamentals of combustion that is not understood. (At first blush this seems surprising, since people are almost as familiar with fire as they are with economics; perhaps that is why human society has never really bothered to completely understand either.) Throughout the centuries, fire has been used primarily as a source of heat, usually by burning homogeneous fuels. Under those circumstances, a micro-understanding of chemical reactions may not be necessary to improve thermal efficiency, but when we incinerate municipal solid waste—a heterogeneous and constantly changing raw material in which heat is only a byproduct and the major objective is to destroy the material in an environmentally benign way—there is need for detailed knowledge of the chemical kinetics and physical flows.

In addition to landfilling and incineration, waste-disposal methods that have been tried or are in use throughout the world include various processes that accelerate natural biological deterioriation, either anaerobically (in the absence of oxygen) or aerobically (with oxygen, as in composting). In the United States such processes are still in trial stages of development.

Everyone's favorite way of trying to eliminate waste-disposal problems is to implement household-waste separation and recycling programs. Not only can such programs reduce the volume of materials that must be disposed of by 20 to 40 percent, they can reduce the rate of depletion of natural resources and society's net use of energy in providing raw materials for production. More importantly, mandatory separation and recycling can raise people's consciousness about what they throw away.

Nevertheless, none of the alternatives to landfilling and incineration are capable of solving our nation's solid-waste problems totally in the long run. Even with a 40-percent rate of recycling and reuse, if the 2-percent-per-year annual growth in trash continues for the next seventeen years, we will have to dispose of the same amount of waste per year in 2007 as we do now.

Furthermore, many steps intended to reduce undesirable environmental consequences of a particular waste-disposal process frequently lead to unintended adverse impacts elsewhere in the waste-management system. The sanitary landfill, intended to protect neighbors from having runoff and leachate (liquids that ooze from the waste) migrate into surface and ground water, is an example; such a landfill slows the rates at which wastes degrade. And what is to be done with the leachate that is collected systematically from these modern landfills? Frequently it is trucked to and run through the community's sewage-treatment plant, where any residual heavy metals collect in the sewage sludge. But then what do we do with this sludge? One possibility is to de-water and incinerate it, but if there are efficient combustion and air-emission controls, most heavy metals will find their way into the ash, and the ash is deposited back in the landfill! So, the cycle of the metals goes on and on. We don't yet know whether the heavy metals are concentrating or diffusing in this cycle, and we don't know which would be better. This example demonstrates why solid waste problems must be studied in a systems-management context if we are to avoid secondary effects that are worse than the original problem we set out to cure.

Figure 1 illustrates the possible major elements of a waste-management system and the many possible feedback paths. We see, for instance, that even reuse and recycling may have some undesirable environmental side effects. These follow from the increased transport and associated vehicular emissions, as well as the impacts resulting from processing and from energy use. The benefits of yard-waste composting are especially significant if the municipal wastes are incinerated; this is because yard wastes literally place a wet blanket on the fire, which can lead to less efficient combustion and increased emissions. Furthermore, the nitrogen in leaves and grass causes increased production of nitrogen oxides in combustion.

STRATEGIES FOR WASTE REDUCTION

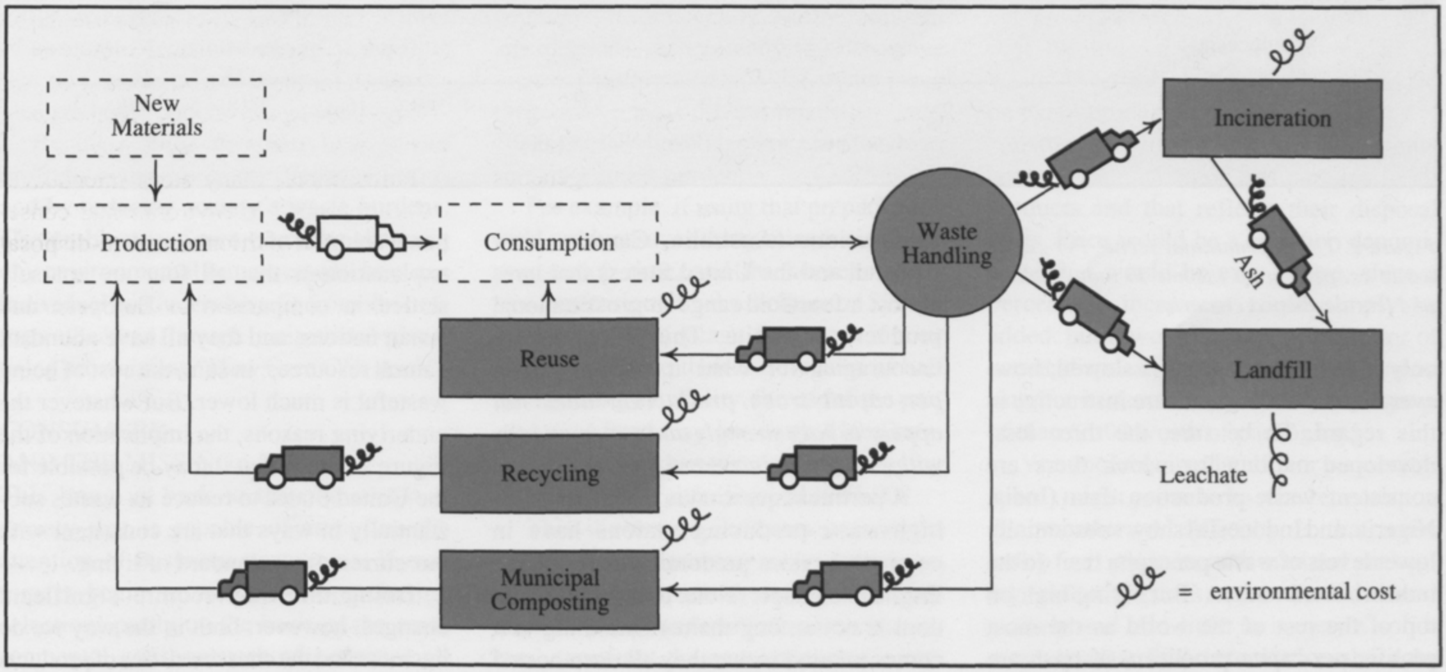
The only certain way of reducing the burdens of waste on society is to produce less of it. This strategy also seems to have fewer potential unintended environmental side effects than disposal methods do.

The greatest fear is that substantial reductions in waste volumes can be achieved

Figure 1. A comprehensive waste-management system (shown in color) illustrating how all of the alternatives for waste disposal carry some environmental cost.

Consumers can prevent some wastes from entering the system through such measures as reusing containers and carrying out proper yard-waste composting at home.

Figure 1



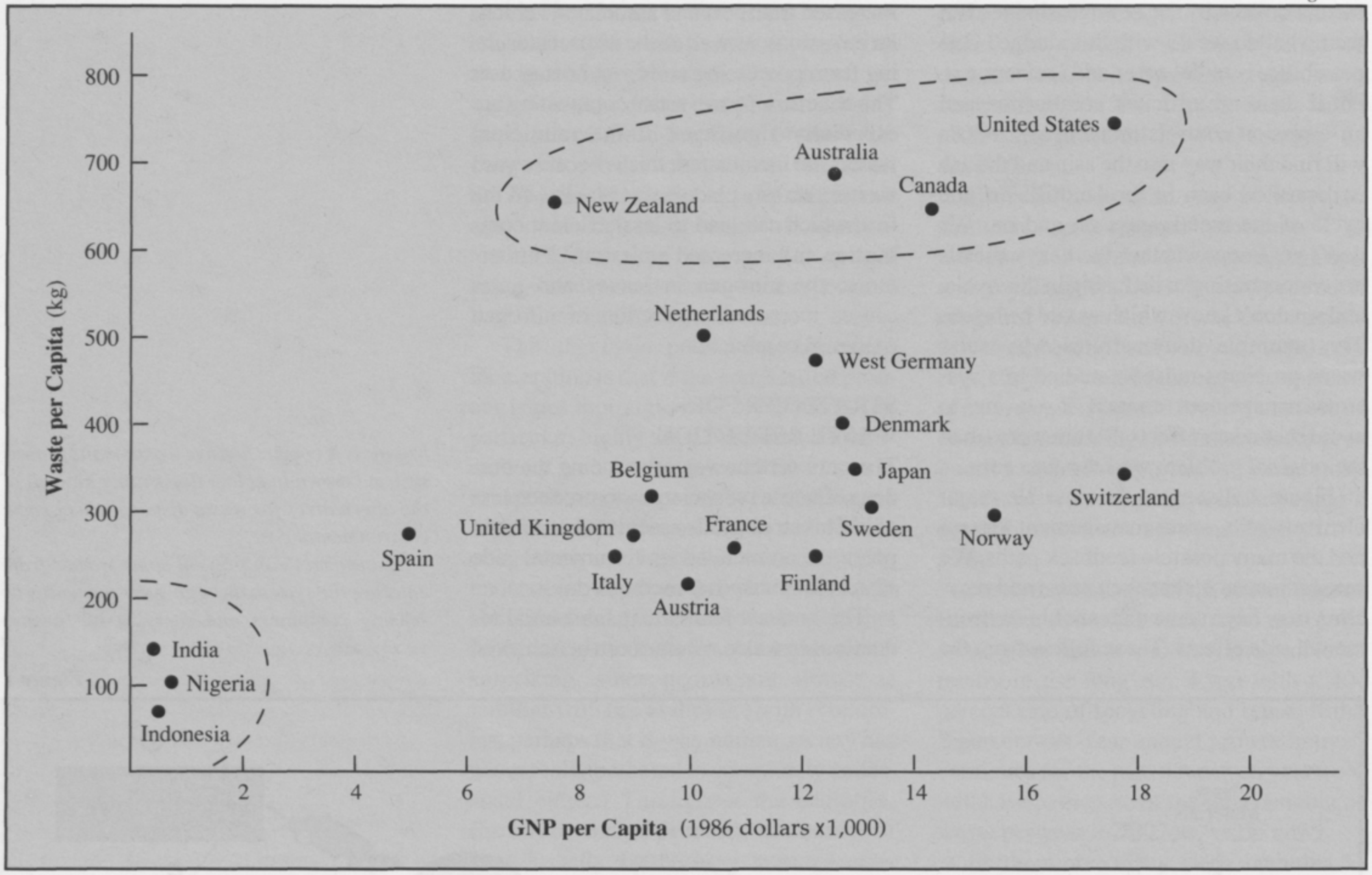


Figure 2. The international scene: Per-capita waste vs. per-capita income in industrialized and less-developed countries.

only if economic growth is slowed; however, the data in Figure 2 are instructive in this regard. To be sure, the three less-developed nations for which there are consistent waste-production data (India, Nigeria, and Indonesia) show substantially lower levels of waste per capita than do the industrialized nations. But sitting high on top of the rest of the world as the most prolific per-capita producers of trash are four nations (Australia, Canada, New Zealand, and the United States) that have almost a four-fold range in gross national product per capita. Thus, Figure 2 is encouraging for what it doesn't show: *per-capita trash production does not appear to vary strongly and systematically with per-capita income.*

A pertinent question is what these four high-waste-producing nations have in common besides predominant use of the English language. (Note: the United Kingdom is not among them.) One thing that comes to mind is that they all once hosted penal colonies of the crown. A more likely explanation is that all four are sparsely settled in comparison to European and Asian nations, and they all have abundant natural resources: in sum, the cost of being wasteful is much lower. But whatever the underlying reasons, the implication of the Figure 2 data is that it may be possible for the United States to reduce its wastes substantially in ways that are consistent with our current high standard of living.

Doing this may require significant changes, however, both in the way we do business and the characteristics of products we consume. Keeping and using products longer and repairing them when they fail means less to dispose of. How products are displayed and sold, the way they are packaged, how they are shipped, distributed, and advertised, and the materials used in manufacture all help determine our society's total waste burden.

What is required in American business is a new revolution like those that occurred in marketing in the 1960s and in manufacturing in the 1980s, bringing about new management practices: from the earliest stage of product inception, managers explore not only what products consumers might buy, but also how these products can be manufactured economically, and what the implications are for disposal of wastes generated in production. It is true that many United States corporations, from manufacturers to retail chains, are organizing environmental and/or waste-management divisions, but what is needed is for those groups to be represented at the highest level of corporate decision-making at the time that new product lines or business strategies are being conceived.

Business must discover how it can profit by being environmentally conscious and by reducing society's waste burdens. The problem is: Since everyone shares in any environmental improvement, how can individual producers benefit from their efforts other than through institutional advertising proclaiming "How Green We Are!"?

CONSUMERS AND THE MISSING LINK

This bring us back to the one sector of society that is capable of attracting the attention of business: consumers. If customers begin to make their purchasing selections partly on the basis of the environmental consequences of activities all along the chain of each product's manufacture, distribution, and disposal, industry is bound to stand up and take notice.

How can we spur the consumer to action? Public-spiritedness is an important first step, but again because of the collective nature of benefits from environmental improvement, consumers may be less willing to boycott otherwise attractive products just because of environmental problems if "everybody else" is buying them. Furthermore, the public's attention span with regard to any single societal problem seems to be limited to about two years, whereas environmental and waste-disposal problems are perpetual.

So while public education helps, we need to institutionalize desirable consumer behavior. We must find ways to overcome both inertia and an extremely strong force that exists in modern America: the importance attached to saving time, particularly in households in which several people are employed professionally. Many "convenience" goods, such as ready-to-microwave gourmet dinners, relieve the tremendous time burden on a professional household even as their packaging contributes to society's waste burden.

For example, if using that prepackaged food product saves thirty minutes in meal-preparation time, and the household has two professionals who both earn $20 an hour ($40,000 a year), then even if they were to evaluate their leisure time at half their earning capability, the use of the prepackaged item may be worth $10. Question: Should we ban that type of packaging if the cost of its safe disposal is $1.00?

This illustration indicates one reason why Americans generate so much trash: we are a highly impatient society. The situation is compounded by the fact that we rarely confront the economic choice outlined in the illustration, since the cost of disposal is not directly assessed on consumers. That is the missing link!

One way to establish this link would be to add a disposal fee to the purchase price of each product. For a community in which the total annual costs for waste collection and disposal amounted to $500 per household, a cost-based disposal fee might average ten cents per item for a household that buys one hundred items per week. While a charge of ten cents might not dissuade the professional household from purchasing extravagantly packaged food items, many households might respond to the economic incentive, as they do by returning bottles and cans in states that impose a deposit of five cents per container.

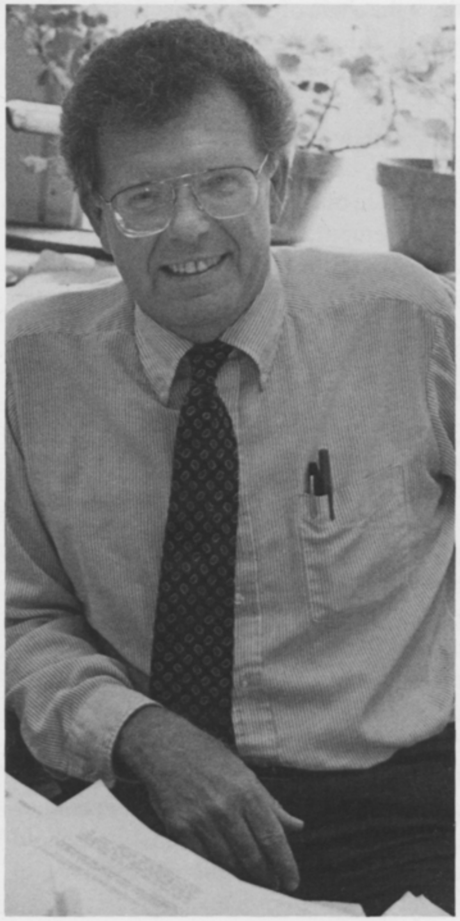
A per-item disposal-fee system would have some undesirable features. These would include the substantial cost of administration if the system were properly designed with different charges for different products according to their disposal cost. Would we need a "commissar of waste" to estimate and assign a disposal fee on every product?

Alternatively, we might look for some common denominator that pertains to all products and that reflects their disposal costs. Price would be a common denominator that would be easy to use, since a percentage increment could simply be added, but it would be a poor indicator of actual disposal costs; a $1,000 diamond ring, for instance, is less costly to dispose of than $1.00 worth of packaging.

Volume (required landfill or incinerator space) might prove to be a better common denominator. A difficulty is that some bulky food products with minimal packaging, such as popcorn, are consumed almost entirely and add little to society's solid-waste burden. Still, information about the volume taken up by a product together with its packaging could easily be added to its bar code and sensed electronically at the cash register. Imperfect as such a system would be, it would be effective because if disposal-cost stickers were added to each product's label or noted at the price display on the shelf, consumers would be confronted by the disposal costs every time they made a purchase decision.

