U.S. Department of Energy

Waste Material Management:
Energy and Materials for Industry
DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.
U.S. industry spends more than $45 billion each year to handle, clean, and dispose of hazardous waste materials. The total cost for disposal of nonhazardous wastes is unknown, although one estimate for municipal wastes would add more than $8 billion to the bill.

Yet industrial and municipal wastes actually represent a reservoir of potential energy and material supply. The energy embodied in waste materials, combined with the energy used in their control and cleanup, amounts to as much as 10% of the energy our nation uses each year. By minimizing or reclaiming these wastes, we could redirect the energy, material, and economic investment in waste management to more productive uses.

Transforming wastes from a treatment problem to an energy and economic opportunity requires innovation at every stage of product design, manufacture, consumption, and disposal. The U.S. Department of Energy (DOE), through its Waste Material Management (WMM) Division, is collaborating with industry to develop the knowledge and technologies necessary to enable this transformation to take place.

The potential payoff is huge. By reducing the quantities of wastes generated and reusing or converting those that are generated, industry can enhance its competitive edge, and our nation can save energy and better protect the environment.

This booklet describes the Waste Material Management programs, which are designed to help tap the potential of waste materials. Each of the programs has a unique and vital relationship with industry. By working together, DOE and industry are turning the challenge of waste material management into the reality of a cleaner, more energy-efficient economy.
The Opportunity of Waste Materials

**waste** (n.) 1. anything that is perceived to have no value and is discarded as worthless; garbage; trash. 2. an untapped resource of energy and materials.

Each year, American industry generates 11 billion metric tons (12 billion tons) of wastes requiring treatment and disposal. About 6% of this waste is classified as hazardous, requiring special cleanup. Another 180 million metric tons (196 million tons) of solid wastes from homes and businesses end up in landfills. These quantities grow larger each year.

Every stage of a product's life cycle produces wastes—through inefficient use of raw materials in the manufacturing process, by generation of industrial by-products and combustion products, and finally, as discarded industrial or consumer products. Comprehensive waste management looks at each of these stages for opportunities to reclaim the waste resource. In general, the earlier in the process that wastes can be handled, the more cost effective and environmentally safe the technique is likely to be.

The most common waste management practice in industry today is "end-of-pipe" control—that is, treating wastes and discarding them to the environment. This practice allows industry to meet the requirements of pollution control regulations. However, end-of-pipe control is becoming increasingly difficult and expensive as environmental regulations tighten further, public scrutiny intensifies, and disposal costs soar.

Disposal of municipal solid waste (MSW) has also become more challenging. Landfills for MSW are becoming scarce. Today we have about 6000 landfills, down from 30,000 in 1976. About 45% of these 6000 are close to capacity and may close in the near future. And the cost of disposing of MSW is rising: in some areas, tipping fees have reached $140/metric ton ($150/ton).

Industry has responded to these challenges with innovation. Recognizing the tremendous potential for cost savings in waste treatment, industry has modified its operations, refined its processes, and developed new technologies that minimize, reuse, or convert waste materials. The result has been significant savings in costs associated with pollution control, energy use, and raw material consumption. Consumers have responded as well, with a newfound zeal for source reduction and recycling.

The resources of the federal government can augment those of the private sector to sustain this progress. To be specific, DOE is applying its financial resources, along with the intellectual and technological resources of the national laboratories, to the needs and opportunities identified by industry. The result is a powerful partnership with the common goals of enhanced industrial competitiveness and improved energy efficiency and security.

---

**Total Annualized Costs for Pollution Control**

![Graph showing annualized costs for pollution control from 1972 to 2000]

- **Existing regulations**
- **New regulations and programs**
- **Full implementation**

*Source: EPA, 1990*
The DOE Program

DOE's Office of Industrial Technologies is working with industry to develop waste management practices that make more efficient use of energy, materials, and money. Working within the framework of the National Energy Strategy, the office's Waste Material Management Division seeks to

- Find and promote cost-effective ways for industry to reduce or minimize wastes or utilize them as raw materials, fuels, or energy
- Enhance fuel flexibility, including the increased use of renewable fuels and feedstocks and of MSW
- Provide information about the options available for improving energy efficiency using cost-effective waste management technologies.

The WMM Division sponsors four programs aimed at developing the waste management technologies that industry needs: Industrial Waste Reduction (IWR), Waste Utilization and Conversion (WUC), Energy from Municipal Waste (EMW), and Solar Industrial Applications (SIA). These programs work closely with each other, with other parts of DOE, and with the other federal agencies involved in waste management research to make sure their activities are complementary.

DOE's Albuquerque Field Office and four national laboratories—Argonne National Laboratory, Los Alamos National Laboratory, the National Renewable Energy Laboratory, and Sandia National Laboratories—provide program management support to Headquarters. Albuquerque and the laboratories execute the research either in-house or through subcontracts to industry, universities, or other organizations.

Each of the programs has a strong link with industry. Through industry review boards, independent analyses, and open solicitations to industry, program managers tailor the research to respond to industry's needs. A special emphasis is placed on sharing project costs with industry. In this manner, DOE leverages the federal investment and involves industry directly in research, providing a direct path for technology transfer.

