Description of Resource Recovery Technologies

In this appendix, the processes for centralized resource recovery are described and the major unit processes of the technologies are identified. Although many processes recover both energy and materials, the technologies for each of these purposes are discussed separately here. A list of additional readings on resource recovery is included.

This appendix is primarily descriptive. It is based on published literature and on conversations with industry, Government, and other experts. Not all of the processes described here are in commercial use. See chapter 5 for a discussion of the status of the technologies and chapter 3 for a discussion of marketing of recovered materials and energy.

Energy Recovery Systems

Mass Incineration Processes

WATERWALL INCINERATION

In waterwall incineration, raw municipal solid waste (MSW) is burned directly in large waterwall furnaces, generally without preprocessing the waste. The primary product is steam, which can be used directly or converted to electric power, hot water, or chilled water. Figure C-1 shows schematically the main features of a waterwall furnace for unprocessed MSW.

In some installations shredding to reduce waste size and/or facilitate recovery of materials takes place. For example, at the Saugus, Mass. plant, large bulky items have been shredded before burning. (The shredder is being removed, however.) At Hamilton, Ontario MSW is shredded before burning. Ferrous metal can be recovered by magnetic separation from ash after incineration, or before incineration if MSW is pre-shredded.

Waterwall combustion systems nave been used commercially in Western Europe since World War II. Data from a recent survey of their experience indicate that European plants tend to achieve large scale using several small modular furnaces. For example, the 634 tons per day (tpd)* Sorain Cecchini facility in Rome, Italy has six, 4.4-ton-per-hour units.(2)

This modular approach contrasts with U.S. practice. The Saugus plant has a design capacity of around 1,500 tpd and uses two European Von Roll furnaces with a capacity of around 31 tons per hour each.

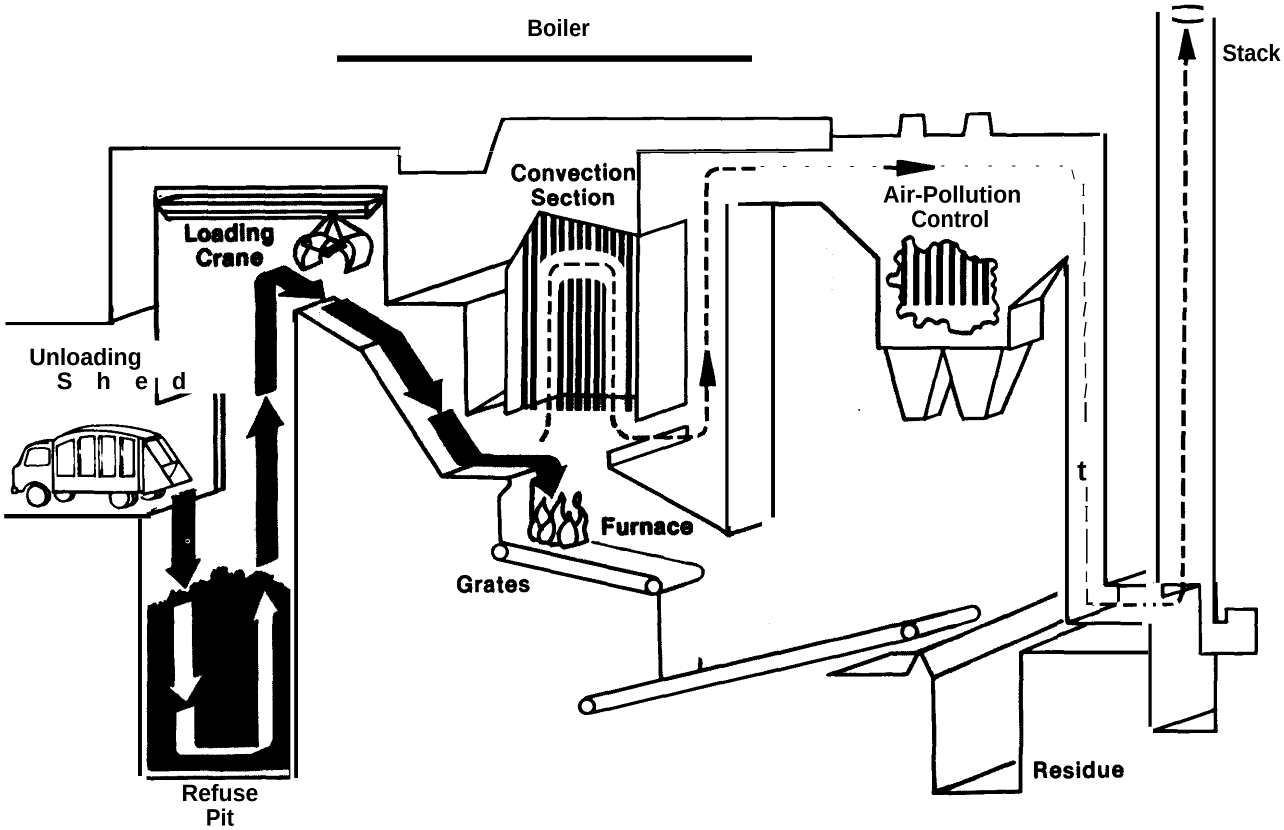
Even though European societies differ from ours, comparisons should be helpful in contemplating future technological directions for U.S. development. The Environmental Protection Agency (EPA) has an intensive, detailed study of European systems underway.