In implementing such a system, a uniform charging system should probably be adopted statewide, or even nationwide, to make administration as easy as possible. Each community should be allowed to include its own percentage add-on, though, to compensate for local disposal costs. A complication is that consumers would have a modest incentive to buy in communities with low disposal costs, but there would be no guarantee that the trash would wind up in the disposal facility of the same municipality. (That is why economists prefer that fees be assessed as close as possible to the point where the cost is incurred or the environmental damage is done.)

Many communities have moved to per-bag trash disposal charges, which use the grossest sort of yardstick—the number of bags tossed—as the charging mechanism. Obviously, different bags will contain different amounts of trash and, more importantly, they will have different kinds of trash representing varying disposal costs. This charging system is easy to administer, however, and has the advantage that each community can assess fees according to its own disposal costs. Mandatory waste separation can lead to a greater homogeneity of trash in all households' bags, but spot checking to encourage compliance raises administrative costs. The greatest potential problem associated with a system of charging per bag is that people tend to avoid



getting rid of their trash in this way. This avoidance is desirable if, for example, consumers compost their kitchen and garden wastes rather than put them out for the garbage truck, but if per-bag charges lead to increased roadside dumping or backyard burning, the biggest public benefit that was originally derived from municipal trash collection will have been diminished.

The present furor over household sorting and recycling of trash, and whether or not and how to charge for its disposal, has a valuable aspect—it creates a heightened consciousness among consumers that getting rid of some products after they have been used may be almost as costly as acquiring them to begin with. Once people have been forced to stop and think about the public cost of their consumption decisions, it is a small next step to use that period of reflection to confront them with the broader environmental impacts associated all along the chain of product manufacture, distribution, and sale.

We have caught the attention of consumers. Can we use the "solid-waste crisis" as an opportunity to force a much wider daily behavioral reponse to a broad range of environmental insults? At long last we have an opportunity to insert the missing link.

Richard E. Schuler, a Cornell professor of civil and environmental engineering and also of economics, is serving as director of the Cornell Waste Management Institute and of the New York State Solid Waste Combustion Institute. Previously he served as a commissioner and deputy chairman of the New York State Public Service Commission and as director of that organization's Office of Research. He is currently a member of the New York State Senate's Advisory Council on Solid Waste.

His academic work has emphasized the application of economic thought to engineering and technical problems. He has been a consultant to numerous government and regulatory agencies and to private industries. He has also held visiting appointments at Duke University and at the Center for Operations Research and Econometrics at the Catholique Université de Louvain, Belgium.

Schuler holds the B.E. degree from Yale, the M.B.A. from Lehigh, and the Ph.D. from Brown. He is a registered professional engineer, and before coming to Cornell in 1972, worked as an economist for the Battelle Memorial Institute and as an engineer and manager for the Pennsylvania Power and Light Company.

GETTING OUT THE WORD ON WASTE

by Ellen Z. Harrison

Along with research and training, the mandate of the Cornell Waste Management Institute (CWMI) includes outreach—the provision of up-to-date, research-based information. When called upon by community leaders, local officials, media representatives, educators, consultants, or interested citizens, the institute's outreach staff helps with specific problems and provides educational programs.

Since its inception in 1987, the CWMI has become known as a source of unbiased information on waste management. This is particularly valuable as communities face the difficult environmental, technical, social, and economic choices associated with waste-management alternatives. Both the range of information required and the fact that the institute is independent and doesn't "push" any particular technology or option makes it a very valuable resource.

Because the institute can draw upon the talents and knowledge of faculty and staff members from all parts of the Cornell community, it can address a wide range of topics, from incineration to conflict management. Among those involved with outreach activities are faculty members and students from Civil and Environmental Engineering, Mechanical and Aerospace Engineering, Agricultural and Biological Engineering, Agricultural Economics, Communication, Natural Resources, Consumer Economics and Housing, Textiles and Apparel, and Cornell Cooperative Extension.

LINKS BETWEEN THE INSTITUTE AND COOPERATIVE EXTENSION

The Cornell Cooperative Extension system, which has associations in every county of New York State and in New York City, provides a unique opportunity for links between the university and many segments of the community. Locally based extension agents and volunteer boards are familiar with local issues. They are able to keep the CWMI staff informed about local educational needs and are also able to assist the institute in reaching local audiences with educational programs. Conversely, the CWMI provides technical support to agents and helps to keep them informed about current programs and information. This partnership has worked very effectively, since solid waste management is an area in which many local governments are turning to Cornell Cooperative Extension for help. Composting and yard-waste management, recycling, and youth education are of special interest.

Cooperative Extension on the national level has adopted the issue of waste management as an initiative. Cornell's program is one of the programs highlighted as models for involvement of the extension system in this timely issue.

APPROACHES USED IN OUTREACH EFFORTS

The outreach programs serve different groups of people in different ways. Popular and technical publications produced by the institute include newsletters, technical reports, and youth workbooks on topics from composting to controlling NO_x emissions from incinerators. A well received series consists of Fact Sheets and accompanying Viewpoint flyers on the same topic, such as composting or the recycling of plastics. Also available are videos, tapes with slides or film strips, tabletop electronic question-and-answer displays, and posters. Some of these materials can be obtained at no charge directly from the institute and others can be purchased or rented at cost through the Cornell Distribution Center.

". . . the CWMI has become known as a source of unbiased information on waste management."

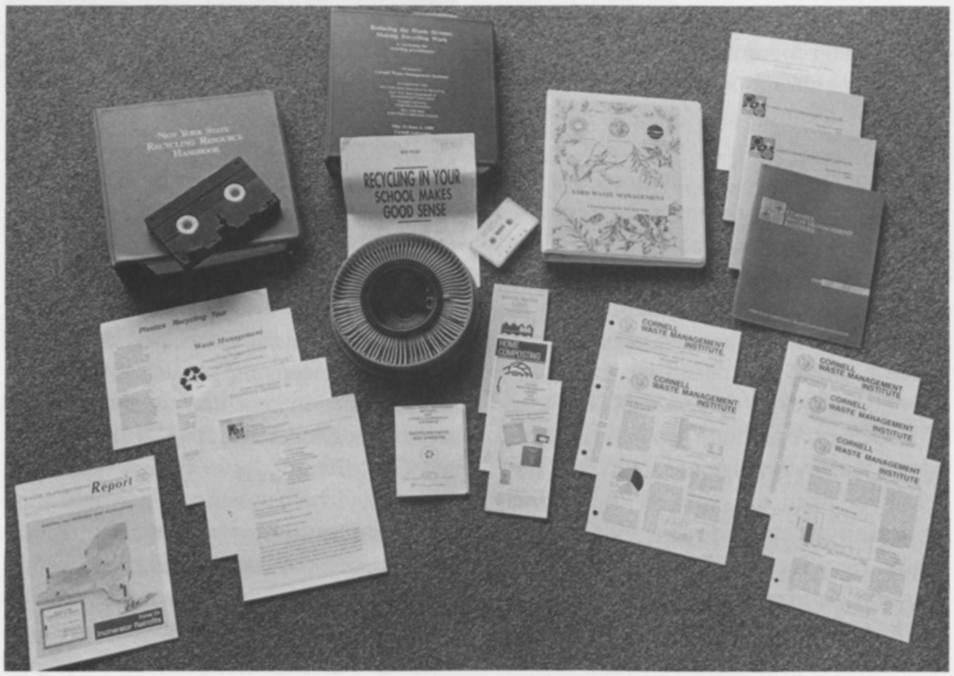
Staff members and associated faculty members also provide educational assistance by giving talks and meeting with groups. For example, the more than seven hundred planners who attended the 1989 annual meeting of the New York State Planning Federation heard Daryl Ditz of the outreach staff discuss solid-waste planning as the conference keynote speaker. Since so many segments of society are affected by solid-waste problems, it is not surprising that garden clubs, teachers' associations, consumer-interest organizations, and Cornell alumni groups, as well as the more expected audience of local officials, have requested CWMI participation in their programs.

Workshops on recycling, composting, and conflict management have been organized by the CWMI in various regions of the state, often in cooperation with local offices of Cornell Cooperative Extension. Recognizing a critical need as many communities hired new, often inexperienced, recycling coordinators, a Recycling Workshop was held at Cornell in 1989; more than two hundred professionals attended.

Tours of facilities are particularly helpful to local officials and professionals, enabling them to see firsthand how others get the job done. Kenneth Cobb, a CWMI staff member with many years of experience with Cornell Cooperative Extension, has hosted tours focused on composting and yard-waste management, recycling, incineration, and plastics recycling.

A clearinghouse operated by the institute on the top floor of Hollister Hall provides information about solid waste that is not readily available elsewhere. Publications, including organizations' reports, are the heart of the collection, which is computer-indexed, allowing users to search by topic and author for relevant materials among the more than twelve hundred items. Engineering students looking for information on the costs of collecting plastics for recycling, hotel students interested in issues associated with use of "styrofoam" disposables in restaurants, and agriculture students interested in composting programs are among those at Cornell who have found useful publications at this library.

Cooperation with other universities in New York State has helped to strengthen the CWMI programs. SUNY Buffalo and Stony Brook each have waste-management programs, and the three universities coordinate their efforts. Together, they publish a newsletter that highlights their waste-management research activities.



Right: The CWMI publishes a variety of publications for specialists, government officials, schools, and the general public.

Left: A tour of yard-waste composting facilities at Colonie, New York, was sponsored by the CWMI this summer.

COMBINING RESEARCH AND OUTREACH ACTIVITIES

CWMI is also involved in projects that combine research and outreach. An example is the work on biomonitoring that Daryl Ditz discusses in this issue of *Engineering*. Cornell researchers who are using plants to monitor toxic emissions from solid-waste incinerators can work with communities that are building incinerators to help them design and implement effective biomonitoring, and at the same time can gain access to incinerator sites and receive help in generating research data.

Sharing knowledge among researchers and practitioners is also the purpose of an industry/university/agency working group on solid-waste combustion that is convened semiannually by the institute and chaired by Frederick C. Gouldin, professor of mechanical and aerospace engineering at Cornell. (An article by Gouldin appears in this issue.) The group includes representatives of the combustion industry, consultants, and state and federal agencies, as well as researchers from Cornell, Clarkson College of Technology, and Rensselaer Polytechnic Institute.

TEACHING YOUNG PEOPLE ABOUT SOLID-WASTE ISSUES

Children are very concerned about the world they live in and will inherit, and they are eager to learn more about it and how to protect it. Youth education in waste management is an important and growing part of the CWMI outreach program.

In 1989 the institute added a youth-education specialist to its outreach staff. Jean Bonhotal came to the CWMI from the Broome County Cooperative Extension association, where she had been involved in environmental education for youth. She has produced a variety of educational materials, including slide sets on waste management and recycling, workbooks on composting and recycling, and posters. Bonhotal trains educators (including Cooperative Extension 4-H leaders) throughout New York State and beyond.

In response to community needs, CWMI is producing a video on manufacturing processes in which secondary materials are used, so that children and adults can see what happens to the materials they separate for recycling. Another ongoing project will result in a computer disk containing suggestions for classroom activities related to waste managment. The idea is that groups at all grade levels can "personalize" the information on the disk and devise exercises to be carried out in their communities.

YARD-WASTE COMPOSTING AND WASTE REDUCTION: HOT TOPICS

Areas in which there is significant potential for implementation of solid waste management practices are the composting of yard wastes, and reduction in the overall quantity of trash.

Yard wastes represent about 20 percent of a community's solid waste. This organic fraction often ends up in landfills, where it takes up valuable space. Composting leaves and grass and chipping woody wastes are viable alternatives that not only keep yard wastes out of the disposal stream, but also allow the organic matter to be recycled back into the soil.

A Cornell team is working on a project to provide communities with technical assistance in yard-waste composting. The team includes Professor David Allee and

David Kay, a research support specialist (Agricultural Economics); Thomas Richard, a senior research specialist (Agricultural and Biological Engineering); Carey Oshins, a graduate student (Natural Resources); and CWMI staffers Kenneth Cobb, Lauri Wellin, and me. The two-year project, which is jointly funded by Cornell, the New York State Energy Research and Development Authority, and the New York State Department of Environmental Conservation, will provide a series of regional workshops for local officials and sponsor a statewide conference, as well as produce and distribute a planning workbook and two video tapes. Key contacts, many of whom are Cornell Cooperative Extension agents, are being developed in each county to provide local educational support and liaison.

Ellen Z. Harrison, the associate director of the Cornell Waste Management Institute, joined the institute in 1987 as outreach coordinator.

She previously worked for several government agencies and was an independent consultant to the Connecticut Department of Health Services and the Connecticut Department of Environmental Protection (1984–85) and deputy director of land management for the South Central Connecticut Regional Water Authority (1985–86).

She has also served as a member of the Conservation and Inland Wetland Commission in Hamden, Connecticut, and currently is a member of the Comprehensive Planning Committee for the Town of Ithaca, New York.

She holds a B.A. degree in geology (with honors) from Boston University (1971) and a M.S. in geology and botany from Cornell (1975).

At the top of everyone's list of ways to manage wastes is reduction at the source—easy to espouse but difficult to accomplish. While New York State has adopted a goal of 8–10 percent reduction by 1997, we are actually experiencing an annual growth both in total solid waste and in per-capita waste production.

Reduction entails new thinking on the part of both consumers and manufacturers. Avoiding disposables, reusing and repairing items instead of discarding them, composting in the back yard, and reducing the use of toxics are all actions consumers can take. Manufacturers can use less material per product, make products last longer (no "planned obsolescence"), and reduce the toxic content of their products. "Lightweighting" of packaging and decreasing the mercury content of batteries are a couple of examples. Industrial response can be encouraged—or coerced—by government actions in the form of regulations or bans. For example, laws requiring manufacturers to provide warranties will promote product durability and repairability. The recent Maine law banning individual juice packs has the effect of reducing nonrecyclable packaging. Alternatively, governments can provide incentives such as legislation mandating deposits on containers, or the imposition of variable charges for trash disposal (with payment by the bag or by weight).

Education and promotion are another approach. CWMI is involved in several efforts to help make reduction a reality by collecting and disseminating information on waste-reduction options for individuals and local governments. A statewide workshop on waste reduction scheduled for fall 1990 will help to focus attention on successful ways of addressing this issue. A study of the changes in people's behavior in regard to reduction and recycling in the face of local adoption of per-can disposal rates is presently underway in Tompkins County and should provide some data that will be helpful to other communities considering this option.

Solid waste management concerns all of society; problems cannot be solved without the collaboration and support of decision makers, professionals, educators, the media, and the public. Because the CWMI outreach program promotes knowledgability, awareness of issues, and consensus, it is a very significant component of the institute's efforts.

The Cornell Waste Management Institute maintains a mailing list of individuals and organizations. Those who would like to be placed on this list to receive publications and information about coming events should send name, address, phone number, and affiliation to Carin Rundle, Waste Management Institute, Cornell University, 468 Hollister Hall, Ithaca, NY 14853–3501.

ETHICS IN SITING LANDFILLS
A Case Study of a Host-Community Benefits Program

by Lyle S. Raymond, Jr.

Few communities volunteer to provide a site for a municipal landfill. One of the major perceived threats is a decline in property values. Another is the possibility of ground-water contamination, even if there are regulations prohibiting the disposal of hazardous wastes and assurances that new technology and management methods can offer adequate protection. What usually happens is that an outside agency selects the unwilling community that is to "host" the facility.

One result of this method of site selection is the perception of "winners" and "losers", and an ensuing political power struggle. A community is a "winner" if it succeeds in causing the landfill to be located elsewhere, but can still use it. A "loser" gets the landfill site. Equity and fairness are rarely discussed.

THE GROWING CONCEPT OF HOST-COMMUNITY BENEFITS

The possibility of offering benefits to a community that "hosts" a landfill introduces a third factor in this power struggle. Simply stated, the idea is that various benefits can counterbalance perceived threats to public health and the community environment. Communities that use a facility but do not have it in their midst are asked to support, on grounds of fairness, certain benefits for the community that must live with the landfill. This concept of *host-community benefits* is also referred to as *benefit sharing* in some New York counties.

Residents of host communities often have many fears about a proposed landfill. They are concerned not only that individual property values may decline, but that the neighborhood image will suffer, diverting desirable development away from the area. In addition to fearing imminent ground-water contamination, they are frequently apprehensive about the possibility of facing decades of risk and uncertainty about environmental problems. Also, there are concerns about increased truck traffic (often on quiet country roads), costs for road maintenance, and environmental degradation such as littering.