### Waste Material Management Programs

#### FY 1993 Funding

<table>
<thead>
<tr>
<th>Program</th>
<th>$ in millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial Waste Reduction</td>
<td>$10.8</td>
</tr>
<tr>
<td>Waste Utilization and Conversion</td>
<td>8.8</td>
</tr>
<tr>
<td>Energy from Municipal Waste</td>
<td>4.7</td>
</tr>
<tr>
<td>Solar Industrial Applications</td>
<td>4.9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$29.2</strong></td>
</tr>
</tbody>
</table>
Mission: To work with industry to develop and commercialize cost-effective technologies and practices that will save energy by reducing waste.

Perhaps the most effective and economical method of waste management is waste reduction. Known also as waste minimization, waste reduction involves reducing or eliminating waste at its source—usually as part of a production process—thereby reducing requirements for treatment and disposal. Waste reduction saves the energy and financial costs associated with waste treatment and the energy used to produce the raw materials and products. It can also lead to increased productivity, because more raw material becomes product.

In the mid-1970s, many companies began to recognize the value of minimizing wastes and, since then, have made great progress in their plants. But much of this attention has focused on the financial, environmental, and public relations benefits of minimizing wastes. Few programs have focused specifically on the potential energy savings.

These energy savings could be significant, however. In fact, reducing industrial waste by 50%—an aggressive but achievable goal—would save enough energy to supply about 30 million homes.

The DOE Industrial Waste Reduction Program focuses on this inextricable link between waste reduction and energy savings. By targeting the industries and processes that use the most energy and generate the most wastes, the program can have the greatest impact on energy efficiency.

Relatively new as a formal program, the waste reduction activities are structured around five key elements that build on the progress industry has already made (see below). These activities are designed to help industry overcome the remaining obstacles to waste reduction, which include:

- The large number of unique industrial processes, each requiring individual solutions
- A shortage of readily available information on recent developments in waste management and their potential cost savings
- A shortage of private money for research and development (R&D) on process and product redesign
- The risks to industry associated with implementing process and product changes

**Industrial Waste Characterization**

The lack of comprehensive, consistent data on the quantity, nature, and source of industrial waste streams is a fundamental problem in identifying opportunities in waste reduction. Most of the data that exist are collected in the context of compliance with environmental regulations. As such, the data tend to describe toxic waste discharges, rather than waste generation. Without comprehensive data on waste generation, targeting waste reduction R&D is difficult to do effectively.

**Key Elements of the Industrial Waste Reduction Program**

- Industrial waste characterization
- Opportunity assessments
- Technology research and development
- Technology and information transfer
- Institutional analysis
seeking expert advice from industry, government, and academia, program managers can identify the industries and processes with the greatest potential for waste reduction and energy savings. Armed with this information, program managers then typically issue solicitations for industry to submit proposals for cooperative research projects. In this manner, the needs and interests of industry drive program research.

For example, one recent study looked at opportunities for waste reduction in the chemical manufacturing industry. Part of the project involved a workshop in July 1991 that was attended by high-level executives of chemical companies to discuss the needs of industry. The group identified the need for new technologies for separations, reactions, and controls for waste reduction. The program responded with a solicitation for cooperative R&D with industry in the fall of 1991. Negotiations are now under way with three firms selected for possible awards.

The next study will extend the focus on chemical producers to chemical users. As in the previous study, program managers will sponsor a workshop with industry representatives to determine the needs for research and development. The results of this opportunity assessment may lead to another solicitation to industry.

To fill this information gap, the program is working with industry and other federal agencies to collect and review existing data bases, reconcile differences among them, and, where possible, standardize the data. The goal of the program is to obtain or develop data that reflect waste generation, rather than discharges. One specific project is being cosponsored by the Department of Commerce to study the expenditures for energy and pollution control associated with each of the products represented by the 5–7 digit Standard Industrial Classification codes.

As the data on waste generation become available, they will form the basis of studies that identify R&D opportunities in various industries. The data will also be useful to industries directly as they pursue waste reduction opportunities on their own. The same information is essential to planning the Waste Utilization and Conversion Program.

**Opportunity Assessments**

Analytical studies of the opportunities for waste reduction help direct the research of the Industrial Waste Reduction Program. By analyzing the available data on industrial waste practices and

President Bill Clinton receives the first no-clean soldering circuit board during a visit to Sandia National Laboratories. The new no-clean process eliminates the need for CFC solvents to clean soldering residues from electronic assemblies.

**Strategies for Reducing Industrial Wastes**

- Improve operational efficiency
- Recycle wastes within the process
- Redesign the production process
- Use alternative feedstocks
- Redesign the product for more effective use of raw materials

The next study will extend the focus on chemical producers to chemical users. As in the previous study, program managers will sponsor a workshop with industry representatives to determine the needs for research and development. The results of this opportunity assessment may lead to another solicitation to industry.
Technology Research and Development

Research and development projects form the core of the program. Projects are chosen according to their potential for saving energy, reducing wastes, lowering costs, and providing the greatest national benefit per DOE dollar. Other critical factors include the degree of industry support and the need for government funds. Projects are designed to involve one or more industrial partner throughout the process of basic research, laboratory tests, field tests, and in some cases, pilot tests. Typically, the level of industry’s involvement and cost-sharing increases as the technology nears commercial readiness, but the level must average at least 50% over the course of the project.