SMALL-SCALE MODULAR INCINERATION

Small-scale modular incinerators feature heat recovery as steam or hot water, and usually forego materials recovery. Most applications to date have been in hospitals, schools, other institutions, and industry whose wastes are more homogeneous than MSW. Thus, application of this technology to MSW is a relatively recent development. Three of these systems were reported as operational in EPA's Fourth Report to the

*All ton units in this appendix are short tons—2,000 pounds.

Figure C-1.—Typical Waterwall Furnace for Unprocessed Solid Waste



Congress: a 50-tpd unit at Blytheville, Ark., a 30-tpd unit at Groveton, N.H. and a 20-tpd facility at Siloam Springs, Ark.(3)

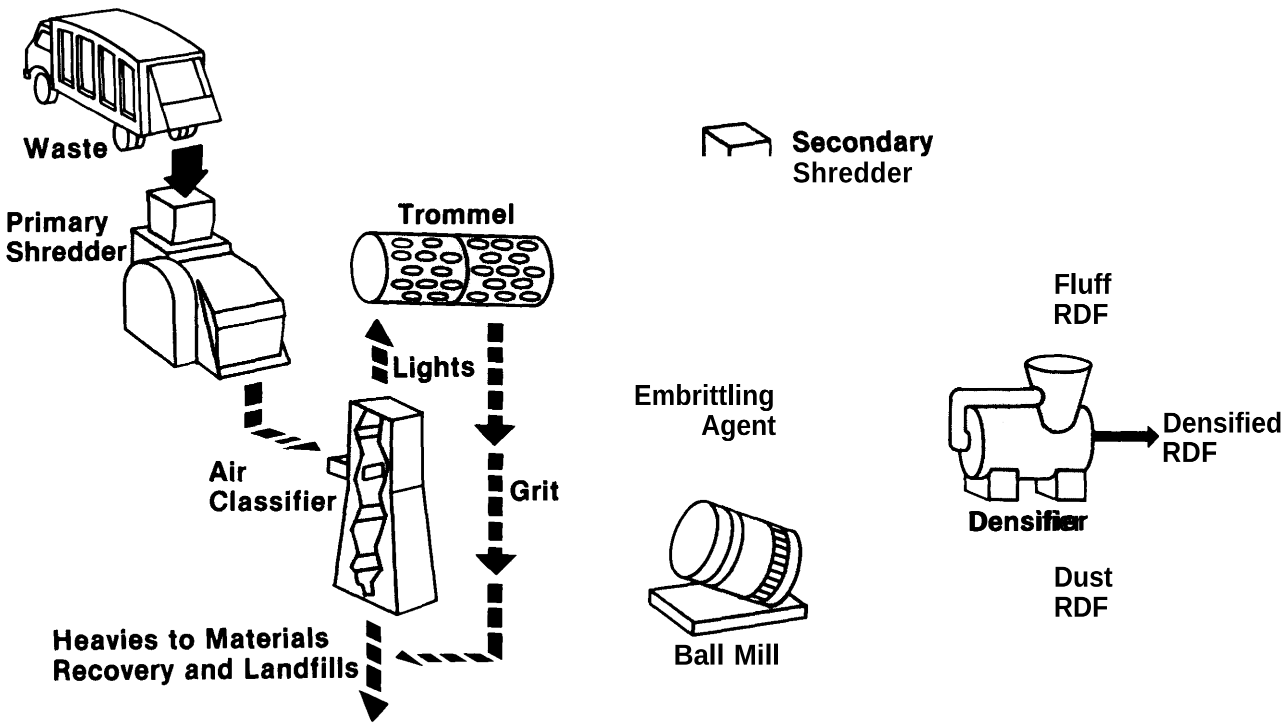
These systems are called modular because individual furnaces are small and desired plant size is achieved by installing several identical units or modules.(4) MSW is incinerated in two stages. First, raw MSW is burned in insufficient air to achieve complete combustion, producing a combustible gas and a byproduct residue. The gas from primary combustion is then burned with an auxiliary fuel [oil or gas) in a secondary combustion chamber with excess air. Hot gases from the secondary combustion chamber are passed through a waste heat recovery boiler or heat exchanger to produce steam, hot water, or hot air. The two-stage combustion process, as contrasted to traditional single-stage incineration, helps to reduce particulate emission problems.