Among the benefits that can be offered to host communities are:

- formation of a Citizens' Advisory Committee to represent the affected community;
- guarantees that potable water will be provided if wells become contaminated;
- free testing of private water supplies;
- extra measures for protection (such as more ground-water and well-water monitoring than is required under existing regulations);
- property-value guarantees;
- the provision of an independent local inspector;
- monetary payments to the town in which the landfill is located;
- creation of an insurance or contingency fund to compensate for future unpredictable or unanticipated effects;
- restoration, improvement, and/or preventive maintenance of affected areas (such as roads and bodies of water adjacent to the facility);
- support for community facilities (fire departments, ambulance units, and health centers, for example);
- provision of community parks, improved fishing areas and wildlife habitats, and other desirable community facilities;
- a voice in the design and operation of the landfill; and
- recycling and resource-recovery programs that will reduce the quantity of waste and therefore also reduce truck traffic and possible leachate problems.

A CASE STUDY: TOMPKINS COUNTY, NEW YORK

The experience of Tompkins County, New York, which is solidly committed to a host-community benefits program, provides an illustration of the process of acceptance and implementation.

The concept was introduced in late 1985 as the county was seeking a new landfill site. The site was selected in 1987 and implementation of the benefits program in the affected neighborhood began in early 1989. Events in Tompkins County unfolded in the following way:

1. **The concept was introduced to the county officials.** The person who served this function held nonelective but recognized positions with the county and town governments, as well as with Cornell University, in the areas of environmental management, planning, zoning, local government, and extension education.

2. **Early receptivity was expressed by key county officials.** The interest of the planning commissioner and the chairman of the solid-waste committee was crucial in making the concept known among other county officials.

3. **The initial introduction of the concept to the public was carried out in a low-key mode.** It was mentioned at several public meetings as part of a presentation on the human factors involved in landfill siting. The local news media gave little attention to the idea until later, when it became apparent that serious consideration was being given to possible official adoption of a host-community benefits program; by that time, key officials and citizen leaders had already been introduced to the concept.

4. **Some town superivisors and key citizens indicated interest.** This was an important factor in expanding awareness of the concept among decision makers. Following a year and a half of low-key networking about the concept, one town supervisor presented the county solid-waste committee with a detailed proposal for a host-community benefits program. This occurred at a time when the county had made a preliminary identification of eligible site areas. The supervisor, whose town included areas under study, stated that endorsement of a host-community benefits program would in no way constitute an invitation to locate the landfill in her town, but that if the landfill site were forced upon the town, a host-community benefits program should be provided.

This presentation generated the first news coverage about the idea. Within four months, the boards of several other towns had passed resolutions in favor of benefits programs (always stating that their town was, nevertheless, unsuitable for the site).

5. **The Board of Representatives adopted a resolution committing the county to negotiate a host-community benefits program with the affected community.** This occurred six months before the site was selected.

6. **A Citizens' Advisory Committee was created after the landfill site had been selected.** Potential members were identified by residents of the affected neighborhood, as well as by known citizen leaders and local officials, and then the committee members were selected by the county from the list.

7. **A Compensation Task Group was created and charged with developing a draft host-community benefits program.** Every county agency involved in the landfill-siting process is represented; these agencies are in the areas of public works, health, planning, assessment, law, and administration. Also included are three members of the Citizens' Advisory Committee and a representative of Cornell Cooperative Extension.

8. **A public-opinion survey of the affected neighborhood was recommended by the task group.** The survey was conducted under contract with Cornell. All property owners within two miles of the proposed landfill site were contacted; 67 percent responded. The survey served to inform residents about the program and to guide the county in the development of an acceptable plan. This proved to be a good public relations move by the county, and it helped clear up misconceptions about what the county was offering to the affected neighborhood.

9. **An educational program was developed by Cornell Cooperative Extension in Tompkins County.** Talks on various aspects of the solid-waste issue were given by residents of the county (not officials, although one was present to answer questions). One of the presentations featured host-community benefits programs. The program of talks was offered to all the towns; several accepted and held well-attended public meetings.

10. **In implementing a host-community benefits program, a Neighborhood Protection Committee was created.** This committee reviews all requests for benefits and recommends appropriate action. So far, the only requests that have been handled concern the protection of property values.

RESULTS OF THE PUBLIC-OPINION SURVEY IN TOMPKINS COUNTY, NEW YORK

The survey was conducted in September and October 1988 by the New York State Water Resources Institute, a unit of the Center for Environmental Research located at Cornell.

All 840 owners of property within two miles of the proposed county landfill site were asked to answer thirty-three questions about themselves (concerning age, occupation, education, income level, and length of residence in the area, for example) and their attitudes toward the landfill and toward a community benefits program. A 67-percent response was obtained.

The graphs summarize some of the data. Categories of respondents are indicated in the key. ***Core*** *refers to respondents whose property lies within about one mile of the site;* ***Non-Core*** *refers to those between about one and two miles of the site.* ***Freeville*** *is a village within a two-mile radius of the site.*

The table summarizes the respondents' expressed preferences for benefits.

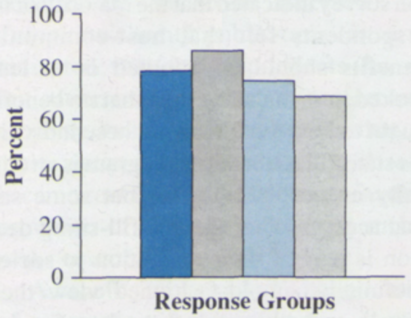
PREFERRED BENEFITS

Top Ten Choices:	*Percent*
Free water tests	95
Replacement of any polluted water	92
Enforcement of speed limits	92
Own property appraisal	92
Public reports on well-testing results	90
Protection of property values	89
Landscaping	88
Restriction of hours for landfill use	87
Local inspector	83
Special fund	82

Lowest Ten Choices:	*Percent*
Community festival	26
Neighborhood swimming pool	27
College scholarship	29
Park/playground	30
Community center	41
Public sewer lines	45
Donation to town	47
Landfill job priority	50
Public water (by time of opening)	50
No disposal of (private) construction debris	53

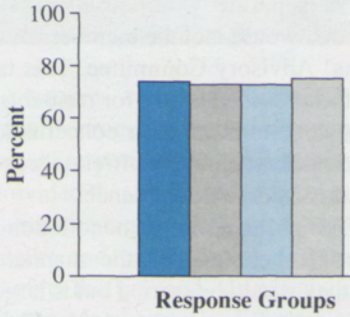
Landfills inevitably pollute ground water no matter how well designed.

Agree strongly or somewhat:

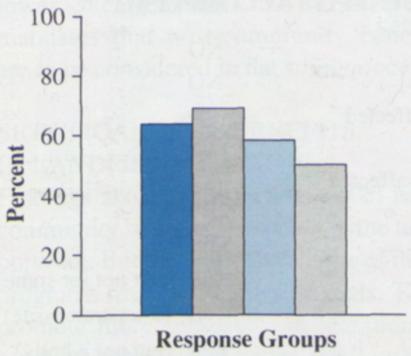


A new landfill must be sited in the county.

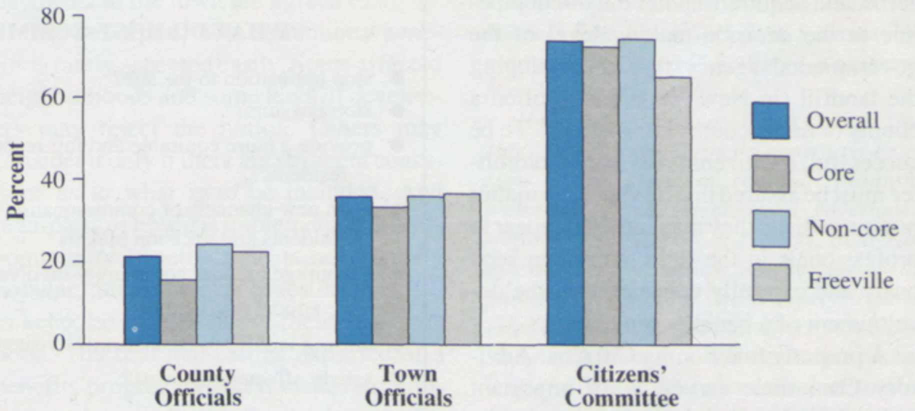
Agree strongly or somewhat:



Benefits should be considered. *Agree:*



Who should be in charge of a benefits program?



"A properly functioning Citizens' Advisory Committee serves as an important outlet for mitigating some of the powerlessness that community residents feel in the landfill-siting process."

THE IMPORTANCE OF CITIZENS' PARTICIPATION

The experience in Tompkins County points up the crucial role that citizens' groups play in the acceptance and implementation of a benefits program.

The creation of a Citizens' Advisory Committee means that the residents of the affected neighborhood have won official recognition of the validity of their concerns, and acquired a potential direct pipeline to the decision-making level of the governmental agency that is developing the landfill (in New York this is often a county or multi-county consortium). To be successful, a Citizens' Advisory Committee must be assured that its views, no matter how unrealistic they may initially appear to professionals in the field, are taken seriously and carefully considered in the development of a benefits program.

A properly functioning Citizens' Advisory Committee serves as an important outlet for mitigating some of the powerlessness that community residents feel in the landfill-siting process. Although the affected neighborhood is already represented by local elected officials, residents are keenly aware that the jurisdiction of these officials is much broader than the affected neighborhood—their constituency includes many people who may not feel as threatened by the landfill. It is advisable to separate discussions of the benefits program from other matters related to the landfill that the Citizens' Advisory Committee will be involved in. One way in which this may be accomplished is by forming a subcommittee of the advisory committee for this express purpose. However, in Tompkins County it was decided to create a separate Compensation Task Group that would include members of the Citizens' Advisory Committee. This task group has provided a way for residents to directly communicate their concerns to a sympathetic body that has official recognition and considerable influence.

In Tompkins County, negotiation of appropriate benefits and the manner in which they would be carried out is largely an informal process, with county officials and the neighborhood representatives on the Compensation Task Group working as a team.

ATTITUDES TOWARD HOST-COMMUNITY BENEFITS

Those who have worked with host-community benefits programs in Tompkins County and also in several other counties in New York State have observed several factors that greatly influence the attitudes of the citizens and of the county officials.

The ethical grounds—what society owes to individuals or neighborhoods, as well as what obligations citizens have to support a facility that is considered necessary for the public good—must be established. The Tompkins County public-opinion survey indicated that the majority of the respondents felt that host-community benefits should be adopted or at least looked into, but a few said that no benefits ought to be given. Most of these individuals stated that a benefits program is an ethically unacceptable bribe, but some said that acceptance of the landfill-siting decision is part of their obligation to society (definitely an old-fashioned view these days!), and others felt that a benefits program is an unnecessary public expense.

WHAT DO HOST-COMMUNITY BENEFITS ACCOMPLISH?

• stop opposition to the site?	NO	
• stop lawsuits?	NO	
• provide a more equitable and fair response to affected residents?	YES	
• open new channels of communication between affected residents and decision makers?	YES	
• encourage broader community involvement?	YES	
• have ethical justification?	YES	(but not for some)
• allow a landfill to be successfully sited?	NO	(a separate issue)
• satisfy affected residents?	YES	(but not wholly)

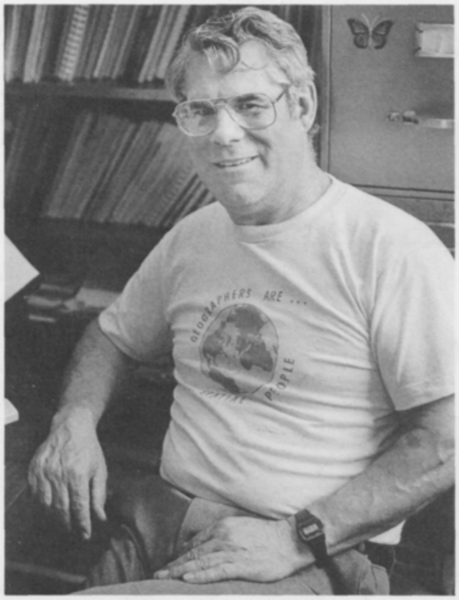
Indeed, suggestions that host-community benefits are offered to reduce the opposition are likely to evoke cries of "Bribery!", "We will not be bought!", or "This town is not for sale!" and the result is likely to be rejection of the program no matter how generous it may be. The benefits must be offered (and accepted) on the basis of equity and fairness.

Opponents of a landfill site confront the question of whether participation in a host-community benefits program weakens their position. Some town officials have dealt with this dilemma by opposing the site but supporting host-community benefits as a contingency or backup plan. This dilemma also affects perceptions of what benefits are "fit to be accepted". The Tompkins County public-opinion survey indicated that the respondents favored mitigation measures such as protection of property values and guarantees that potable water would be supplied if wells became contaminated, but did not favor the provision of unrelated amenities such as parks or ambulance units.

A benefits program has a better chance of acceptance if a commitment is made well before a site is selected rather than if it is offered only if opposition develops after the site selection. (This issue may have lower salience in states in which state law mandates that host-community benefits are to be considered in the siting process.)

SIGNIFICANCE OF BENEFITS IN LANDFILL SITING

Findings about the effectiveness of host-community benefits are shown in the table opposite. But the real significance of these programs rests on broader grounds. They promote more sensitive consideration of residents' fears, and better relationships between residents and decision makers.



Another significant aspect is that a benefits program can be a very economical way of responding to the fears of residents, provided that the benefits are mainly mitigation guarantees, triggered only if harm occurs, and that the facility is operated in a manner that prevents harm from occurring. The cost factor may be different, of course, if the demand is for compensation rather than mitigation, or if substantial monetary payments to the town are agreed to.

The concept of host-community benefits is rarely accepted easily. Some affected neighborhoods and some landfill developers may reject the notion. Others may consider it only if there are stringent conditions as to what is to be included. And regardless of how it is implemented, a host-community benefits plan is never really popular; the prime goal of residents is still to keep the landfill out of their neighborhood. The best that can be expected of a benefits program is that it makes the situation as fair as possible for the people who live near the landfill. It is upon this basis that the provision of host-community benefits is becoming an accepted part of the siting process.

Lyle S. Raymond, Jr., is an extension associate and water resources specialist in the New York State Water Resources Institute, a unit of the Center for Environmental Research located at Cornell.

Raymond received a B.A. degree in social sciences from Utica College of Syracuse University in 1963 and a M.A. degree in geography from Syracuse in 1966.

He has been associated with Cornell since 1966, working with Cornell Cooperative Extension in the areas of regional planning, watershed management, local government, wetlands, flood risk reduction, acid rain, ground water, water law, risk perception, and public policy making. He is especially interested in human factors that affect public decision-making processes. He has been associated with the Water Resources Institute and its predecessors at Cornell since 1969.

COMBUSTION SIMULATION

A New Tool for the Design of Waste Incinerators

by Frederick C. Gouldin

Most of our nation's garbage and trash ends up in landfills, and as waste generation steadily increases, many landfills are nearing capacity. As most of us have become aware, we face severe waste-management problems, if not a crisis. There is a need to either site new landfills or employ other waste-management systems.

Landfills are difficult to site. Nobody wants a dump located nearby. A consequence that is experienced all too frequently is the need for long-distance trucking of waste when the local landfill reaches capacity and no new facility is in place. Another problem with landfills is that they are subject to problems of ground-water contamination, vermin, gas production, and leakage; modern sanitary landfills rely on containment, which cannot be 100 percent effective and which significantly retards the biodegradation of waste.

What about alternatives? Figure 1 shows that incineration and recycling play rather minor roles. Rightfully, waste reduction and recycling should make much larger contributions to waste management in the United States than they do. A review of practices in Western Europe and Japan clearly shows that these methods can and should be major contributors to waste management in modern, productive societies, and that businesses, communities, and individuals in the United States simply must increase dramatically their commitment to reduction and recycling. But such a review also shows that reduction and recycling alone do not solve all waste-management problems and that other means, such as incineration and landfilling, are required and therefore need to be improved and refined.