![Resonant Cavity Microwave Applicator](Image)

Source: Argonne National Laboratory

Argonne National Laboratory is leading a task to recover the hydrogen sulfide generated in petroleum refining and natural gas production. The system uses a microwave reactor to split the gas into hydrogen and sulfur.

Several current projects focus on recovering or reducing emissions of waste gases. For example, one project cosponsored by Dow Corning has developed new technology for the silicon industry that replaces conventional open-hearth furnace technology with a new closed furnace. The new furnace, now being tested at a pilot plant, dramatically reduces energy use and emission of silicon dioxide, and could help the U.S. silicon industry regain its competitive edge against low-cost imports. Another project involves conducting laboratory research on a technique for recovering hydrogen and sulfur from the hydrogen sulfide generated from petroleum refining and natural gas production.

Other projects target reduction of solvent use, which would lower emissions of volatile organic compounds into the atmosphere. For one of these projects, DOE teamed with the 3M Company to develop coatings that use photocatalytic curing systems instead of solvents. The new coatings have large potential applications in the aerospace industry and in tape manufacturing. Another solvent project resulted in the formation of the Joint Association for the Advancement of Supercritical Fluid Technology, a consortium of industry partners. The partnership is developing precision cleaning techniques that don’t use chlorofluorocarbons or other chlorinated solvents.

The IWR Program has also joined forces with the Environmental Protection Agency (EPA) and the U.S. Department of Commerce in a program called NICE³ (National Industrial Competitiveness through Environment, Energy, and Economics). Begun as a pilot program in FY 1991, NICE³ cosponsors research with industry to demonstrate new technologies that prevent pollution and improve energy efficiency, identify barriers to industrial pollution prevention techniques, and develop strategies to overcome these barriers. In FY 1993, the program is being jointly funded by EPA and DOE and is targeting the chemicals, petroleum, primary metals, and paper industries.

Technology and Information Transfer

Industry involvement in all aspects of the IWR program forms the cornerstone of the program’s technology transfer. By tailoring activities around the needs of industry, involving it in collaborative R&D, and conducting field tests in operating plant environments, the program ensures that new technologies will be adopted rapidly by the private sector. Industry involvement takes various forms, including contract research, grants, and cooperative research and development agreements (CRADAs).
Besides interacting directly with industrial partners, program managers are developing a comprehensive plan for technology transfer that will integrate various methods of communicating with the industrial community. These methods include

- Publishing fact sheets, brochures, and reports
- Preparing slide or video presentations
- Disseminating databases
- Conducting workshops and contractor review meetings
- Giving presentations at technical conferences
- Publishing articles in technical and trade journals.

This unit, developed by PPG Industries, Inc., recovers cleaning waters containing water-based coatings. The project is part of the NICE® program sponsored by DOE and the Environmental Protection Agency.

Institutional Analysis

The program also addresses the nontechnical factors that sometimes affect decisions to implement new technologies. Some of these factors relate to the financial and structural aspects of industry, such as the cost of capital, macroeconomic factors, size of companies, and industry-specific competition. Additional constraints may include regulatory requirements, liability concerns, corporate philosophy, market conditions, and product specifications.

Understanding these issues is vital to developing an effective and realistic program plan. The program examines these issues in studies conducted collaboratively with industry and in close coordination with the opportunity assessments. One such study was completed in FY 1992; it examined the incentives and disincentives to waste reduction created by the current legislative and regulatory climate. The report reflects input from several trade associations and individual industrial firms.

Working with the Boeing Company, scientists at Los Alamos National Laboratory are developing a process to recycle metal ions from electroplating wastes.
impressive rate. However, the effectiveness of this route is directly affected by the cost-effectiveness of the reprocessing technologies and the availability and proximity of markets for the recycled materials.

To fully exploit the energy and materials resource embodied in industrial and consumer wastes will require new technology. DOE’s Waste Utilization and Conversion Program is designed to work with industry to develop the needed technologies. By doing so, the program can help industry remain competitive and enhance the energy efficiency and environmental quality of our nation.

The WUC program has four basic elements. Similar in approach to the Waste Reduction Program, this program begins each new area of research with an analysis of the particular waste stream and its potential for conversion or utilization. With help and advice from industry experts, analysts estimate the potential net energy benefit and identify needed R&D. Program managers can then select projects with the greatest potential for success and for energy and cost savings.