Refuse-Derived Fuel Systems

Solid refuse-derived fuel (RDF) is produced by separating MSW and mechanically removing the organic combustible fraction using wet or dry processes. The fuel product of dry processing can be fluff RDF, densified RDF, or dust or powdered RDF depending on the subsequent processing used. Most RDF plants also recover one or more of the following materials; ferrous, aluminum, glass, or mixed nonferrous metals. Figure C-2 schematically portrays the main processes for producing the different RDF fuels.

In dry mechanical processing of the type used in the St. Louis, Me.; Ames, Iowa; and Washington, D.C. facilities, raw waste typically is first shredded to 8 inches or less in size. This shredded material is next put through a device called an "air classifier" that separates the light organic material from

Figure C-2.–This Simplified Flow Diagram Shows How the Dry Processing Approach (No Water Slurry) Can Be Used to Produce Fluff, Densified, or Dust RDF



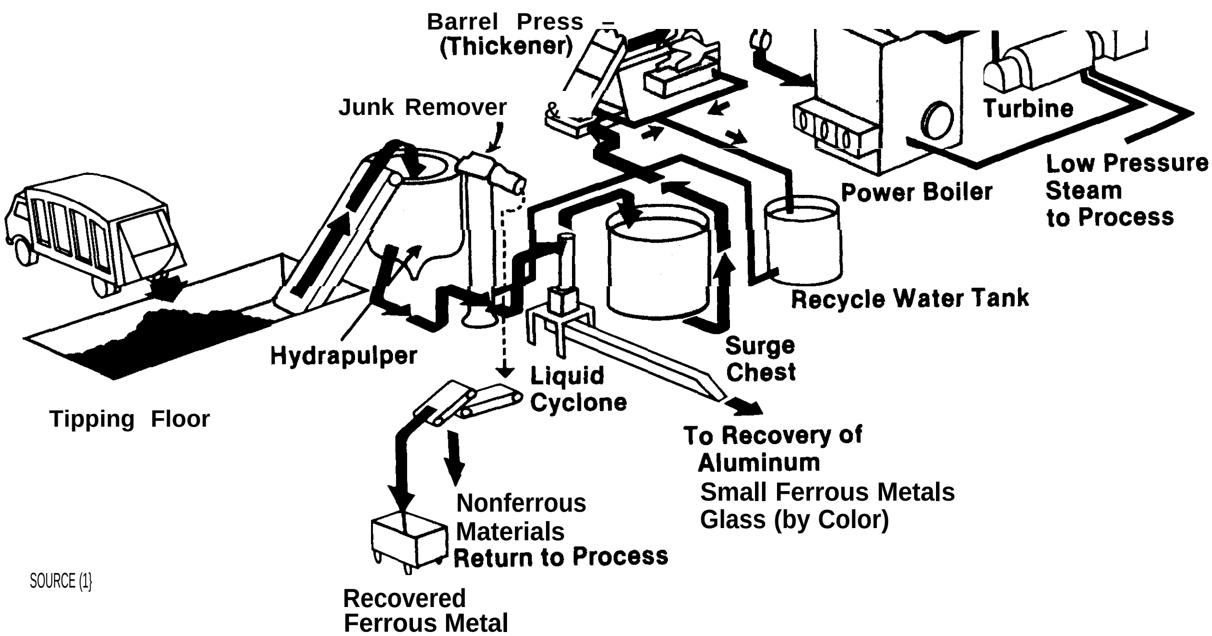
metals and other heavy organic and inorganic materials. The light material then goes through a rotating screen or "trommel" to remove abrasive fine sand, glass, and grit. The heavy materials from the air classifier and trommel move to a magnetic separating device that recovers ferrous material. Some plants also attempt to recover aluminum, glass, and mixed nonferrous metals, using processes described in a later section.