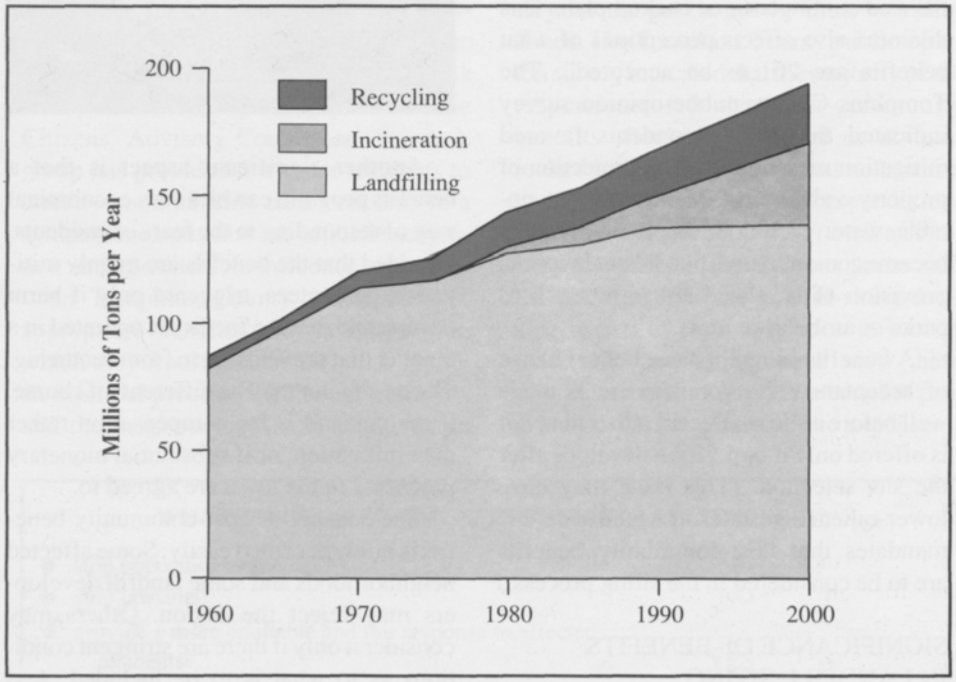


Figure 1. Municipal solid waste management in the United States. (Source: Franklin Associates)

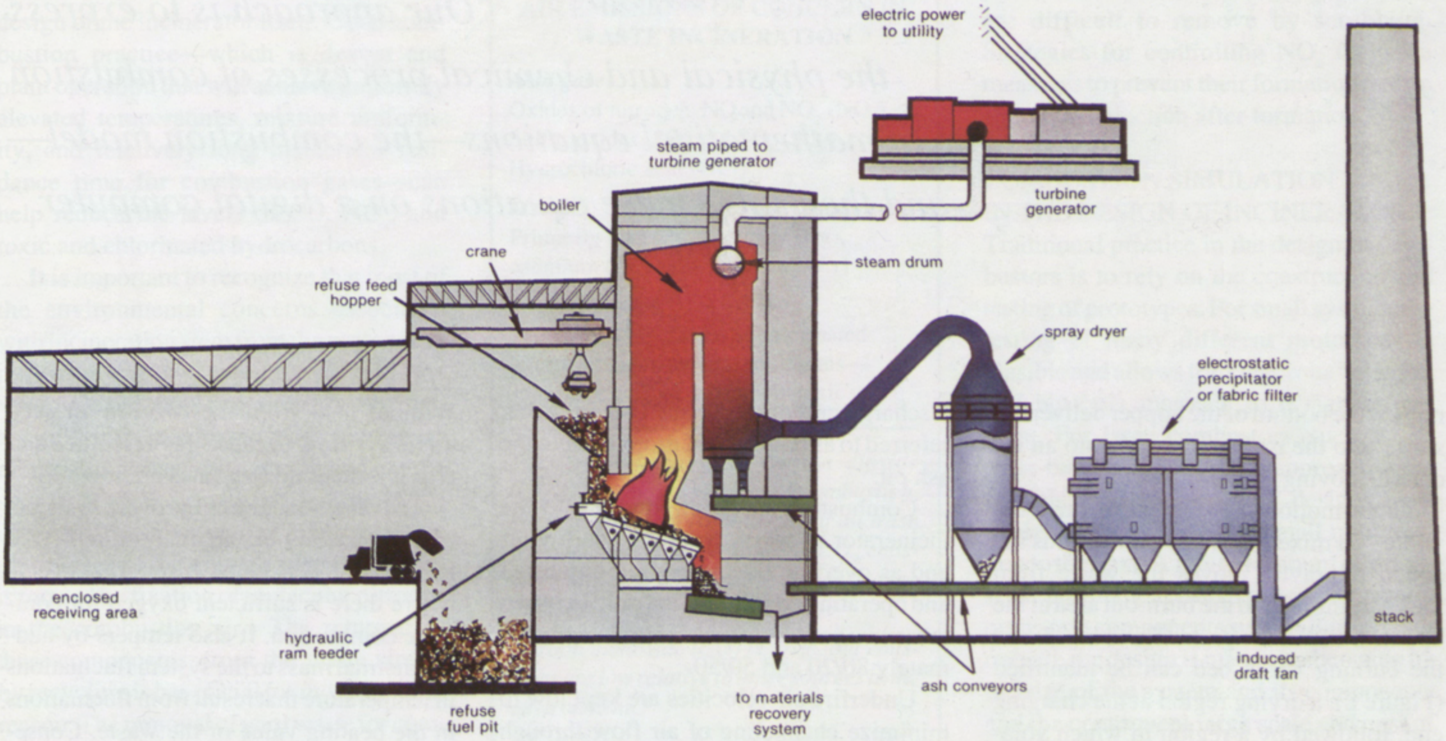


Figure 2. Schematic diagram of a typical mass-burn incinerator facility.

The drying region of the grate is to the left; in the center, where the volatile components are released from the bed, flaming combustion is observed; and at the right is the burn-out region. Combustion air is supplied from the bottom of the grate and flows upward through the bed. Additional air—overfire air—is supplied from jets (not shown) in the walls just above the bed. Devices for gas scrubbing and particulate removal help control emissions of pollutants, including SO_x, HCl, fly ash, heavy metals, and dioxins.

(Source: Wheelabrator Technologies, Inc.)

THE MODERN INCINERATOR: A WASTE-TO-ENERGY FACILITY

Although incinerators have been in limited use for many years, the modern incinerator with its steam-generation capability and pollution-control devices is fairly recent in the United States and still has a rather minor waste-management role. On the other hand, its use is growing (Figure 1).

A major advantage of incineration is the potential for extracting usable energy. The average heating value of municipal waste in the United States is approximately 5,000 British thermal units per pound (Btu/lb); this compares, for example, with 11,000 to 14,000 Btu/lb for bituminous coal. The modern incinerator is designed to recover this energy for industrial process heat, space heating, or electric power. While initially the opportunity for energy recovery was overstated and the costs were underestimated, the industry has matured and energy recovery is now a feature of almost all new incinerator designs. Since the total amount of energy in the nation's waste is a small fraction of the amount that is consumed, waste combustion and energy recovery will not significantly displace other sources of energy. Still, energy recovery is good conservation and will reduce the net cost of incineration.

In recent years the most frequently selected kind of incinerator has been the directly fired, water-walled, mass-burn variety (Figure 2). Trucks discharge the waste into a pit from which it is loaded into a hopper for charging to the incinerator. One of the features of mass burn is that only the largest items get special handling: objects such as refrigerators and washing machines are removed and items such as furniture are shredded. Large hydraulic

"Our approach is to express the physical and chemical processes of combustion in the form of mathematical equations—the combustion model—and then solve these equations on a digital computer."

rams at the bottom of the hopper deliver the waste into the incinerator and onto an inclined, moving grate.

Grate motion is designed to keep the waste bed mixed, and this motion plus the action of gravity moves the waste from the charging area to the burn-out area at the opposite end of the grate. Three regions in the burning waste bed can be identified (Figure 2): a drying region at the charging end, followed by a region in which volatiles are combusted, and finally a burn-out region. The processes that occur in these regions correspond to three stages that can be observed in the combustion of a green log: Initial heating of the log raises its temperature to the point at which moisture evaporates. Further heating causes volatile organic compounds in the log to evaporate and flames are seen. And finally, after the volatiles have been released, the remaining combustible material—mostly carbon—burns as glowing coals. What remains after the fire extinguishes is primarily unburned carbon and ash.

A waste incinerator is designed so that the burn-out region of the grate is long enough to ensure a very high degree of combustion; ideally, noncombustible ash (mostly glass and oxidized low-molecular-weight metals) is all that remains at the discharge end of the grate. This material, referred to as bottom ash, drops off into the ash pit.

Combustion air is introduced into the incinerator in two ways—as underfire air and as overfire air. Depending on design and operating conditions, the ratio between these two sources varies between approximately 80/20 and 50/50.

Underfire air velocities are kept low to minimize channeling of air flow through the bed, to increase contact time between the waste and air, and to limit the fraction of waste that burns while suspended above the bed in the air flow and therefore contributes to the so-called fly ash. (When there are no devices on the stack to control fly ash, most of it is emitted to the atmosphere in the stack gases.)

The overfire air jets have several functions. One is to promote mixing of gas flows that come from different regions of the bed. Although the bulk of the chemical reactions converting waste and oxygen to combustion products occur in the bed, there are important chemical reactions (discussed below) that occur in the gases above the bed, and these must be taken into account. Mixing is needed because the composition of gases flowing from the bed varies from one bed region to another. Without help from the overfire air jets, mixing is slow because gas velocities and also turbulent mixing rates are low.

The other function of the overfire air jets is to increase the air-fuel ratio in the incinerator. This helps ensure that everywhere there is sufficient oxygen for complete combustion. It also tempers by adding thermal mass to the system fluctuations in temperature that result from fluctuations in the heating value of the waste. Consequently, the overfire air jets are high-velocity and their placement and orientation are important design considerations.

Energy recovery is through the generation of steam. Heat transfer occurs to a portion of the incinerator walls, the water walls, and several heat-transfer sections located downstream of the incinerator. The combustion gases, upon leaving the incinerator, pass through a heat exchanger, a scrubbing unit (usually a spray dryer), and a particulate-control device.

POLLUTION CONTROL IN MODERN INCINERATOR SYSTEMS

As emissions from incinerators into the air have become a major public concern, so have pollution-control devices become integral components of modern waste-to-energy incineration systems. Emission control has also become a factor in the design of the incinerator itself. Good combustion practice—which is design and plant operation that will achieve uniformly elevated temperatures, mixture uniformity, and relatively long incinerator residence time for combustion gases—can help reduce the levels of CO, NO_x, and toxic and chlorinated hydrocarbons.

It is important to recognize that most of the environmental concerns associated with incineration stem from the presence of pollution-causing components in the waste. Compounds containing heavy metals, sulfur, fixed nitrogen, and chlorine are all present in the waste stream and are the source, either directly or indirectly, of almost all the substances of public concern. (A fraction of the emitted nitrogen oxides is formed by fixation of molecular nitrogen in the combustion air.) The removal of these components from the waste stream by recycling is beneficial for more than one reason. The removal of yard waste for composting, for example, reduces not only the amount of solid waste, but its moisture and fixed-nitrogen content, thereby increasing the ease of incineration and reducing NO_x formation.

Air emissions of concern are primarily acid gases, metals, and toxic organics (see the table). Metals and toxic hydrocarbons are found also in the bottom ash and there is concern that they might escape from an ash-containing landfill to contaminate the surroundings and ground water. (Contamination of ground water by heavy-metal-containing leachate from rain-water runoff is currently of greater concern, however.)

The basic approach to controlling the environmental problems is to destroy when possible and contain when necessary. For example, in order to ensure full oxidation to CO_2 and H_2O, incinerators operate with overall air flows well above the flow necessary for complete combustion. The presence of excess air and the mixing induced by air injection promote the destruction of CO and toxic organic compounds such as dioxins and furans.

AIR EMISSIONS OF CONCERN IN WASTE INCINERATION

Acid gases
Oxides of nitrogen: NO and NO_2 (NO_x)
Sulfur oxides: SO_2 and SO_3 (SO_x)
Hydrochloric acid (HCl)

Metals
Primarily lead (Pb), mercury (Hg), cadmium (Cd), and chromium (Cr)

Toxic organics
Especially two classes of chlorinated hydrocarbons—dioxins and furans—some of which are extremely toxic

The "greenhouse gas", carbon dioxide (CO_2), is a major product of combustion, but it should be noted that even if all trash were incinerated, the resulting CO_2 emissions would be very small in comparison to existing sources.

Carbon monoxide (CO) is toxic, but emissions are low relative to other sources in the environment.

Particulates are of concern because they are dirty, can cause respiratory problems, and may contain toxic compounds, including heavy metals.

With metals, the objective is to concentrate them in the captured ash. This is achieved primarily by limiting the amount of fly ash and by removing the fly ash from the combustion gases before they are released to the environment.

A good percentage of SO_x and HCl can be removed by gas scrubbing. NO_x control is more of a problem because these compounds are not water-soluble and therefore are difficult to remove by scrubbing. Strategies for controlling NO_x focus on measures to prevent their formation and on chemical reduction after formation.

COMBUSTION SIMULATION IN THE DESIGN OF INCINERATORS

Traditional practice in the design of combustors is to rely on the construction and testing of prototypes. For small systems the testing of many different prototypes is feasible and allows for a vigorous "build'm and bust'm" approach to design refinement. For large combustors, such as the mass-burn incinerator, this approach is not feasible, and consequently designs have evolved slowly from one small modification to the next. A limited amount of small-scale prototype testing is done, especially on system components such as burners, but overall, the design is made cumbersome by the size of the system and its components and the consequent large scale and cost of physical testing.

In the Combustion Simulation Laboratory at Cornell our primary goal is to develop computer-based design and analysis tools that improve the design process and reduce its dependency on prototype testing. These tools will speed design, allow for more testing of new concepts because of simulation capability, reduce the cost of design, and lead to better designs.

Our approach is to express the physical and chemical processes of combustion in the form of mathematical equations—the combustion model—and then solve these equations on a digital computer. Thus the process of simulation development is composed of two distinct tasks: model development and numerical solution of the model equations. Each task presents unique and substantial challenges.

"A major objective . . . is to develop approximate, model equations that both provide an adequate description and are numerically tractable."

THE TWO TASKS: DEVELOPING EQUATIONS AND SOLVING THEM

The study of combustion requires the study of several different rate processes: fluid flow, heat and mass transfer, and chemical and physical transformation reactions. Combustion derives its unique character from the autocatalytic nature of the exothermic, multi-step chemical reactions that transform fuel and oxygen to oxidation products; in our case, the fuel is solid waste and the desired products are carbon dioxide and water. The rates of the reactions are highly sensitive to temperature, and since the energy released by exothermic reactions increases the system temperature, the result is an acceleration of the combustion reactions.

Our present understanding of fluid flow and of heat and mass transfer is felt to be sufficient for writing a set of coupled, differential equations describing these processes. However, these equations are so complex that they have been solved for only a few problems. In the case of incinerator simulation the primary factors that contribute to the difficulty of solution are flow turbulence (unsteady, chaotic flow), complex flow geometry, and the presence of multiple phases (solid, liquid, and gaseous). In addition, the equations have mathematical characteristics (nonlinearity and stiffness) that make their solution difficult. A major objective of researchers working on the flow and transport problems of combustion is to develop approximate, model equations that both provide an adequate description and are numerically tractable. With the continuing, rapid development of computational capacity, more and more complex model equations can be solved numerically, allowing for the development of increasingly accurate and general model equations.

In contrast, our understanding of chemical and physical transformation processes is not complete, and new investigations of combustion problems frequently lead to the discovery of new transformation paths and processes. A major reason for this state of affairs is that chemical reactions in combustion are chain reactions involving many different chemical species and reaction steps. The addition of new chemicals to a system introduces the possibility of new chemical compounds and reaction paths.

The necessity of keeping track of many different compounds and reactions increases the mathematical complexity of combustion simulation. For example, each chemical species considered adds a differential equation to the coupled set of equations that must be solved. The forms of the chemical source terms are changed, as is the degree of coupling between the equations. Thus, when developing chemical and physical transformation models, one attempts first to determine all the important species and phases and the important transformation paths, and then to develop a transformation model that is, again, realistic and tractable.

As noted, the capability of carrying out numerical computations on digital computers has greatly expanded our ability to solve complex model equations. Indeed, the need to develop numerical methods for computer solution of these and other mathematical problems has resulted in a new field of applied mathematics—that of numerical analysis. Research in this field addresses questions such as the accuracy of solution methods, their speed and reliability, and their generality. Also, solution methods frequently require iterative procedures, and for these methods questions of stability and convergence are of concern.

From this brief discussion it should be

clear that one who would pursue combustion simulation faces a multifaceted problem requiring expertise in several areas—fluid flow, heat and mass transport, chemical reaction and phase change, and applied numerical analysis. And as the research proceeds, one must take care to assess the accuracy of both the combustion models used and the numerical solutions obtained.