**Technology Research and Development**

The technical element of the WUC program aims to develop new technologies for reusing waste materials that offer high pay-off in the mid- or long term. The preferred path for conducting these R&D projects is a cooperative effort involving one or more industrial partners teamed with DOE laboratories or university research centers. Experience has shown that these teams are the most successful in developing cost-effective, practical technologies and transferring them to industry.
Research currently sponsored by the program is broad-based. The selection of topics and projects is guided by the same set of criteria considered by industry in deciding whether to institute a particular waste conversion strategy. Both program managers and industrial waste managers ask the following questions:

- Is there a market for the resulting product?
- What is the product’s value?
- Is there a good match between the optimal scale of the conversion process and the size of the available waste streams?
- Are there increasing disincentives to the current practice?
- What new technology is required?

A major focus of the technical program is materials separation and recycling. Several projects address recovery and utilization of metals, including galvanized steel scrap, scrap aluminum, and “red metal,” the copper alloys used to make faucets, valves, and other plumbing fixtures. These projects are cost-shared with individual companies or industrial trade groups. Other projects target postconsumer goods such as plastics, waste tires, and waste carpet.

The program is also developing technologies for converting waste components to higher value materials. For example, scientists at Argonne National Laboratory can now convert potato wastes to biodegradable plastics. Plastics made by the process are now being tested by potential users. In another project, researchers developed a continuous fermenter-separator for producing ethanol from food processing wastes. Conducted at Purdue University, the project was cost-shared by several corporate sponsors, including Kraft General Foods, Inc.; Catalytics, Inc.; Permeate Refining, Inc.; and the Wisconsin Milk Board.

An investigation into “design for recyclability” is an emerging IWR project. The concept involves designing products and manufacturing processes in such a way that eventual recycling of the product becomes easier and cheaper. A joint project with the Bureau of Mines will identify materials not being recycled, determine the constraints to recycling, and evaluate possible design changes to make recycling easier.

### Strategies for Reusing Industrial Wastes

- Separation and recycling
- Conversion to reduce toxicity or prepare for recycling
- Remanufacture to reassemble discarded goods and new parts into new products
- Demanufacture to disassemble discarded products for further use
- Direct conversion to energy through combustion or catalytic conversion
- Remining or extraction to recover valuable materials from discards

---

Scientists at the National Renewable Energy Laboratory have developed a process to make adhesives and resins from waste wood. These resins can replace petroleum-based resins in molding compounds.
Air Products and Chemicals, Inc. developed a batch reactor to treat scrap tire rubber. The reactor modifies the rubber's surface, allowing it to be mixed with polymers to form composite materials.

**Pilot and Demonstration Projects**

Pilot-scale or demonstration projects play a key role in technology development. Successfully demonstrating new technologies at a large scale eliminates some of the risk industries face in adopting new technologies. These demonstration projects offer a prime opportunity for industries to share the costs and minimize the risks associated with innovation.

Several WUC projects are in the demonstration project stage. One involves a new process for removing zinc from galvanized steel scrap. Jointly sponsored by Metal Recovery Industries, Inc., a pilot plant for this technology is nearing completion in East Chicago, Indiana, under the metals initiative program. Also ready for pilot-scale testing is the process for converting food wastes to ethanol. A third project, cosponsored by Manville Sales Corporation, tested a process for reusing asphalt shingle manufacturing waste in a full-size commercial roofing plant. This technology is now ready for commercial application.

**Technology Transfer**

Like the Waste Reduction Program, the WUC program places a strong emphasis on working closely with industry. Many times the industrial partners are potential users of the technology and put it immediately into action. Other times partners are companies that might license the technology and market it to industrial users. Either way, these partners offer an effective mechanism of technology transfer.

The program also employs other mechanisms to reach a broader audience of potential users. Chief among the techniques are publishing papers, journal articles, and brochures, and attending trade fairs and exhibits. Program managers maintain lists of appropriate industry representatives and keep them informed of activities. The program also sponsors review meetings and workshops that are open to the public.

**Technology and Data Assessments**

Assessments of the needs and practices of industry and the opportunities for R&D help guide program activities. One study currently under way focuses on metals recycling. Working closely with industry, program analysts are examining opportunities such as recovery of iron from baghouse dust. Results of this and other studies will help program managers target future initiatives in R&D.
Mission: To ensure that economic and environmentally sound options are available for productively using municipal waste.

In 1990, Americans discarded 180 million metric tons (196 million tons) of waste to municipal facilities (estimates range up to 240 million metric tons [270 million tons] for residential, commercial, and institutional waste) with an energy value of as much as 4% of our nation’s annual energy consumption. Some of this energy is reclaimed through recycling and waste-to-energy conversion. However, the bulk of municipal solid waste, about 67%, is buried in landfills, taking its energy and material value with it. Although programs aimed at reducing the generation of wastes should slow the growth rate of MSW, its disposal will continue to be an issue far into the future.

At the local level, managing MSW has become one of the most controversial environmental issues facing communities. The best approach to municipal solid waste management is a coordinated one that combines four options: source reduction, recycling, conversion to energy, and landfilling. The ideal mix of options for any particular location depends largely on local conditions: the cost and availability of landfills, accessibility to recycling facilities and markets for recycled products, the cost and environmental requirements of converting waste to energy, municipal budgets, and public concerns.