Based on experiences with the first generation of dry waste separation systems that employed shredding and air classification, attention has recently been given to a wider variety of processing schemes. One includes a trommel, or screening device, as the first processing step, to remove whole cans and bottles prior to waste shredding. In another variant, the shredder is eliminated and air classification is used as a first step. This is based, in part, on the concept that shredding, which is the locus of most operating explosions (see chapter 5), should be avoided. The best arrangement and design of first-stage dry mechanical separation processes is an important area of current research on resource recovery.

As shown in figure C-2, the light organic material from the trommel goes to a secondary shredder that further reduces the particle size to less than 11/z inches. The resultant material is called "fluff RDF. " Fluff RDF can be passed through a pelletizing or briquetting machine to yield "densified RDF. " The objective of densification is to improve storage, handling, and stoker-furnace burning characteristics. Alternatively, the light output from the trommel can be treated with a chemical embrittling agent and ground to a fine powder in a ball mill to produce a "dust or powdered RDF" with a particle size of around 0.15 mm. This is the basis of the Combustion Equipment Associates ECOFUEL-H[Q] process.

Figure C-3 illustrates the wet process RDF method. With this technology raw refuse is

Figure C-3.— Wet Process Energy Recovery System



SOURCE (1)

fed to a hydropulper (a machine like an oversized kitchen blender] where high-speed rotating cutters chop the waste in a water suspension. Large items are ejected and the remaining slurry is pumped into a liquid cyclone separator where smaller heavy materials are removed. Water is then removed to leave "wet RDF" with from 20- to 50-percent water content, which can be burned alone or as a supplement to coal, depending on its water content.

The wet pulping method has several advantages and disadvantages relative to the dry process. Sewage sludge can be mixed with the wet pulp prior to dewatering and the resulting mixture can be burned as a method of codisposal. Dewatering, however, is expensive and energy intensive. The wet process reduces the likelihood of explosion or fire in the size reduction phase, as compared to dry mechanical processing. It is possible to recover some organic fiber by the wet process. However, the quality of this fiber is insufficient for it to be used to produce paper. The only domestic application in one small plant at Franklin, Ohio, has been as a reinforcement in roofing material.

Pyrolysis Systems

Pyrolysis is destructive distillation or decomposition of organic materials in MSW at elevated temperatures in an oxygen deficient atmosphere. The product of pyrolysis is a complex mixture of combustible gases, liquids, and solid residues usable as fuels or chemical raw materials. The characteristics of the pyrolysis products depend on such variables as time in the reactor, process temperature and pressure, oxygen content of the gas in the reactor, particle size of the MSW feed, and the choices of catalysts and auxiliary fuels. Differences in these parameters distinguish the several proprietary processes that have been developed, Four proprietary systems are presently in some stage of demonstration. Two of these produce low-Btu gas: Monsanto's Landgard and the Andco Torrax processes. The Union Carbide Purox system produces medium-Btu* gas. The Occidental Research Flash Pyrolysis process produces a liquid fuel.**

In the Monsanto system, figure C-4, MSW is shredded before it is pyrolized with a supplementary fuel in a large (20 ft diameter, 100 ft long) horizontal, refractory-lined kiln. Solid residue from the kiln is water quenched and separated into ferrous metal, glassy aggregate, and char. The char is dewatered and landfilled. In the Andco process, figure C-5, raw MSW enters a vertical shaft furnace after large items are removed and is pyrolyzed with auxiliary fuel. As the charge descends it is dried and converted to gases, char, and ash. The low-Btu gas produced must be burned onsite to produce steam or hot water.

The only Monsanto system in operation, a 1,000-tpd plant in the city of Baltimore, is currently undergoing modification to solve air pollution and other technical problems. Monsanto has withdrawn from the project. Andco has no plants in the United States. A 200-tpd plant is in startup in Luxembourg, and two others are under construction, one in France and one in West Germany.

In the Union Carbide Purox system, figure C-6, ferrous material is magnetically sepa-

*Low.Btu gas has a heating value of around 100 to 150 Btu per standard cubic foot (scf), the heating value of medium Btu gas is 300 to 400 Btu per scf. By comparison, natural gas has a heating value of about 1,000 Btu per scf.