THE CORNELL WORK ON CUMBUSTION SIMULATION

Over the last two decades, combustion simulation has undergone significant advancement and at present plays an important role in combustor design. Design applications of simulation are now made to gas-turbine and jet-engine combustors and to spark-ignition engines. Simulations are under development for coal-fired boilers and design applications are anticipated.

Our research team in Cornell's Sibley School of Mechanical and Aerospace Engineering is working on simulation methods for incinerators, using as a starting point the most recent developments in combustor design for furnaces and gas turbines. The work is supported by the State of New York as part of the New York State Solid Waste Combustion Institute.

To develop an incinerator simulation, we have broken the problem down into a series of component problems; each problem is solved separately and then the parts are integrated to form a whole. Examples of component problems are combustion in the waste bed, overfire air injection, radiative heat transfer, NO_x formation and control, heat-exchanger design, and gas-scrubber design.

We are now focusing on the simulation of above-bed processes in the incinerator: overfire air injection, radiative heat transfer, ammonia injection for NO_x reduction, turbulent mixing, and mixed forced and natural convection. On the basis of our past experience and our progress in other areas, we are optimistic that we can develop useful simulation tools that will incorporate our current understanding of the important physical and chemical processes and that can be readily modified to incorporate new findings about important processes affecting combustion and performance.

Specifically, our procedure is to pose a set of differential equations along with appropriate boundary and initial conditions, and then solve them numerically. Major challenges in posing these equations and conditions are to account for turbulence, important chemical reactions, the geometry of the incinerator, conditions of gases leaving the waste bed, and the addition of overfire air in small, high-velocity jets. Once the model equations are posed, they must be transformed into a form that can be solved by large-scale computation.

In our case a solution is sought on a set of discrete mesh points, and the differential equations are replaced by a set of algebraic difference equations. The solution of these difference equations is an approximation of the solution of the original differential equations; the difference between the solutions is referred to as numerical error. Factors that affect numerical error include the form of the transformation between the differential and difference equations—the differencing scheme—and the number of mesh points.

In general, the more mesh points the smaller the numerical error, but the larger the computer required for solution. That is why supercomputer facilities are essential to our work. We are fortunate to have access to the computers of the Cornell National Supercomputer Facility (CNSF).

PROBLEMS IN THE SIMULATION OF INCINERATORS

The geometry of an incinerator makes it difficult to simulate. For one thing, the flow is three-dimensional and a large number of mesh points is required for the numerical solution; for example, a 100x100x100 mesh has a million points. Also, the very large flow contraction just above the bed causes numerical problems, and it can cause flow separation that needs to be calculated accurately. An additional difficulty is encountered in simulating the overfire air jets along the front and back walls of the incinerator. The placement, direction of flow, and flow velocity of these jets are critical design decisions that we plan to help make through simulation. The difficulty is that since the diameters of these jets are relatively small, it is necessary to have a fine enough mesh to obtain an accurate numerical solution of the jet flows and still avoid overdoing the mesh density elsewhere.

Turbulence modeling, which attempts to develop model equations for estimating the mixing and transport effects of turbulent velocity and property fluctuations without solving the full time-dependent equations, has been an area of active research for some time, and several models are available. We are using a well tested model (called the k-ε model) in which the expressions for the effects of turbulence on mass, momentum, and heat transfer are similar to those that are valid for laminar flow, except that the molecular diffusivity, viscosity, and conductivity are variables dependent on two turbulent quantities, k (the kinetic energy of turbulent velocity fluctuations) and ε (the rate at which the energy is ultimately dissipated by viscosity.) Model equations for k and ε are posed and solved. Since this model has been widely used, both its strengths and weaknesses are well known.

Most of the fuel is consumed by chemical reactions in the waste bed. With regard to the above-bed region, therefore, we are interested in a subset of reactions that are important for their influence on air emissions but do not affect the temperature significantly. Examples of such reactions include the oxidation of residual CO to CO_2, the formation of NO, and the oxidation of residual hydrocarbons and chlorine-containing hydrocarbons that might contribute to toxic emissions. The treatment of these and other important chemical reactions is hindered by a lack of knowledge of some of the important reaction steps and the difficulty of modeling the effects of turbulence on these reaction rates. Given this situation, our objective is to determine what conditions of temperature and chemical mixture favor desirable reactions and then use simulation to determine how such conditions might be achieved in the incinerator.

Because the combustion processes in the waste bed are very complicated, we have decided not to attempt to model them during the initial phases of our work. Even so, to simulate the over-bed region, we must specify conditions in the gases flowing out of the bed. This problem is dealt with by performing a parametric study to determine how different bed exit conditions affect processes in the over-bed region.

CALCULATIONS FOR A TWO-DIMENSIONAL INCINERATOR

We are currently performing calculations on a two-dimensional incinerator (see Figures 3 and 4). We are studying the quality of our numerical solutions and the effects of geometry changes and overfire air injection. Chemical reactions, heat transfer, and buoyancy effects are not accounted for in these calculations, but will be added to our simulation as progress is made.

Figure 3 shows the velocity fields represented by velocity vectors located at the center of the mesh cells used for the calculations. The magnitudes of the velocities are indicated by the length of the vectors.

Figure 4 shows distributions of turbulent viscosity obtained by k-ε model calculations for several sets of conditions. Turbulent kinematic viscosity is a measure of the turbulent fluid mixing rate; high values indicate high turbulence levels and high turbulent transport rates. A noticeable feature of these results is the change in the recirculating flow patterns. The importance of such observations to designers is clear, as is the potential usefulness of simulation results such as these for design applications.

Figure 3a

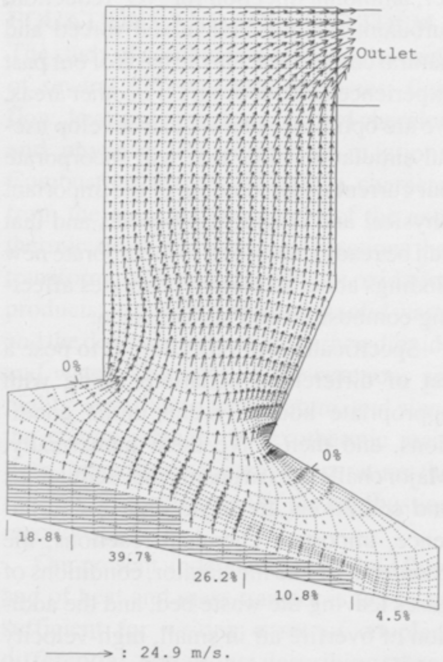


Figure 3b

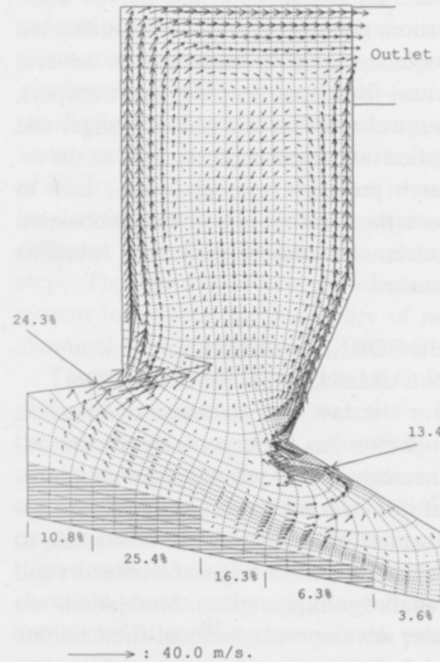
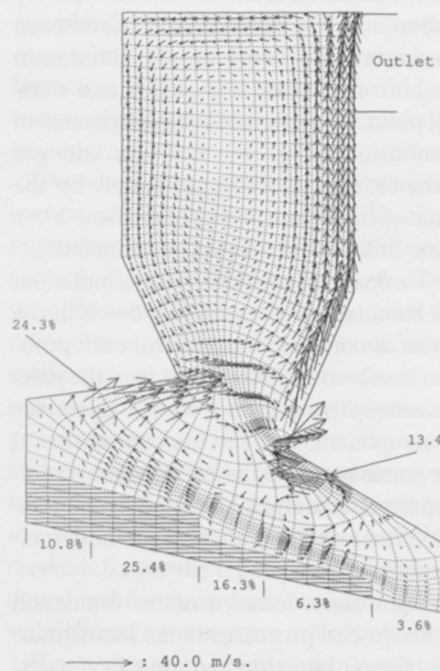


Figure 3c



Figures 3 and 4 on these pages represent test cases pertaining to 2-D numerical simulations of a solid-waste incinerator. These examples show some results of changes in combustor geometry and rate of gas flow, and the effect of overfire air in the combustion chamber. The so-called "k-ε" turbulence model was used.

The Figure 3 images show velocity distribution. The grid is 20 x 47. The hatched sections were added to accommodate code discretization constraints. Percentages indicate the proportion of air entering different sections of the combustor.

Figure 3a pertains to a configuration designated Geometry I. The conditions are: cold flow, no overfire air, Reynolds number = 1.4×10^5, average velocity = 4 m/sec. In Figure 3b the geometry is the same, but there is overfire air injection with an initial jet velocity of 90 m/sec. In Figure 3c the overfire air injection is the same as in 3b, but the configuration is Geometry II.

Figure 4 shows turbulent kinematic viscosity contours for the test cases represented in Figure 3. Turbulent kinematic viscosity is a measure of the turbulent fluid mixing rate.

Figure 4a is for Geometry I with no overfire air. The laminar kinematic viscosity = 1.5×10^{-5} m^2/sec. Figure 4b pertains to Geometry I with overfire air injection. In Figure 4c there is overfire air injection and the combustor configuration is Geometry II.

Figure 4a

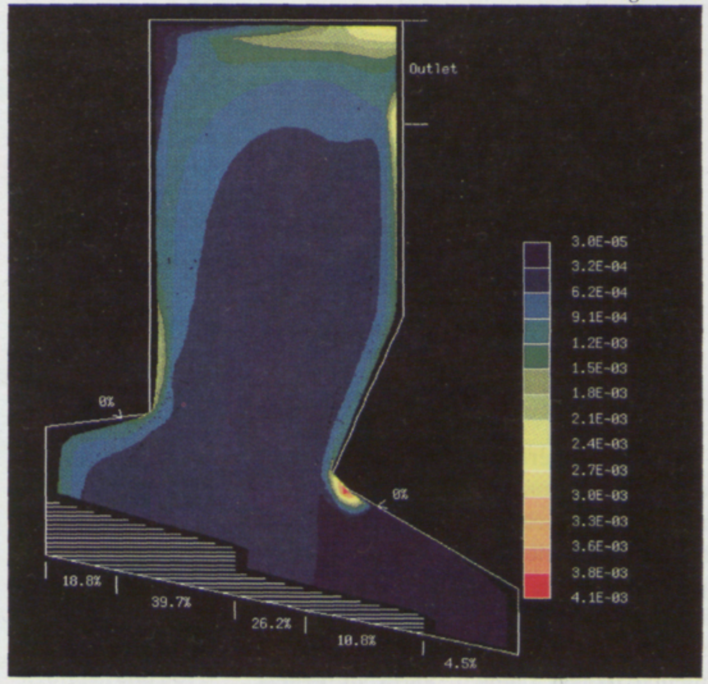


Figure 4b

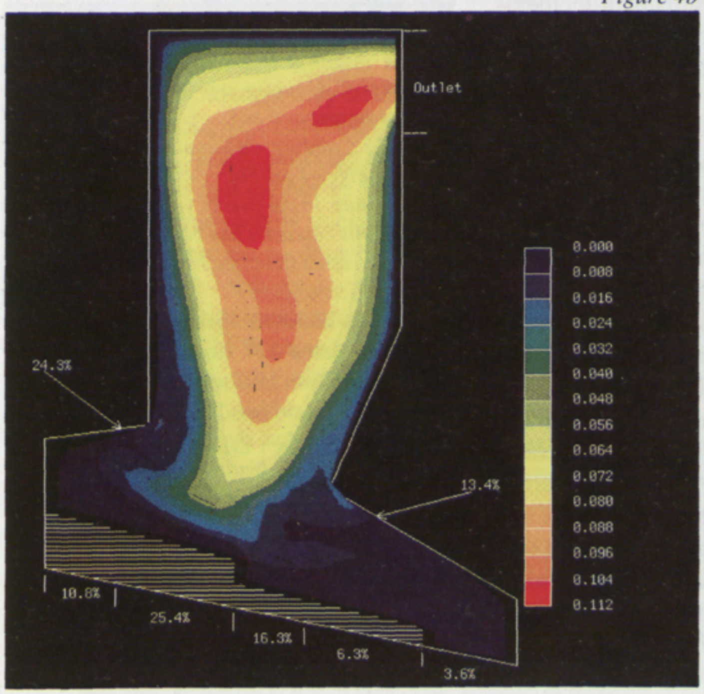
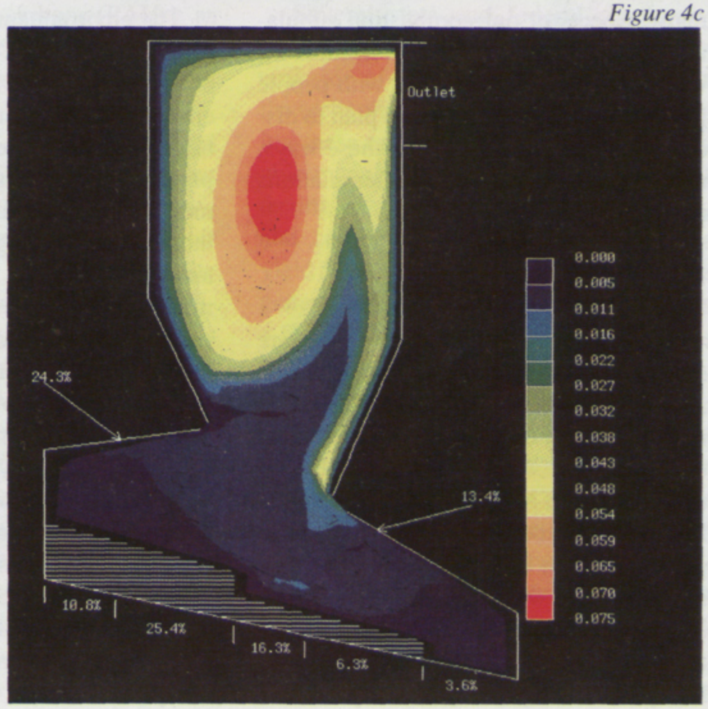
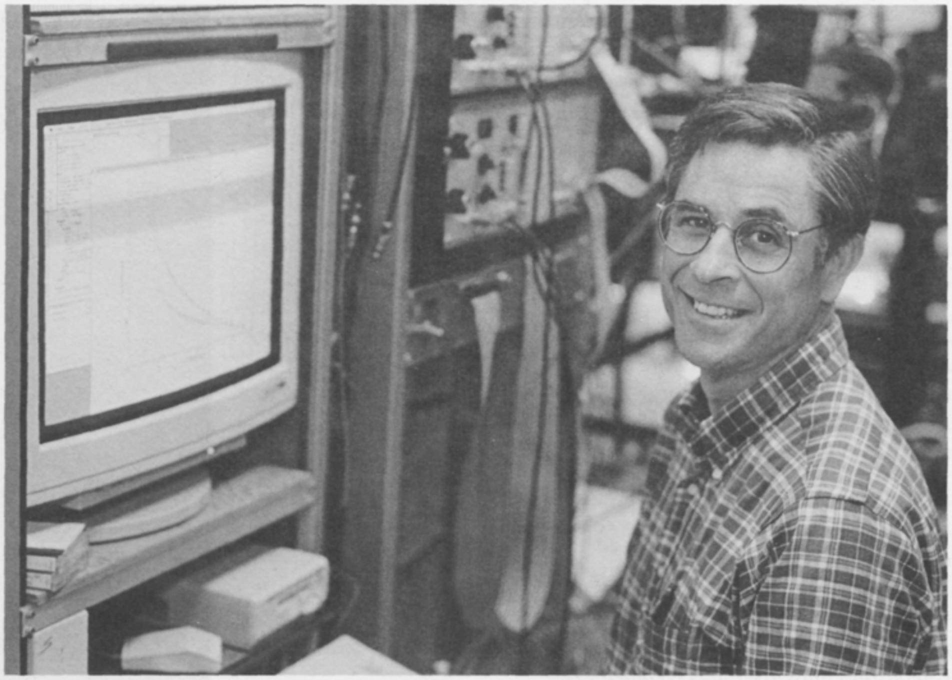


Figure 4c



Since numerical simulation is built upon combustion models that are approximations, and because it is difficult to obtain accurate numerical solutions to these complex model equations, there is a need to verify results to the highest degree possible. To this end we are building an experimental model that will allow us to test many aspects of our combustion simulations without lighting a match. In addition, we have established contacts with people in the incinerator industry and plan to discuss our results with them. In these ways, much can be done to test the simulations and our simulation methods.