As an energy resource, MSW is unique. It can produce energy through combustion or other conversion processes, and it can save energy by displacing virgin material feedstocks through recycling. It can also improve the environment by reducing the amount of wastes that must be landfilled and displacing emissions from other resources.

A significant industry already exists in our nation for converting MSW into energy. About 140 waste-to-energy plants are operating today with a combined electricity-generating capacity of more than 2400 megawatts, which displaces about 0.4% of our fossil fuel use. Some of these plants burn MSW directly. Others use a solid fuel called refuse-derived fuel made by reducing the particle size of MSW; removing the metals, glass, and other inorganic materials; and, sometimes, forming the remaining combustibles into pellets or briquettes. The refuse-derived fuel is then burned in dedicated boilers or in existing coal-fired boilers, displacing some of the coal. Another group of plants collects the methane-rich gases generated within existing landfills to use as fuels or substitutes for natural gas.

Additional plants either planned or under construction could add another 1800 megawatts of electric capacity. The National Energy Strategy predicts that waste-to-energy plants could eventually contribute about 2.2 exajoules (2.1 quadrillion Btu) of energy by 2010, more than 6 times today’s level.

To harness this source of energy, data on the energy, economic, and environmental aspects of the MSW management options are needed. Without good data, officials and the public find it hard to make complete and informed decisions on which options to choose. In addition, some institutional barriers
inhibit investment in conversion plants. For example, the air emission standards governing waste-to-energy plants are more stringent than those for fossil-fuel-fired plants. And 4 years of research indicate that the quality of leachate from ash monofills approaches drinking water standards. Yet some people still question the environmental risks posed by ash and gaseous emissions produced by waste-to-energy plants.

The DOE Energy from Municipal Waste Program focuses on converting the MSW resource to energy and using it productively in recycled products. The program’s goal is to provide the science, technology, and information necessary for municipal waste managers to design coordinated, cost-effective MSW programs that will be acceptable to the public. The key elements of the EMW program include data collection and analysis, technology development, institutional assessments, and technology and information transfer.

Data Collection and Analysis

One objective of the program is to collect a comprehensive set of consistent and reliable data on municipal waste and waste disposal options. The data should allow decision makers to compare alternative MSW management options with full consideration of their energy, environmental, and economic effects on individual situations.

To collect the data, the program researchers are working with industry and other federal agencies, in particular EPA, to review existing published data, analyze these data to assess their credibility, and reconcile differences where they exist. In many cases, the data do not exist—for example, energy and environmental effects of recycling paper, glass, and other waste streams have not been quantified. This makes it difficult to compare the various alternatives available to a municipal solid waste manager on a uniform basis. This element of the DOE program is collecting data from materials recovery facilities, combustion plants, integrated waste management systems, and recycling facilities for newsprint and glass. Researchers are also acquiring data from other nations to allow examination of their approaches to waste management.

As these data become available, they are provided to solid waste managers and other decision-makers at all levels of government (federal, state, county, and city). Data are also provided to industry so that it can develop systems for more energy-efficient use of the MSW resource without adversely affecting the environment.

Technology Development

MSW can be transformed into several forms of useful energy or energy-conserving products. These transformations take place in three types of processes: material recovery and reuse (recycling), thermochemical conversion, and biochemical conversion. The program is addressing each of these areas.

Material recovery and recycling in the states is growing. Yet the energy and environmental impacts of these facilities are not understood. As data become available, the program will begin technology development projects to make these facilities energy efficient and capable of using separated materials economically.
DOE program is working with industry to resolve issues of ash disposal and pollution control from plants.

Thermochemical processes for recovering the energy value of MSW use heat to break down the organic constituents. Researchers are evaluating techniques for reducing emissions from combustion plants by using low-cost methods of sorbent injection of MSW. Another project targets co-combustion of MSW (up to 30% by weight) with coal to determine the effect on emissions and ash residues. Co-combustion of MSW with sewage sludge is also being investigated. All these projects are cost-shared with industry.

Biochemical processes use microorganisms or enzymes to break down larger organic molecules into energy products. These processes operate at milder conditions than do thermochemical processes, but they require reaction times of several days or longer to complete. The program sponsors research on landfill gas production; this work focuses on gas migration and fugitive emissions. Researchers are also conducting laboratory research on high-solids anaerobic digestion and codigestion of sewage sludge with the organic fraction of MSW. No commercial facility for anaerobic digestion exists in the United States, although some pilot systems have been evaluated in the past. A project to develop and operate a demonstration-scale system for anaerobic digestion is being pursued. The project will link program researchers, private industry, and a host community to obtain data for future commercial development of this promising technology.

Institutional Assessments

Two issues in particular have an enormous impact on the construction of energy conversion plants. First, a large body of environmental regulations results in a lengthy, difficult permitting and siting process. Second, because these plants are capital-intensive investments, financing is difficult.

The program is analyzing these institutional barriers to develop solutions that allow utilization of the MSW resource. Program analysts are examining existing and pending legislation at federal and state levels to determine its effect on energy production and the MSW management industry.

Technology and Information Transfer

Effective technology and information transfer is critical to the success of the EMW program and the waste management industry. Inaccurate and
incomplete data reinforce the many misconceptions about the relative costs and benefits of MSW options and technologies, and these misconceptions sometimes drive the decision-making process.