**Liquid pyrolysis oil has a heating value of about 10,000 Btu per pound, roughly half that of No. 6 fuel oil.

Figure C-4.—The Monsanto Landgard System Produces a Low-Btu Gas Which is Immediately Burned Onsite for the Production of Steam

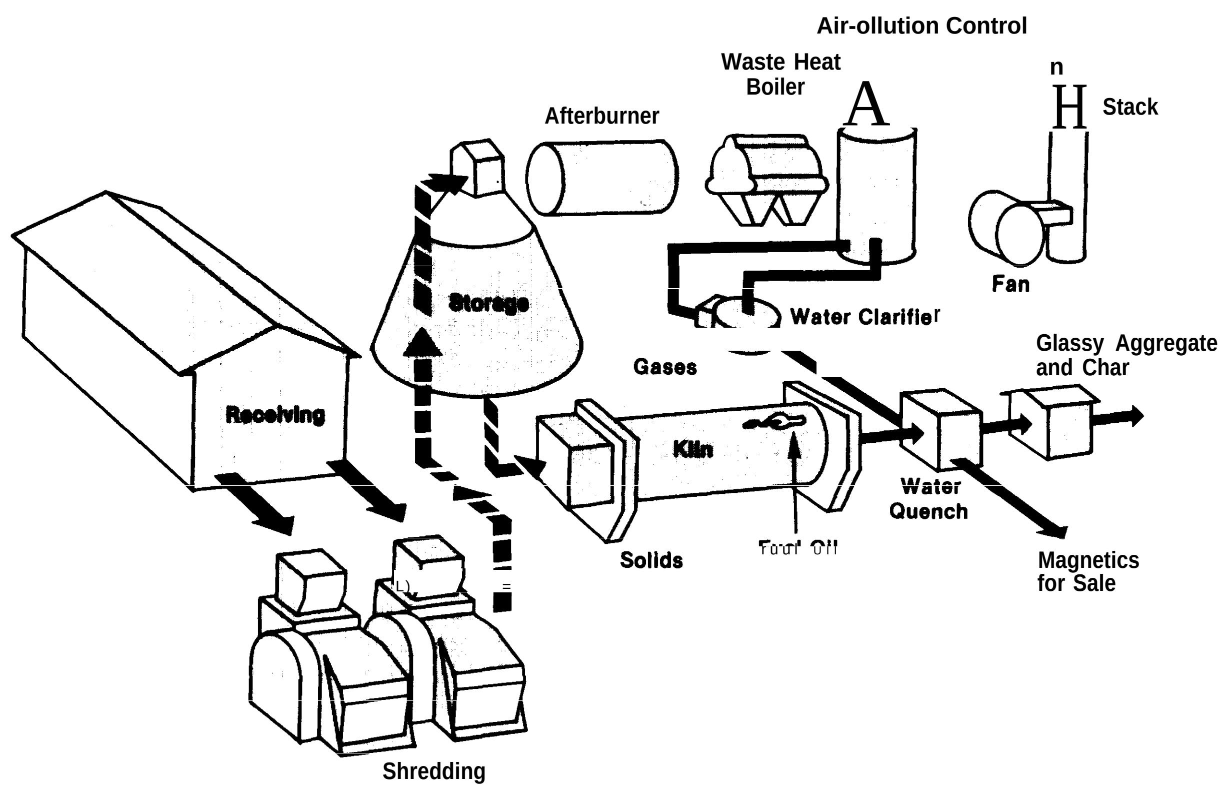
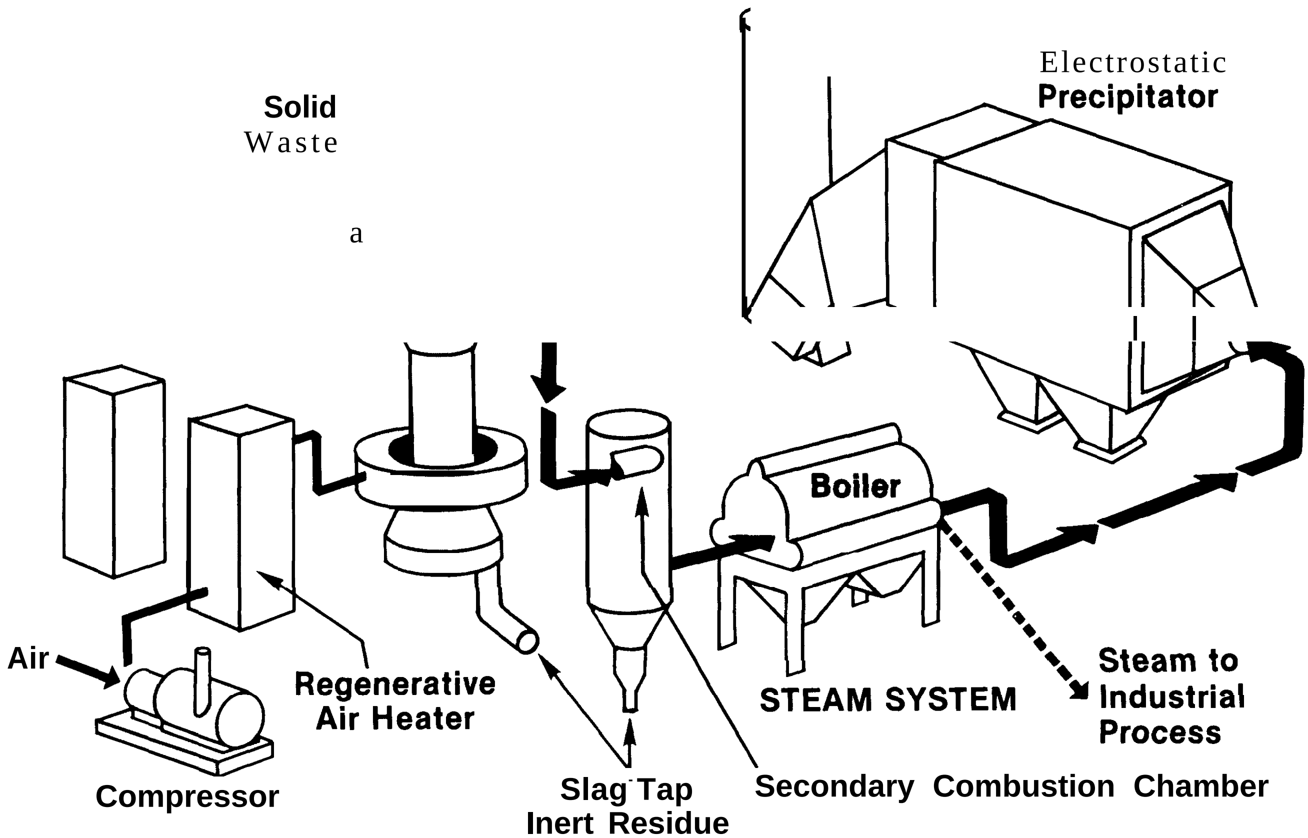