THE ROLE OF MUNICIPAL WASTE INCINERATORS

The numerical simulation tools we are developing at Cornell will speed the design and development of municipal waste incinerators for cleaner and more efficient operation. Our work so far has dealt with the reduction of NO_x emission by ammonia injection and the simulation of over-bed processes, with an emphasis on flow and mixing. Future work will include studies of the formation of toxic compounds during the combustion of plastics, and the fate of heavy metals, especially mercury.

The environmental effects of incineration are currently a matter of public concern, much of which is focused on emissions of dioxins and furans and of heavy metals. Indeed, public opinion has played a significant role in the establishment of emission standards for all types of incinerators, and significant reductions in airborne emissions have been made by manufacturers responding to public pressure and regulatory actions. Further reductions will be obtained, and numerical simulation can help achieve them.

While improvements are feasible and will be made, today's modern incinerator with stack-gas controls such as gas scrubbers and particulate-removal devices has relatively low emissions. It is a viable tool to help deal with the waste that is left after intensive waste-reduction and recycling programs have been implemented and actively promoted.

Frederick C. Gouldin, a professor of mechanical and aerospace engineering, is director of Cornell's Combustion Simulation Laboratory, part of the New York State Solid Waste Combustion Institute. In the twenty years he has been at Cornell, his research has centered on combustion and related fields such as air pollution and energy efficiency.

Gouldin studied at Princeton University for the B.S.E. and Ph.D. degrees. He joined the Cornell faculty in 1970 after receiving his doctorate. During sabbatical leaves, he has conducted research at the Combustion Sciences Division of Sandia National Laboratories and at Cambridge University, England.

He is an associate fellow of the American Institute of Aeronautics and Astronautics, and a member of the Combustion Institute, the American Society of Mechanical Engineers, and the Society of Automotive Engineers. He is a recipient of the SAE's Teetor Award.

BIOLOGICAL MONITORING OF AIRBORNE POLLUTION

by Daryl W. Ditz

Common plants such as grasses, mosses, and even goldenrod may turn out to have a new high-tech role as monitors of airborne pollution from solid waste incinerators.

Certain plants that respond to specific pollutants can provide continuous surveillance of air quality over long periods of time: they are *bio-indicators*. Other species accumulate pollutants and can serve as sensitive indicators of pollutants and of food-chain contamination: they are *bio-accumulators*. Through creative use of these properties, biological monitoring can provide information that cannot be obtained by current methods such as stack testing.

At Cornell a project to develop a biomonitoring system for assessing the emissions from solid waste incinerators is being planned by the Solid Waste Management Institute in conjunction with the Ecosystems Research Center and the Boyce Thompson Institute for Plant Research. In the system, biological sampling will be combined with modeling of the deposition patterns of airborne pollutants and with statistical analysis. The goal is to develop a system that will reliably measure the levels, geographical extent, and accumulation of these pollutants in the environment.

THE NEED FOR MONITORING EMISSIONS FROM INCINERATORS

Solid waste incinerators produce a variety of air pollutants that have the potential for adversely affecting health and the environment. These include some notorious carcinogens such as dioxins, furans, and polycyclic aromatic hydrocarbons (PAHs), as well as toxic heavy metals and more familiar pollutants such as carbon monoxide and hydrochloric acid.

A 1989 report of the Environmental Protection Agency (EPA) concluded that "products of incomplete combustion" pose a higher risk of cancer than any single air pollutant. According to the report, the estimated cancer incidence from this ill-specified mix of pollutants far exceeds that for more infamous substances such as benzene, asbestos, and vinyl chloride. Although they are not the foremost culprits—they rank seventeenth—solid waste incinerators are among the sources of incomplete combustion. They rank just below oil and coal incinerators (number 16) and well below motor vehicles (number 1), and even wood smoke (number 5).

Currently, less than 15 percent of this nation's solid waste is incinerated, but the EPA has projected that by the end of this decade the number of facilities, now 130 nationwide, will be at least doubled. It is not surprising that control of the air emissions (and also solid residues) from incineration has grown as a technical, environmental, and regulatory priority.

Several state and federal regulatory agencies have proposed new limits on the emission of some of these pollutants. Yet the technology does not exist for monitoring these emissions in a continuous, reliable manner. Instead, there is occasional testing of stack gases, a difficult, costly, and cumbersome process that does not yield adequate information. Stack tests are generally based on samples collected over a few hours once every year or even less frequently.

Measuring the concentration of pollutants in the surrounding area also presents problems. A major difficulty is that the concentrations in ambient air, particularly at some distance from the incinerator, are considerably below the levels in the stack, and analysis is constrained by detection limits. For example, the concentrations of polychlorinated dioxins and furans are often near the levels of picograms per cubic

Figure 1

Figure 2

meter in the ambient air and tens of picograms per liter in rainwater. (A picogram is 10^{-12} gram.) Furthermore, the transport of pollutants and therefore the spatial distribution is affected by meteorological variations and geographical conditions.

One of the most extensive programs to monitor ambient air is being conducted near the Greater Detroit Resource Recovery Facility, a major incinerator handling 2,400 tons of solid wastes per day. Data concerning a wide range of organic and inorganic air pollutants have been collected at the zone of highest estimated impact and at another site several miles farther away. Unfortunately, the high-impact area is adjacent to a large automotive assembly plant and two interstate highways, and the background site is still within the urban area and generally downwind from the city center. These circumstances have made it difficult to assess the incremental effect that the facility has had since it began operation in 1989. Preliminary data from the two test locations do not reveal any clear increase in most pollutants, although several kinds of PAHs tested higher after the first full summer of operation than in the previous summer.

Applications of biomonitoring are illustrated in Figures 1–5.

Figures 1 and 2 show foliage that has been damaged by exposure to atmospheric ozone. These plants—Bel W-3 tobacco in Figure 1 and common milkweed in Figure 2—are classic bio-indicators of ozone.

Figure 3 is a contour map of the Rhône Valley in Switzerland, where fluoride pollution from smelters is highly correlated with the fluoride concentration in pine needles, represented by the heights of the vertical bars.

Figure 3

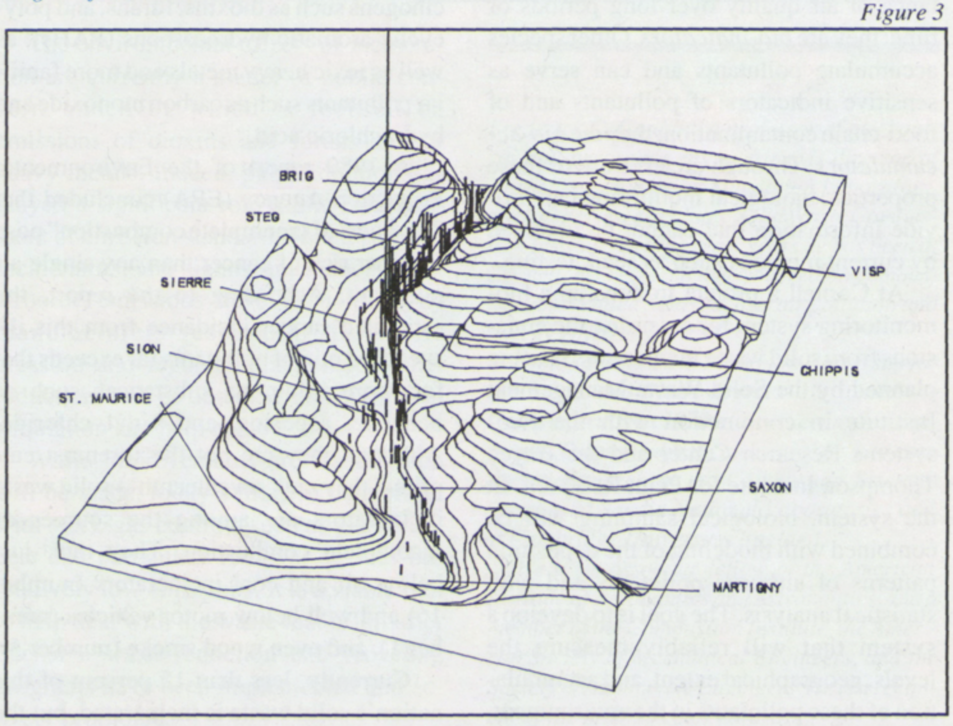


Figure 4

Figure 5

Figure 4 shows a series of rye grass cultures next to an Autobahn in Germany. The grass is a bio-accumulator of pollutants in vehicle emissions, and the different stands of grass show concentrations of lead that are in accordance with the distance from the roadway of the particular test plot.

Figure 5 shows a sampling station containing several plant species for biomonitoring. This arrangement permits exposure of the plants to any airborne pollutants and at the same time provides protection from birds and other predators. Sampling stations like this are being used by the Cornell researchers.

The most serious problem with ambient air monitoring, though, is that it does not take into account the most significant pathway for exposure to pollutants. The most detailed estimates of health risks from solid waste incinerators indicate that food-chain contamination, not direct inhalation of polluted air, is the dominant hazard. Evidence supporting this conclusion turned up last year in The Netherlands, where milk was found to be contaminated by dioxins. The Dutch authorities responded to this unsettling discovery by tightening the limits on dioxin emissions from a dozen garbage incinerators and one industrial-waste incinerator.

Ironically, the propensity of certain pollutants to accumulate in living organisms provides the key to a better way of quantifying airborne pollution: the use of biological monitors.

BIOLOGICAL MONITORING OF AIR POLLUTION

Biological monitoring is hardly a new idea; scientific use of the method goes back well over a century. The proverbial "canary in a coal mine", a bio-indicator with a high sensitivity to toxic gases, had a real and indispensable role as a monitor of air quality.

Over the last few decades, many species of plants that exhibit special pollutant sensitivities have been identified. Examples, illustrated in Figures 1 and 2, are leaves of tobacco and milkweed that have been damaged by exposure to atmospheric ozone.

The use of bio-accumulators is another approach to biomonitoring. This method relies on species that are generally more resilient to pollutant exposure and act as "pollutant sponges", accumulating the substances in their tissues. This can result in food-chain contamination, such as the occurrence of high concentrations of mercury or chlorinated organics in fish that have fed on plants and lower organisms. Pine needles have been shown to be highly reliable accumulators of fluorides emitted by aluminum smelters in Switzerland (see Figure 3).

Figure 4 shows a test site in Germany where a common rye grass is used as an indicator in a series of plots at different distances from the Autobahn. Elevated concentrations of heavy metals such as lead and cadmium can provide important information about the relative contributions of vehicles and other sources of pollutants.

A growing literature describes both laboratory and field experiments that demonstrate this accumulating property of plants. Ten years ago, a survey of polychlorinated biphenyl (PCB) concentrations in goldenrod revealed unexpected sources of the long-lived pollutant in upstate New York. More recently, West German scientists have successfully employed curly kale, a waxy cabbage-like plant, to measure PAHs around power plants and across urban areas. These researchers are now turning their attention to biomonitoring of solid waste incinerators.

ADVANTAGES OF BIOMONITORING OVER TRADITIONAL AIR SAMPLING

The use of bio-accumulators for monitoring airborne pollutants offers three clear advantages over traditional ambient air monitoring:

1. Many plants are highly efficient collectors of low levels of gaseous and aqueous chemicals. This is a very valuable function for the plants, enabling them to extract carbon dioxide from the air and minerals from the root zone, and it is a valuable property for monitoring because the plants can magnify the very low concentrations of airborne pollutants.

2. Unlike most ambient air sampling programs, biomonitoring allows samples to be collected over long periods—weeks or months or more—at relatively modest cost (see Figure 6). This helps to characterize long-term, integrated exposure to emissions that are overlooked by current "snapshot" sampling techniques.

3. The use of organisms as pollutant receptors takes account of the actual routes of exposure—wet and dry deposition, gaseous diffusion, and soil uptake—yet permits the control of key variables such as soil type, height above ground, and plant strain.

EARLY WORK ON BIOMONITORING OF INCINERATOR EMISSIONS

In this country there have been two efforts to detect pollutants from solid-waste incinerators in soil, vegetation, and milk, but neither has yielded conclusive results.

In Rutland, Vermont, bioassays of soil, plants, and milk were used to evaluate possible effects of airborne particulates from a 120-ton-per-day modular mass-burn incinerator. Samples of milk, grass, carrot, and potato were collected at three different times from several locations near the incinerator. Although testing began after the plant's start-up, subsequent closure stemming from financial difficulties afforded an opportunity to find out whether any changes occurred in the absence of incineration. The conclusions are still tentative, but the data suggest the presence of organic mutagens (not necessarily from the incinerator). This project was conducted by several offices of the Environmental Protection Agency in collaboration with state environmental authorities.

In 1987 the New York State Departments of Health, of Environmental Conservation, and of Agriculture and Markets collaborated in a study of pollutants in soil, grass, and milk collected near a solid waste incinerator in Cuba, New York. Samples were obtained from one upwind and three downwind sites. Analytic difficulties have frustrated efforts to evaluate the results.

Figure 6

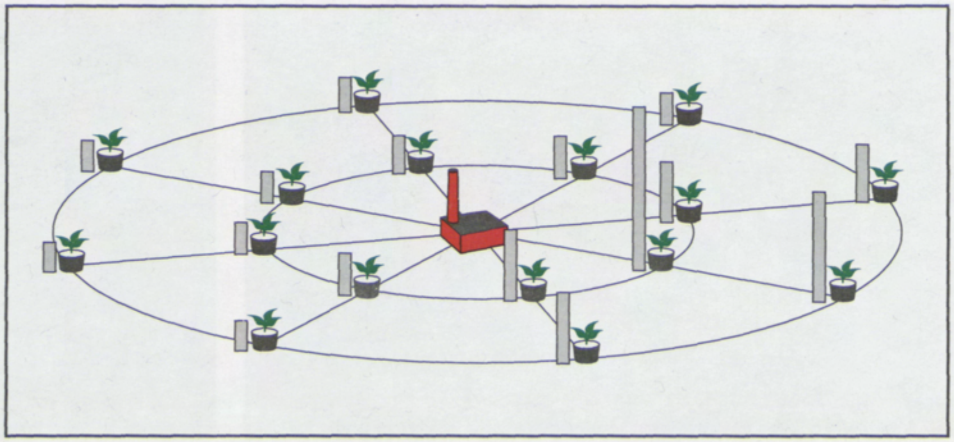


Figure 6. An example of a grid for biological receptors in the area around an incinerator. The potted plants represent sampling stations in a hypothetical biomonitoring system. The heights of the gray bars represent measured pollution levels. Careful location of the stations can provide crucial information about the patterns of pollutant exposure. This is central to the proper attribution of pollution to sources.

THE PROPOSED RESEARCH AND ITS SIGNIFICANCE

The Cornell study of pollutant distribution around solid waste incinerators is being planned by researchers at the Cornell Waste Management Institute in collaboration with other experts on and off campus. Cornellians include Leonard Weinstein, who is director of the Program in Environmental Biology at the Boyce Thompson Institute for Plant Research and also director of the Ecosystems Research Center; and George Casella, associate professor of plant breeding and biometry. Representatives of several New York State agencies are expected to cooperate.

The use of plants as pollutant accumulators is central to the study. To ensure that the data can be analyzed correctly, a number of variables will be taken into account:

- Base-line and operational (before-and-after) monitoring will be conducted around a modern incinerator. This implies that sampling must begin even before the facility is certain to operate. Yet even if a biomonitoring program is initiated and the facility is not constructed, the base-line sampling will not be a wasted effort. With appropriate consideration in the early de-

"The use of organisms as pollutant receptors takes account of the actual routes of exposure... yet permits the control of key variables...."

sign of the biomonitoring program, the samples and data collected through this "environmental audit" will benefit future assessments of environmental change.

- A suitable model for atmospheric transport and deposition will be used in the design of a receptor grid (see Figure 6) and in the interpretation of results.
- Detailed statistical analysis of results will be used to provide information about the spatial and temporal patterns of pollutant accumulation.

A significant aspect of this project is that it will improve the understanding of emissions by providing data collected at intervals *between* stack tests. It will also provide information that will help establish critical assumptions about food-chain exposure to pollutants—assumptions that are central to estimations of health risks.

Biological monitoring is not a substitute for the currently mandated stack tests or for continuous emission monitoring. Rather, it provides additional and unique information. Other advantages are that it is comparatively inexpensive, it is noninvasive, and it does not depend on access to the emissions source.