To provide industry and the public with current, credible information, the program is enhancing its information transfer program in cooperation with the EPA and appropriate industry associations. This effort will use a variety of tools to communicate with the MSW community and the public, such as

- Publishing fact sheets, brochures, and case studies
- Preparing and presenting slide shows or videos
- Disseminating data
- Conducting conferences, workshops, and educational programs
- Hosting contractor review meetings
- Presenting papers at technical conferences
- Publishing articles in technical and trade journals.

In addition, as results of the program's Data Collection and Analysis element become available, program managers will package and disseminate this information to those responsible for decisions on waste management. Finally, the program will work with its industry partners and contacts to make sure new technologies are made available to the companies that can use them.
Mission: To develop and adapt solar technologies for use in industrial applications to increase fuel flexibility, reduce energy costs, and decrease environmental impacts.

American industry generates about 650 million metric tons (720 million tons) of hazardous wastes each year. Less than one-tenth of these wastes is destroyed; the remainder must be stabilized in some manner for permanent storage or disposal. There are also 28,000 sites nationwide with contaminated soil or water that must be remediated. Cleaning up these wastes by conventional methods—inincineration, air stripping, carbon filtering, or ultraviolet irradiation—is energy intensive. As an alternative, a portion of the waste could be cleaned up by the sun.

Solar energy can be used to detoxify both contaminated soil and water. The process works somewhat differently for the two media. Solar water detoxification is a photochemical process—contaminants are destroyed by the chemical action of light. The waste water and a catalyst such as titanium dioxide are exposed to sunlight. Ultraviolet light activates the catalyst, resulting in oxidation of the contaminants. The result is clean water, carbon dioxide, and dilute concentrations of mineral acids, which can be easily neutralized. So far, the process has been demonstrated with chlorinated solvents, dyes, and fuel oils.

Unlike the one-step water process, soil detoxification is a two-step process. First the soil is heated to vaporize the organic contaminants. This concentrated waste stream is then exposed to sunlight concentrated up to 1000 times. The infrared and visible parts of the spectrum heat the waste to 700°–1000°C; the high-energy ultraviolet light then destroys the molecules. Alternatively, the concentrated stream of contaminants can be treated at lower temperatures with lower concentrations of sunlight. This process involves shining ultraviolet light on a catalyst, which initiates the destruction of the chemicals.

Solar detoxification is just one of the possible applications of solar energy to meet industrial needs. It can also provide thermal energy to displace the 30% of the total primary energy used in the industrial sector for process heat. The technology has already been demonstrated for heating air or water directly or for heating a working fluid that can be stored for later use. Commercial applications have included steam generation at up to 315°C; laboratory systems have generated temperatures up to 1500°C. Although technical performance of these systems has been dramatically improved compared with that of the early systems installed in the 1970s, substantial market barriers continue to inhibit widespread application.

Scientists are exploring another area of application—advanced materials. Using solar furnaces that concentrate sunlight up to 50,000 times, researchers are exploring the possibilities of making advanced materials such as diamond-like carbon films, submicron ceramic powders, and high-quality superconducting films.

Key Elements of the Solar Industrial Applications Program

- System and market assessments
- Technology development
- Technology transfer
Using solar energy for these applications offers industry several advantages. First, solar systems can help industry become less dependent on fossil fuels, particularly imported petroleum. Second, using solar energy can avoid the environmental problems associated with fossil fuel use. Third, as the technology continues to evolve, some types of solar systems will become cost-competitive in virtually all regions of the country.

DOE's Solar Industrial Applications Program is helping to provide the technology required for industry to realize these advantages. By also addressing the institutional and market barriers to solar-based technologies, the program can ensure that industry has the information it needs to consider solar applications. The program has three main elements: system and market assessments, technology development, and technology transfer.

System and Market Assessments

System and market assessments play a vital role in identifying the needs of industry and the opportunities for market penetration of the solar technologies. One recent study focused on the performance and cost of solar detoxification technology and examined regulatory issues affecting its commercial viability. The study identified as many as 24,000 potential sites requiring cleanup of groundwater or industrial waste water. About 5,000 of these are in the 13 southwestern states with the highest solar insolation.

A second study examined the near- and long-term market potential for solar process heating systems. The study concluded that with aggressive R&D to lower costs, solar systems could provide as much as 4.0 exajoules (3.8 quadrillion Btu) of energy to manufacturing operations and 3.4 exajoules (3.2 quadrillion Btu) to commercial facilities in 2030.

The program also recently sponsored studies by the National Research Council, the Massachusetts
Institute of Technology, and SRI International to help identify opportunities for using highly concentrated sunlight in advanced industrial processes.

The three groups agreed that advanced materials applications should be the first target for program research and establishing industrial partnerships. As a result, two CRADAs for development of advanced materials were recently signed—one with Coors Ceramics and the other with Brush Wellman, Inc.