Figure C*5.—Torrax Slagging Pyrolysis System



ratecl from shredded MSW prior to feeding. Shredded refuse fed into the top of the vertical shaft furnace descends by gravity into zones of increasing temperature where drying. then pyrolysis, and finally char combustion and slagging take place. The temperature in the bottom zone, the slagging zone, is high enough to reduce the residual to a molten slag that continuously drains into a water quench to produce a hard granular aggregate material called frit, The Purox process feeds the furnace pure oxygen, rather than air as in the Monsanto and Torrax systems, and produces medium-Btu gas product. Its smaller volume and higher Btu content facilitates economic shipment over reasonably long distances. Union Carbide has been operating a 200-tpd demonstration plant at Charleston, W. Va., but no commercial facility yet exists.

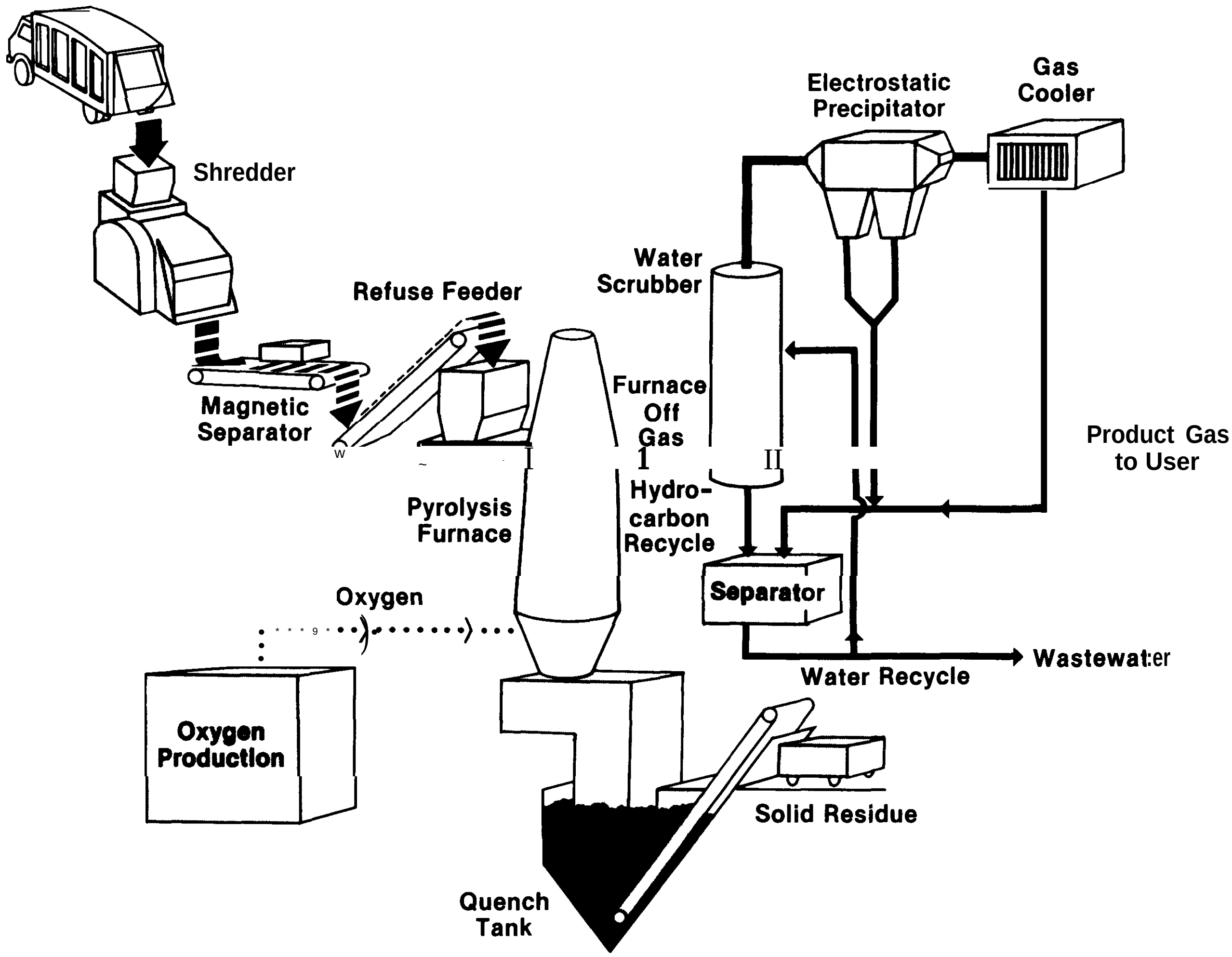
In the Occidental liquid fuel pyrolysis process, shown in figure C-7, raw MSW is first shredded and air classified to recover ferrous metal, aluminum, and glass prior to pyrolysis. The light organic fraction is dried, shredded again in an inert gas atmosphere, and then introduced to the pyrolysis reactor. Pyrolysis in the reactor vessel produces an oil-like fluid somewhat comparable to No. 6 fuel oil* that can be burned in existing oil-fired, steam-electric powerplants. A 200-tpd demonstration plant in San Diego County, Calif., was reported to be undergoing operational testing in early 1978. A subsequent report in May 1978 indicated that this system was not operating and faced major cost increases if it were to be continued.(5)

Biological Systems

This description focuses on three biological waste-to-energy technologies: recovery of

*Ibid,

Figure C-6.—Union Carbide Purox System Produces a Medium-Btu Gas for Sale to Offsite Users



methane from landfills, anaerobic digestion, and hydrolysis.