The novel biological system developed for monitoring emissions from incinerators will also have importance in a larger context: It promises to be a valuable general method for monitoring a variety of pollutants in the environment.

Daryl W. Ditz, a senior extension associate in the Cornell Waste Management Institute, is responsible for a variety of research and public outreach projects. He is also a lecturer in civil and environmental engineering.

Ditz holds a B.S. degree in chemical engineering from the University of Wisconsin (1982) and a Ph.D. in engineering and public policy from Carnegie Mellon University (1987).

THE SEWAGE SLUDGE STORY

by John H. Martin, Jr.

A commitment to restore the physical, chemical, and biological integrity of the nation's surface waters was made with the passage of the Federal Water Pollution Control Act Amendments of 1972 (PL 92–500). One of the programs initiated by these amendments provided financial assistance to municipalities for upgrading existing wastewater treatment facilities and for the construction of new facilities when necessary. While this program has generally produced the desired improvements in surface-water quality, it has also resulted in a substantial increase in the quantity of wastewater-treatment residuals, or sludge, that is generated, and consequently in the tasks of sludge stabilization and disposal.

In 1989 the U.S. Environmental Protection Agency estimated that 7.8 million tons of sewage-sludge solids are generated annually at the approximately 15,300 publicly owned wastewater treatment facilities; this translates into 64 pounds for every individual in the United States. The annual total is expected to double by the year 2000 because of population growth, more stringent treatment requirements, and improved treatment-plant operation.

This continuing growth in the total mass of sewage-sludge solids has been accompanied by a changing regulatory and economic environment that is forcing many municipalities to develop new approaches to sludge disposal. In this article I will discuss current disposal practices and future options.

WHAT IS SEWAGE SLUDGE AND WHAT ARE ITS CHARACTERISTICS?

Sewage sludge is a general term to describe those solids removed from wastewater in a form that contains a large amount of entrained water. Typically, sewage sludge contains: (1) those solids present in untreated wastewater in a settleable form, and (2) excess microorganisms synthesized in biological treatment processes. Sewage sludge also may contain products formed by the addition of coagulants to remove colloidal and suspended pollutants, chemical precipitates formed by reaction of added chemicals with dissolved pollutants, and/or adsorbents used to remove dissolved pollutants.

The principal component of sewage sludge generated at publicly owned wastewater-treatment facilities is carbon present in a variety of naturally occurring organic compounds such as proteins, fats, and carbohydrates. These compounds are waste products of human digestive processes or are products of biological transformations of these wastes. Thus, sewage sludge is primarily of agricultural origin and contains significant concentrations of potentially valuable plant nutrients such as nitrogen and phosphorus.

Sewage sludge also contains a variety of organic and inorganic trace constituents from both agricultural and nonagricultural sources. Some, such as polychlorobiphenyls (PCBs) and cadmium, are highly toxic and can be harmful to a number of animals, including humans. Others, such as nickel and zinc, are essential nutrients for both plants and animals at low concentrations, but are toxic at higher concentrations.

Concentrations of toxic and potentially toxic organic and inorganic trace constituents of sewage sludge vary widely among wastewater-treatment plants, reflecting differences in wastewater characteristics. A common misconception is that all toxic and potentially toxic materials in sewage sludge are from industrial sources. Although industrial wastewater can be a major source, toxic and potentially toxic

". . . 7.8 million tons of sewage-sludge solids are generated annually. . . . this translates into 64 pounds for every individual in the United States."

sludge constituents can also be from seemingly innocuous sources such as households and commercial establishments. For example, copper plumbing with soldered connections can be a significant source of copper, zinc, and lead in sludge, and common household chemicals such as pesticides and cleansers can contribute toxic compounds.

Sewage sludge also contains pathogenic microorganisms—bacteria, viruses, parastic protozoa, and helminths—of enteric origin. Although the densities of specific species of pathogenic miroorganisms can be highly variable, sewage sludge derived from the treatment of wastewater containing fecal material generally contains some species of enteric pathogens.

The quantity of sewage sludge generated during wastewater treatment is a function of the degree of treatment or purification and of the specific unit processes used. Although there are exceptions, most of the wastewater discharged from publicly owned treatment facilities in the United States receives a minimum of secondary treatment (see Figure 1). As defined by the American Public Health Association, secondary treatment typically includes primary treatment (clarification to remove settleable solids) followed by a biological process to remove colloidal solids and soluble organic compounds.

According to a 1989 report of the Environmental Protection Agency, primary treatment typically generates 2,500–3,500 gallons of sludge per million gallons of

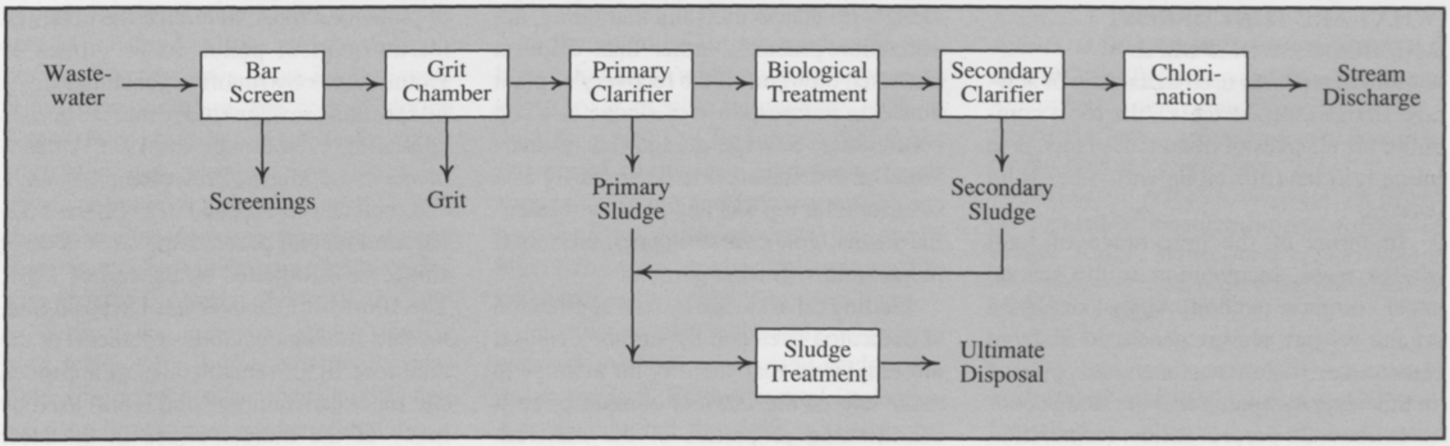


Figure 1. Flow diagram of wastewater treatment using a biological process to provide secondary treatment.

wastewater. This sludge contains 3–7 percent solids. Biological treatment (using activated-sludge, trickling-filter, or other biological processes) generates an additional 15,000 to 20,000 gallons of sludge per million gallons of wastewater. Sludge produced by secondary-treatment processes is commonly referred to as secondary sludge and typically contains between 0.5 and 2 percent solids.

In some situations, secondary treatment is not adequate to satisfy effluent quality standards and additional treatment is required. Then, tertiary or advanced treatment processes, such as filtration and chemical precipitation, are employed. One example of advanced wastewater treatment is the addition of aluminum or iron salts to remove phosphorus, a process that can increase the volume of sludge by another 10,000 gallons per million gallons of wastewater treated.

Prior to ultimate disposal, sludges are generally reduced in volume by various unit processes that thicken, stabilize, and dewater the product. The cost of sludge treatment and disposal is one of the more significant components of the total costs for wastewater treatment.

SLUDGE DISPOSAL METHODS

Method of Disposal	**Percentages in Treatment Plants of Various Sizes***			
	Small (<1 MGD)	Medium (1–10 MGD)	Large (>10 MGD)	**Total** (%)
Municipal landfills	54.6	60.1	33.2	41.0
Incineration	>0.1	5.4	29.0	21.4
Land application	20.5	25.2	11.9	15.6
Distribution & marketing	0.7	2.1	12.4	9.1
Ocean disposal	>0.1	>0.1	7.9	5.5
Surface disposal	10.0	2.4	1.8	2.5
Monofills	0.5	1.5	1.4	1.3
Other	13.6	3.2	2.4	3.5

**in millions of gallons per day (MGD)*   *Source: Environmental Protection Agency, 1989*

WHAT ARE THE CURRENT METHODS OF DISPOSAL?

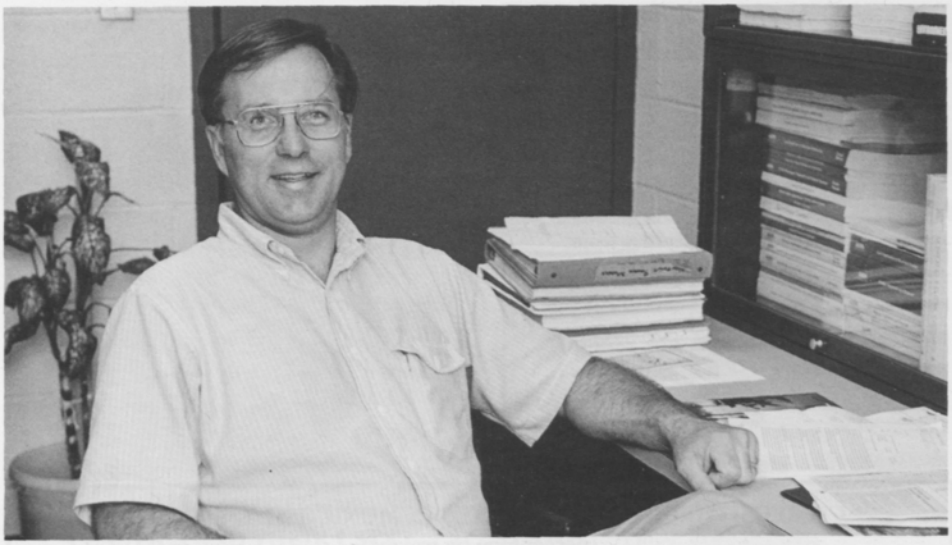
Of all the methods used to dispose of sewage sludge (see the table), the most common, for all sizes of treatment plants, is to place it in landfills along with other solid wastes.

In terms of the percentage of total sludge mass, incineration is the second most common method. Almost one-third of the sewage sludge generated at large wastewater-treatment plants is disposed of in this way. Assuming that the sludge contains about 20 percent solids, incineration reduces the volume by about 90 percent on a wet-weight basis; the remaining 10 percent is ash. Thus, incineration is a volume-reduction but not an ultimate disposal process.

Application to agricultural and forest land and to dedicated sites is the third most common sludge-disposal method. An estimated 77 percent of the sludge that is currently disposed of by land application is applied to land that is used for raising agricultural crops. Actually, land application, along with distribution and marketing, are utilization practices rather than disposal methods; they permit the recovery of plant nutrients and make use of sludge as a soil conditioner. Sewage sludge that is marketed or distributed is used primarily as a substitute for top soil and peat for residential lawns, golf courses, parks, and ornamental and vegetable gardens.

Getting rid of sludge by land application at dedicated sites and by surface disposal are similar in that there is no attempt to make use of the nutrient content or soil-conditioning properties of the material. The objective in using dedicated sites for land application of sludge is to bind hazardous heavy metals and destroy organic constitutents through microbial and chemical processes that occur naturally in the soil. In contrast, surface disposal has no objective other than disposal; thus, it is more comparable to disposal in a landfill or monofill (a landfill that accepts only sewage sludge). Another difference is that dedicated sludge-disposal sites frequently have some form of vegetative cover, such as sod or pulpwood trees, to reduce the potential for transport of pollutants to surface or ground water by runoff or leaching.

Dumping sewage sludge into the oceans continues, even though the 1977 Amendments to the Marine Protection, Research, and Sanctuaries Act of 1972 (PL 92–532) required that all ocean disposal of sewage sludge be terminated by the end of 1981. The 106-Mile Ocean Waste Disposal Site, located 106 nautical miles southeast of the Ambrose light, remained as an approved site for ocean dumping and is still used by many of the municipalities in the New



York City area. Disposal at this site will be discontinued at the end of 1991, however, as required by the Ocean Dumping Ban Act of 1988 (PL 100–688).

FUTURE TRENDS IN THE DISPOSAL OF SEWAGE SLUDGE

It is clear that there will be significant changes in the profile of sludge-disposal practices in the future. One change that can be expected is decreased dependence on municipal landfills and monofills because of the continuously decreasing space available in existing facilities and the difficulties in siting new ones. Even if space were not a major problem, the cost of sludge disposal in landfills might make other alternatives an economic necessity for municipalities. Another factor that will change sludge-disposal practices is the elimination of ocean dumping by the end of next year, as discussed above.

Without any new technology that is both technically and economically feasible, the options other than landfill disposal are limited to either beneficial use in some form or incineration. Each approach has certain merits but also entails risks. For example, disposal of sludge by application to agricultural and forest land provides the opportunity to recover plant nutrients and thus reduce dependence on chemical fertilizers, but it creates the risk of contamination of the food supply and water resources by toxics and pathogenic microorganisms. While incineration eliminates these risks, it creates others. Emissions of particulates, carbon monoxide, and oxides of nitrogen and sulfur degrade the ambient air quality, with the potential for adversely affecting human health. In addition, there is concern about toxic organic compounds such as dioxins, which can be formed during the process of combustion, and toxic metals such as cadmium and mercury, which can be volatilized. Although these risks can be reduced by emissions control, they must be taken seriously.

In order to reduce the risks associated with all methods of sewage-sludge disposal, the U.S. Environmental Protection Agency adopted, in 1989, a policy that appears to be both logical and equitable. This strategy has two parts—waste reduction, and control of sludge quality. Reduction is achieved by discouraging practices such as the use of garbage-disposal units and encouraging the use of wastewater-treatment and sludge-stabilization processes that minimize final sludge mass and volume; with this approach it appears possible to achieve significant reduction in the amount of sludge that ultimately must be disposed of. Control of sludge quality can be accomplished through source-control measures and pretreatment to prevent sludge contamination. Industrial wastewater pretreatment is already in place and appears to be effective. The overall policy of risk reduction seems much preferable to the alternative of having society accept the risks.

Clearly, solving the problems of sewage-sludge disposal will not be easy. The encouraging aspect is that technically sound and economically feasible strategies are evolving.

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His current research and extension efforts are focused on management and disposal of sewage sludge, management of agricultural and food-processing wastes, and the effects of land use on water resources.

Martin holds B.S. and M.S. degrees from Rutgers University and is a Ph.D. candidate in agricultural and biological engineering at Cornell.

PLASTICS IN THE WASTE STREAM

Special Properties, Special Problems

by Ellen Z. Harrison

The special properties that make plastics useful do not disappear when they are thrown away, and as a result, they present special problems in solid waste management.

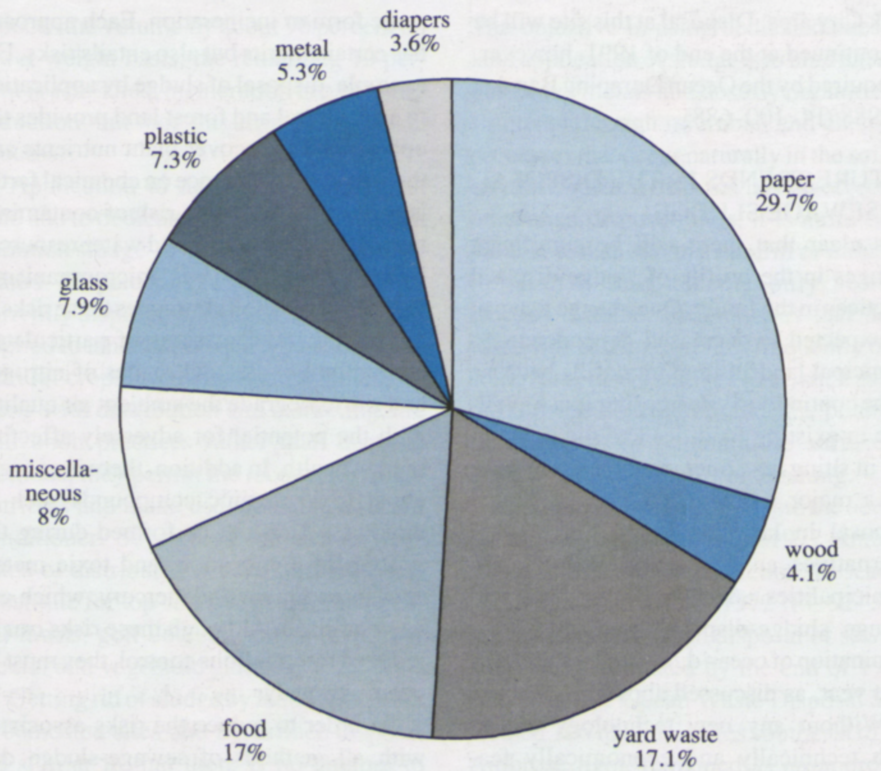
The problems are significant, for plastics make up a growing proportion of our solid waste. The production of plastics in the United States has been increasing 10 percent per year over the past thirty years, and much more rapidly in the last decade. Correspondingly, the percentage of plastics in municipal solid waste has been increasing; it is now about 8 percent by weight, and estimates are that by the year 2000, it will increase to 10–14 percent. In terms of volume, the figures look worse: plastics already occupy 18 percent or more of the space in landfills.