**Industrial Applications of Solar Energy**

- Detoxifying contaminated water
- Destroying chemical wastes in soil
- Providing process heat
- Developing materials with enhanced properties

CRADAs for development of advanced materials

Technology Development

The market readiness of solar industrial technologies varies widely from solar process heat, which is ready for deployment in many locations, to advanced materials processing with the solar furnace, which is in the early stages of applied research. Solar detoxification is in between. Some detoxification systems are being used for field tests and demonstrations, while the enabling technology is being refined in the laboratory. Consequently, the SIA program encompasses a wide range of technology development activities.

For the process heat application, the program's emphasis is on working closely with the existing solar thermal industry to expand market penetration. One approach supports several prefeasibility studies, which allow small solar companies to bring together users, owners, and financing for process heat projects. The program also works with the states, the U.S. Department of Defense, and other government agencies that can justify solar systems on the basis of their low life-cycle costs. These markets will provide the proving grounds for process heat systems.

Work on solar water detoxification is aimed at improving the cost and performance of the technology. One major development has been the field test conducted at a Superfund site at Lawrence Livermore National Laboratory. The test was cofunded by DOE's Office of Environmental Restoration and Waste Management. At the Lawrence Livermore site, a solar detoxification system was used to clean up trichloroethylene and other volatile organic compounds in the groundwater. Successfully completed in 1992, this field test was followed by another test at the Tyndall Air Force Base, Florida, to determine the efficiency of cleaning groundwater contaminated with a mixture of fuel oils. In 1993, these efforts will lead to industrial system designs, cost-shared by industry.

The high-flux solar furnace at the National Renewable Energy Laboratory can concentrate sunlight up to 50,000 times. Joint projects with industry are exploring options for making ceramic powders, ultrahard coatings, and other advanced materials.
Soil detoxification is the subject of a joint project of DOE, the Department of Defense, and the EPA. The project will test a pilot-scale system for cleaning up aromatics, chlorinated aromatics, chlorinated solvents, and fuel oil. Initial tests at NREL will be followed by a field test at the Sierra Army Depot, California, and then a full-scale demonstration in 1995. This project will determine the feasibility of using solar energy to clean contaminated soil.

Progress on using concentrated sunlight to produce advanced materials is in earlier stages of research. Researchers for the CRADA with Coors Ceramics are conducting laboratory tests on a novel process for producing silicon-carbide powder for sintering applications. For the Brush Wellman CRADA, NREL scientists are conducting proof-of-concept testing of a process for metallizing ceramic parts for advanced electronic packaging. In addition, laboratory-directed research is investigating advanced coatings—in particular, deposition of thin, diamond-like carbon layers for electronic and tribological applications.

**Technology Transfer**

Like the other WMM programs, technology transfer is an integral part of the SIA activities. The program joins with industrial partners in every area to conduct cooperative research and cost-shared demonstrations. In this manner, research is targeted at the technology industry needs. In addition, cooperation with industrial partners early in the development process results in effective technology transfer.

The program uses other techniques of transferring information and technology to industry including

- Working with local and state governments and other federal agencies
- Coordinating with industrial trade groups
- Sponsoring conferences, workshops, and exhibitions
- Publishing fact sheets, brochures, and reports.
By working together, DOE and industry are turning the challenge of waste material management into the reality of a cleaner, more energy-efficient nation.

DOE’s Waste Material Management programs are making a difference. To date, seven new technologies are helping industry minimize or reuse its wastes. Together, these technologies are saving industry nearly 5 gigajoules (500 billion Btu) each year, worth more than $1 million. With continued market penetration, annual savings from these technologies could grow to 47 petajoules (45 trillion Btu) in 2010, worth more than $110 million at today’s prices. These savings will grow as some of the additional 35 projects currently under way and future successful research projects reach the marketplace.

DOE’s Waste Material Management programs are making a difference. To date, seven new technologies are helping industry minimize or reuse its wastes. Together, these technologies are saving industry nearly 5 gigajoules (500 billion Btu) each year, worth more than $1 million. With continued market penetration, annual savings from these technologies could grow to 47 petajoules (45 trillion Btu) in 2010, worth more than $110 million at today’s prices. These savings will grow as some of the additional 35 projects currently under way and future successful research projects reach the marketplace.

Early R&D in the Solar Industrial Program provided the foundation for today’s process heat industry, which delivers hot water, hot air, and steam in applications across the United States and abroad. Compared with the early systems of the late 1970s, today’s systems deliver 5–10 times more energy per unit of collector area at one-tenth of the capital cost. The DOE program is working with the private sector to identify applications and to cost-share projects that will demonstrate to industrial energy managers that solar energy is an economical and reliable option for their energy needs.

In addition, solar detoxification technologies are moving rapidly toward full-scale demonstration. And tests at the program’s high-flux solar furnace recently set a new world record for solar concentration, providing a new, exciting tool for solar research.

These successes of the Waste Material Management Programs have come as a direct result of the interest, support, and involvement of industry. By maintaining this relationship with the private sector, the WMM Division strives to continue its record of achievement. In the process, industry will be more competitive, our nation’s energy supply will be more secure, and our environment will be enhanced.
Industrial Waste Reduction Program

Data Collection
- Characterization of Major Data Sources for Industrial Waste Reduction
- Simultaneous Waste and Energy-Environment-Economic Tabulations (SWEET)

Opportunity Assessments
- R&D Opportunities in the Chemical Manufacturing Industries
- R&D Opportunities in the Chemical Users Industries
- R&D Opportunities in the Petroleum Industries

Technology R&D
- Enclosed Silicon Production Furnace for Reducing Waste Gas Emissions
- Dual-Cure Photocatalyst System for Coatings
- Collection of Vapor-Liquid Equilibrium Data for Acid Gas-Mixed Amine Systems
- Conversion of Industrial H₂S to Sulfur and Hydrogen
- Reclaiming and Reusing Waste Water
- Methanol Recovery Process
- Control Strategies for Volatile Organic Compounds
- Solvent Reduction through Self-Cleaning Soldering Process
- Solvent Waste Minimization by Supercritical CO₂ Cleaning
- Hydrous Metal Oxide Catalysts for Production of Oxygenated Products
- Electroplating Waste Minimization
- Membrane Vapor Recovery Systems
- National Industrial Competitiveness through Efficiency: Energy, Environment, and Economics (NICE³, with EPA)
- Solicitation for Waste Reduction in the Chemical Industry

Technology Transfer
- Pollution Prevention in the Manufacturing Industries (cosponsoring American Institute of Chemical Engineering Symposium)
- Inventory of organizations conducting R&D in Industrial Waste Reduction and Minimization

Institutional Analysis
- Legislative and Regulatory Incentives and Disincentives to Industrial Waste Reduction

Waste Utilization and Conversion Program

Technology R&D
- Material Separation and Recycling
  - Dezincing Galvanized Steel Scrap
  - Purifying Scrap Aluminum
  - Removing Lead from Red Metal
  - Recycling Aluminum Salt Cake
  - Recycling Plastics from Auto Shredder Residue
  - Waste Tire Utilization
  - Roofing Waste Utilization
  - Waste Carpet Utilization
  - Mixed Plastics Utilization

Remanufacturing/Demanufacturing
- Design for Recyclability

Conversion of Waste Components to Higher Value Materials
- Plastics from Potato Wastes
- Ethanol from Food Processing Wastes
- Biotechnology for Higher Value Chemicals from Waste
- Phenol Substitutes from Wood Wastes
- Higher Value Fermentation from Paper Mill Effluent
- Higher Value Fibers from Pulp and Paper Industry Wastes
- Biological Conversion of Waste Gases into Acetic Acid
- CO₂ Utilization

Energy-Efficient Waste Treatment
- Freeze Crystallization Water Recovery
- Ceramic Membrane Separations of Oily Waste Water

Technology and Data Assessment
- Systems Analysis for Metals Recycling
- Waste Data Project
Energy from Municipal Wastes Program

Data Collection and Analysis
Collect Existing MSW Data
Develop and Maintain MSW Data Base

Technology Development
Thermochemical Technologies
- Develop New Pollution Control Strategies
- Improve Ash Management
- Improve Technology for Cofiring MSW with Sewage Sludge

Biochemical Technologies
- Enhance Landfill Gas Recovery
- Develop and Test Innovative Anaerobic Digestion Systems

Institutional Assessments
Assess Legal and Regulatory Issues

Technology and Information Transfer
Develop Information Transfer Plan
Communicate Results of Data Analysis and Assessment

Solar Industrial Applications Program

Systems and Market Assessments
Water Detoxification
Soil Detoxification
Solar Process Heat
Advanced Materials Processing

Technology Development
Water Detoxification
- Catalyst Research
- Collector and Reactor Research
- Field Experiment at Tyndall Air Force Base, Florida

Soil Detoxification
- Tri-Agency Soil Detoxification Project (with Department of Defense and EPA)

Advanced Industrial Processes
- Furnace Development
- Industry Collaborations (with Coors Ceramics and Brush Wellman, Inc.)

Technology Transfer
Industrial Process Heat
- Support to the California Energy Commission
- Support to Federal Energy Managers
- Planning for Industry Demonstration Projects

Solar Detoxification
- Industry Collaboration and Support
- Working through Waste Water Management/Control Associations

Advanced Materials
- Industrial Collaborations
- Support for Solar Supplier Industry

For More Information

Waste Material Management Division
CE-222
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

Mr. Kurt Sisson, Rm 5F-035
Division Director

Mr. Bruce Cranford, Rm 5F-043
Manager, Industrial Waste Reduction

Mr. Alan Schroeder, Rm 5F-043
Manager, Organic Waste Utilization

Mr. Stuart Natof, Rm 5F-035
Manager, Solid Waste Utilization

Mr. Simon Friedrich, Rm 5G-067
Manager, Energy from Municipal Waste

Mr. Frank Wilkins, Rm 5G-067
Manager, Solar Detoxification Applications

Mr. Cliff Carwile, Rm 5F-035
Manager, Solar Industrial Applications

Mr. Tom Foust, Rm 5F-035
Manager, Industrial Waste Reduction RD&D