One of the valuable and troublesome characteristics of plastics is durability; we are confronted with images of dumps filling up with containers that will last forever and resist compaction. Indeed, on the plastics front the issue that is getting the most attention these days is whether plastics can and should be made degradable (a complex matter, as I will discuss).

Even more crucial, though, are the ques-

Figure 1

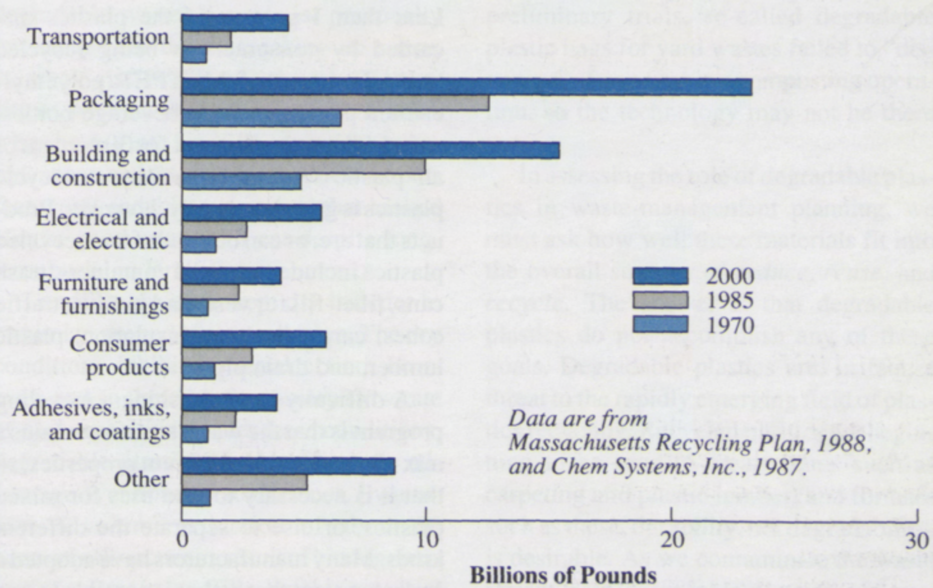
COMPOSITION OF SOLID WASTES IN MUNICIPAL LANDFILLS
(percentage by weight)



Data are from the University of Arizona, 1986.

Figure 2

THE MARKETS FOR PLASTICS, 1970–2000



Data are from Massachusetts Recycling Plan, 1988, and Chem Systems, Inc., 1987.

SOME COMMON PLASTICS AND THEIR USES

LDPE (low-density polyethylene)
17.3% of 1988 domestic plastic resin demand. Familiar as plastic-film items such as grocery bags.

HDPE (high-density polyethylene)
14.6% of 1988 domestic plastic resin demand. Familiar as milk and water jugs, detergent bottles, and the base cups of soft-drink containers.

PET (polyethylene terephthalate)
Familiar as soft-drink bottles.

PP (polypropylene)
12.8% of 1988 domestic plastic resin demand. Familiar as durable items, fibers, yogurt containers, and diaper liners.

PVC (polyvinyl chloride)
14.6% of 1988 domestic demand. Commonly used in durable construction products such as pipes and siding.

PS (polystyrene)
9% of 1988 domestric plastic resin demand. Familiar in foamed form (Styrofoam is a brand name) as fast-food packaging, hot cups, and meat trays; also used in rigid and semi-rigid containers.

Multilayer or barrier plastics
combine various plastics in layers. Common in squeezable bottles.

tions of how plastics can be recycled and how consumer use can be reduced. In the whole field of solid waste management, how to *dispose* of the wastes is far from the only consideration. *Reduce, reuse,* and *recycle* are major goals, and in the case of plastics, these approaches are just beginning to be pursued. They have high priority in the work of the Waste Management Institute at Cornell.

PLASTICS IN PRODUCTS AND IN OUR TRASH

Plastics constitute a wide range of polymer-based materials that can be formed into a desired shape with some degree of rigidity. Some of the most common types are described in the table. Various chemicals may be added to the basic polymer; on the average, 17 percent of the weight of a plastic object is due to additives, and in some cases it is as high as 60 percent.

Of the 56 billion pounds of plastics sold in the United States in 1988, about one-third was used in short-life applications such as packaging. The next highest categories were 25 percent for construction and 11 percent for consumer products. Because packaging is thrown away so quickly, it represents 50 to 80 percent of the plastics in the waste stream. (Packaging of all kinds constitutes about a third by weight of the solid-waste stream; plastics account for about one-sixth of this amount, and paper about half.)

Major advantages of plastics as products are that they are light in weight and tend to retain their shape—they are not easily crushed. These properties aggravate the problems of disposal, however. Durable products do not decompose in landfills and light-weight, uncrushable objects take up a lot of space in trucks and landfills.

CHALLENGES IN DEVELOPMENT OF RECYCLING TECHNOLOGIES

Less than 1 percent of the plastics discarded by consumers is being recycled today. Nearly all of this is PET (polyethylene terephthalate) from beverage bottles; soft-drink bottles account for 30 percent of all plastic waste. The ability to recycle plastics is growing rapidly, however. Products that are, or can be, made from recycled plastics include non-food containers, trash cans, fiber-fill for vests and jackets, traffic cones, carpet backing, insulation, plastic lumber, and drain pipe.

A difficulty in establishing a recycling program is that the waste stream contains a mix of plastics with different properties, so that it is necessary to find uses for mixed plastics, or else to separate the different kinds. Many manufacturers have adopted a coding system that makes it possible to sort containers at recycling centers (although the need for manual reading of the codes makes the process not very feasible at facilities where the objects are passed along on conveyor belts). Mechanical and chemical processes are also used to separate different types of plastics, such as PET and HDPE, and methods for removing

USES FOR RECLAIMED PET
(millions of pounds)

	1987	1992
Fiber	90	180
Injection molding	25	160
Extrusion	25	130
Non-food-grade containers		30
Structural foam molding		30
Paints, polyols, other chemical uses	10	20
Stampable sheet		30
Other (not yet identified)		20
Total	150	600

Data from Plastics Recycling Foundation

Figure 3

MATERIALS IN A TYPICAL 2-LITER BEVERAGE BOTTLE

labels, caps, and rings from plastic bottles are being developed.

One of the complications in recycling is the increasing use of multi-layer packaging (in some kinds of bottles, for example). Another difficulty is that some of the additives in plastics are known or suspected carcinogens. For example, the heavy metal cadmium, which is a component of a pigment used to color plastics, can have deleterious effects on health. About one-fourth of the cadmium used in the United States is present as a pigment in plastics.

As we look to recycling as part of a solution to the problems of waste disposal and depletion of natural resources, we need to consider the number of times that a recycled plastic material can be expected to be recycled again. Glass containers, for example, can be recycled indefinitely, but many of the products made from recycled plastics will be discarded after a single use. We need to keep the goal of continued recycling and reuse in mind.

At the present time, the use of recycled or degradable plastics in food-contact applications is prohibited as a safeguard against any possible contamination. Beverage containers, for example, cannot be

"Less than 1 percent of the plastics discarded by consumers is being recycled today."

recycled back into beverage containers because of concern over possible contamination. Also, there is concern that containers used by householders to store toxics such as pesticides might find their way into recycled materials, and since plastics may adsorb these pesticides, any containers subsequently made from these recycled plastics might be contaminated.

Another major problem with plastics recycling is the high cost of collection. Because of the large volume-to-weight ratio, transporting empty plastic containers means trucking around a lot of air and only a little material.

DEGRADABLE PLASTICS: SOLUTION OR PROBLEM?

As people are becoming more aware of environmental issues, including problems of solid waste disposal, the idea of biodegradable plastics has taken hold among consumers and even legislators. But there are concerns about safety and effectiveness that we should consider before rushing to change our buying habits or passing new laws.

What is meant by *degradable* plastic? Normally plastics break down very slowly or not at all, but recently it has been found that small amounts of additives (such as 5 percent cornstarch) can make a plastic subject to biodegradation or photodegradation. How fast and under what conditions of light, moisture, and aeration this will happen has not been well established, however. Research into the question of degradation processes and products is just beginning.

Degradability does not necessarily help very much in a modern landfill. Currently, about 65 percent of our solid wastes are biodegradable, but that certainly has not meant that they cause no problems after they are dumped. Ground-water pollution remains a serious problem. Moreover, biodegradable wastes can persist practically unchanged for decades, taking up space. "Garbologist" William Rathje, the University of Arizona professor who made news when he dug into landfills around the country, unearthed thirty-year-old newspapers that were readable and carrots that looked almost good enough to eat despite long-term burial in landfills.

Landfills are often kept dry in order to minimize ground-water pollution. The dry conditions inhibit bacterial action, however, and so there is often a very slow rate of decomposition. Under these conditions, degradable plastics would offer little advantage over nondegradable ones. Eventually, a volume reduction of about 30 percent will occur as a result of biodegradation of wastes in landfills, but this potential saving of landfill "space" may not be significant when weighed against disadvantages of degradable plastics.

An important consideration is safety. Very little is known about the nature of the intermediate and end products of the degradation of plastics. Some of the so-called degradable plastics may simply break down into tiny pieces with the same chemical composition. Others may release toxic chemicals—particularly from substances added to the basic polymer—into the air or water. No good data are available yet on the leachability of additives or the potential for harmful effects if animals ingest small pieces of plastic material.

If breakdown products can be shown to be safe, there are some appropriate uses for degradable plastics. Useful products might include degradable films for agricultural mulch (the plastic would not have to be picked up later) and degradable bags for collecting leaves and yard wastes for composting (the plastic would compost along with the refuse). Unfortunately, in some preliminary trials, so-called degradable plastic bags for yard wastes failed to "disappear" after a year in a composting operation, so the technology may not be there yet.

In assessing the role of degradable plastics in waste-management planning, we must ask how well these materials fit into the overall strategy of *reduce, reuse*, and *recycle*. The answer is that degradable plastics do not accomplish any of these goals. Degradable plastics are, in fact, a threat to the rapidly emerging field of plastics recycling. Recycled plastics are beginning to be used to create items such as carpeting and plastic lumber, and for uses such as these, durability, not degradability, is desirable. As we contaminate the waste stream with degradable plastics, we may threaten the prospects for recycling.

Another question is whether degradable plastics can be safe and effective substitutes for the plastics in products now on the market. For example, there is concern that food packaged in biodegradable plastics might become contaminated with bacteria, and no food-contact applications for degradable plastics have been allowed by the Food and Drug Administration. Making a plastic degradable may reduce its strength so that an object has to be made thicker, thereby increasing cost and material usage.

Requiring that plastic diaper liners be degradable is suggested as a way of helping to address the problems caused by disposable diapers in the waste stream. The problem is significant, since diapers make up an astonishingly high percentage of landfill refuse (see Figure 1). But degradable liners do not offer a solution—diapers would still constitute a large fraction of our trash.

Some of the motivation behind legisla-

"Consumers can be effective through their buying and disposal practices. The key is to go back to the principal waste-management goals: reduce, reuse, recycle."

tion requiring products to be degradable is to reduce litter. For example, six-ring connectors for soft drinks and beer are frequent targets of legislation requiring degradable plastics. The idea is to get rid of unsightly refuse and protect animals that might get tangled up in the rings. But it might take months or years for the plastic to decompose. Simply outlawing six-rings or changing their design would be more effective. Besides, many people suspect that degradable plastics would actually encourage littering because of an assumption that litter would just magically disappear.

WHAT ABOUT PLASTICS AND THE OZONE LAYER?

The release of chlorofluorocarbons (CFCs) into the atmosphere has been linked to destruction of ozone that is present in a layer of the atmosphere and is critical for protection from harmful radiation. Coolants in refrigerators and air-conditioners are the primary contributors of CFCs, but in the past, CFCs were also used as blowing agents to foam polystyrene for products including hot-drink cups and other food containers.

This hazard has been reduced as a result of consumer pressure: manufacturers have switched to less harmful blowing agents for the manufacture of food containers. CFCs are still used in the production of some foamed polystyrene products, such as construction materials.

WHAT CAN LEGISLATORS AND CONSUMERS DO TO HELP?

Legislation at the federal, state, and local level has sought to address some of the concerns over plastics in the waste stream, but unfortunately, most will not really have much impact. Laws requiring certain plastics to be degradable, for example, will not reduce the amount of waste going to our landfills and incinerators. Laws banning plastics for certain uses such as fast-food packaging may sound good, but replacing them with paper and cardboard does not solve our disposal problems. More reasonable are laws such as one passed in Minneapolis that bans the use of containers that are not recyclable, with *recyclable* taken to mean currently being recycled at a meaningful rate.

Consumers can be effective through their buying and disposal practices. The key is to go back to the principal waste-management goals: *reduce, reuse, recycle.* Guidelines for environmentally conscious consumers are:

- Don't buy disposable plastics.
- Don't use more when less—or none—will do.
- Say "no thanks" to extra packaging.
- Reuse containers, including bags, when you can.
- Recycle when possible—and until the technology for recycling plastic catches up to that for paper and glass, choose paper grocery bags and glass containers and see that they get recycled.

As engineers, municipal officials, legislators, and the public are becoming increasingly aware, the role of plastics in modern life includes their place in waste-disposal strategy.

Ellen Z. Harrison, a senior extension associate and the outreach coordinator of the Cornell Waste Management Institute, also contributed the article on pages 11–14 in this issue.

FACULTY PUBLICATIONS

Current research activities at the Cornell University College of Engineering are represented by the following publications and conference papers that appeared or were presented during the three-month period January through March 1990. (Some earlier entries omitted from previous Quarterly *listings will be included in the next issue of the* Quarterly.*) The names of Cornell personnel are in italics.*

■ AGRICULTURAL AND BIOLOGICAL ENGINEERING

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LETTERS

Editor:

The claim of a shortage of engineers presented in the spring 1990 issue [citing a National Science Foundation projection] is untrue and irresponsible. In most parts of the United States it is still very difficult to get any engineering/scientific job. NSF's counts have already been questioned. Hundreds apply for most jobs. Thousands of degree recipients go without jobs every year, with a pileup of surplus people educated in science and engineering of hundreds of thousands since 1970, with many more coming when they are laid off weapons work. NSF has never attempted to survey ALL degree holders in the U.S., nor has anyone else. Propagating the myth of a present or future shortage just continues the boom-bust cycle in science/engineering. See my letter (*New York Times,* Sunday, 11 June 1989).

Still, upgrading engineering education is VERY important. My skills in new instructional delivery systems have gone unused since 1977. No one wants to abolish the lecture system.

(Dr.) John Mauldin, B.E.P'65
Pueblo West, Colorado

Note: Mauldin's comments are in reference to the new NSF Engineering Education Coalitions Initiative, which is designed "to increase dramatically the quality of U.S. undergraduate engineering education as well as the number of engineering baccalaureate degrees awarded, especially to women and underrepresented minorities" and to promote "new structures and fresh approaches affecting all aspects of U.S. undergraduate engineering education, including both curriculum content and significant new instructional delivery systems". Cornell is the administrative head of a coalition of eight educational institutions that has been selected for funding under the initiative (pending approval of the National Science Board, which meets this summer).

Editor:

I just received two Cornell engineering publications and would like to advise you of address changes for them. . . .

As always, the Quarterly is a great job. It is instructive, it provides ideas that we should consider, and it keeps me up to date on faculty changes and accomplishments. The significant number of retirements (notably Gordon Fisher, who had a big hand in bringing me to Cornell) really brought home the fact that the faculty and staff has changed greatly since I was there.

Continued best wishes in connection with what is surely the finest scheme of publications of an engineering college anywhere.

Richard H. Gallagher, President
Clarkson University
Potsdam, New York

Note: Gallagher was a member of Cornell's structural engineering faculty from 1967 to 1978, when he became dean of the engineering college at the University of Arizona. Before going to Clarkson, he was a vice president at Worcester Polytechnic Institute.

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