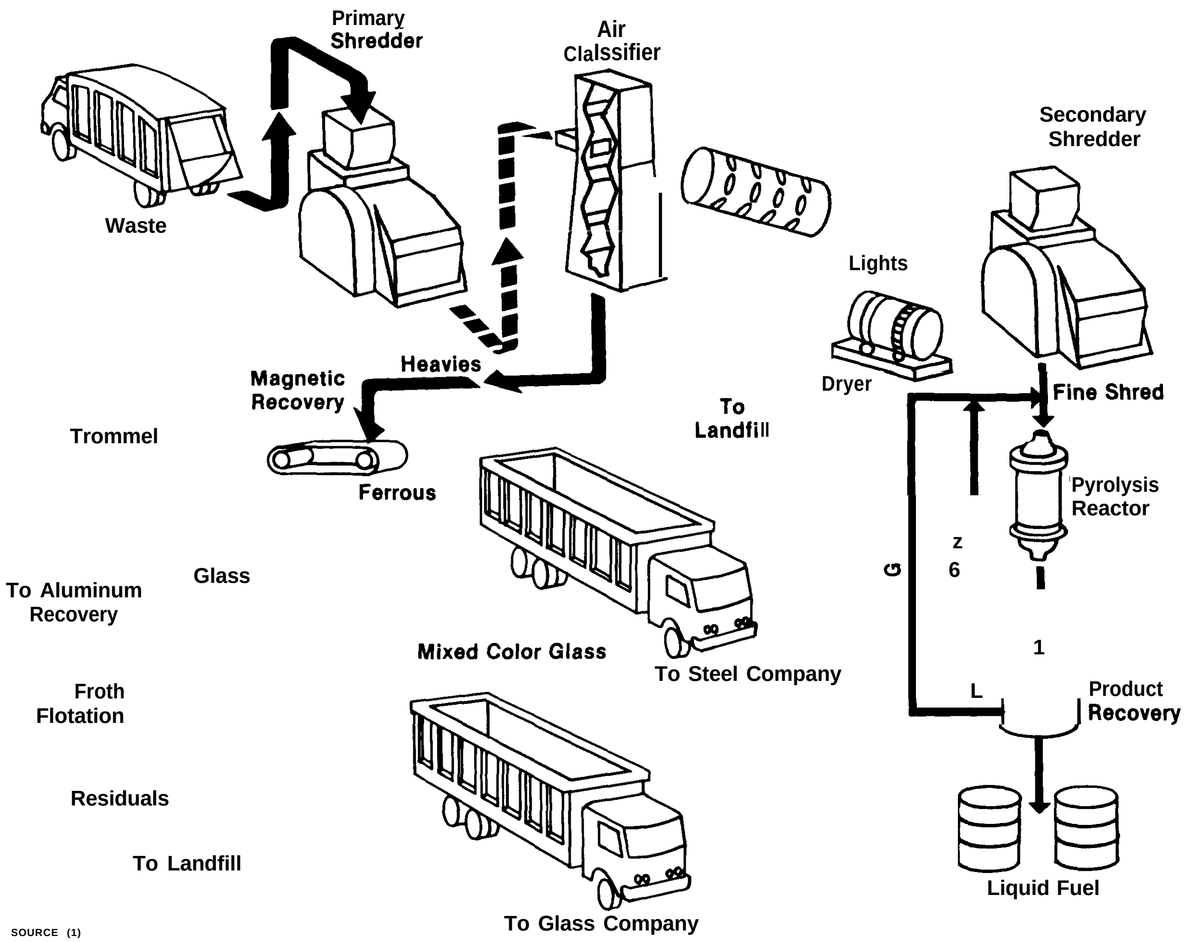
METHANE PRODUCTION FROM LANDFILLS

Natural decomposition of MSW in landfills produces a gas composed of roughly 50-percent methane and 50-percent carbon dioxide. If landfill geological characteristics are satisfactory, gas can be withdrawn through wells drilled into the landfill and can be treated to remove moisture, hydrogen sulfide, and other contaminants. Carbon dioxide can be removed leaving pipeline quality methane. Corrosion problems with this technology appear to be under control.(s) Recovery of methane from an old sanitary landfill is being explored at the Pales Verdes landfill at Los Angeles where approximately 500,000 cubic feet of purified methane is being recovered per day. Enough methane is recovered daily at the Pales Verdes site to meet the energy needs of some 2,500 homes.(5) EPA is evaluating several landfill gas-producing projects.(3)

ANAEROBIC DIGESTION

Methane can be recovered from anaerobic digestion of MSW in large tanks or reactors as shown in figure C-8. Anaerobic digestion of waste is accomplished by two types of bacteria: (i) acid formers that convert waste to organic acids, and (ii) methane producers that convert the acids to carbon dioxide, methane, and small quantities of other gases. One of the potential problems with methane

Figure C“7.—Production of Liquid Fuel From Solid Waste Using the Occidental Process

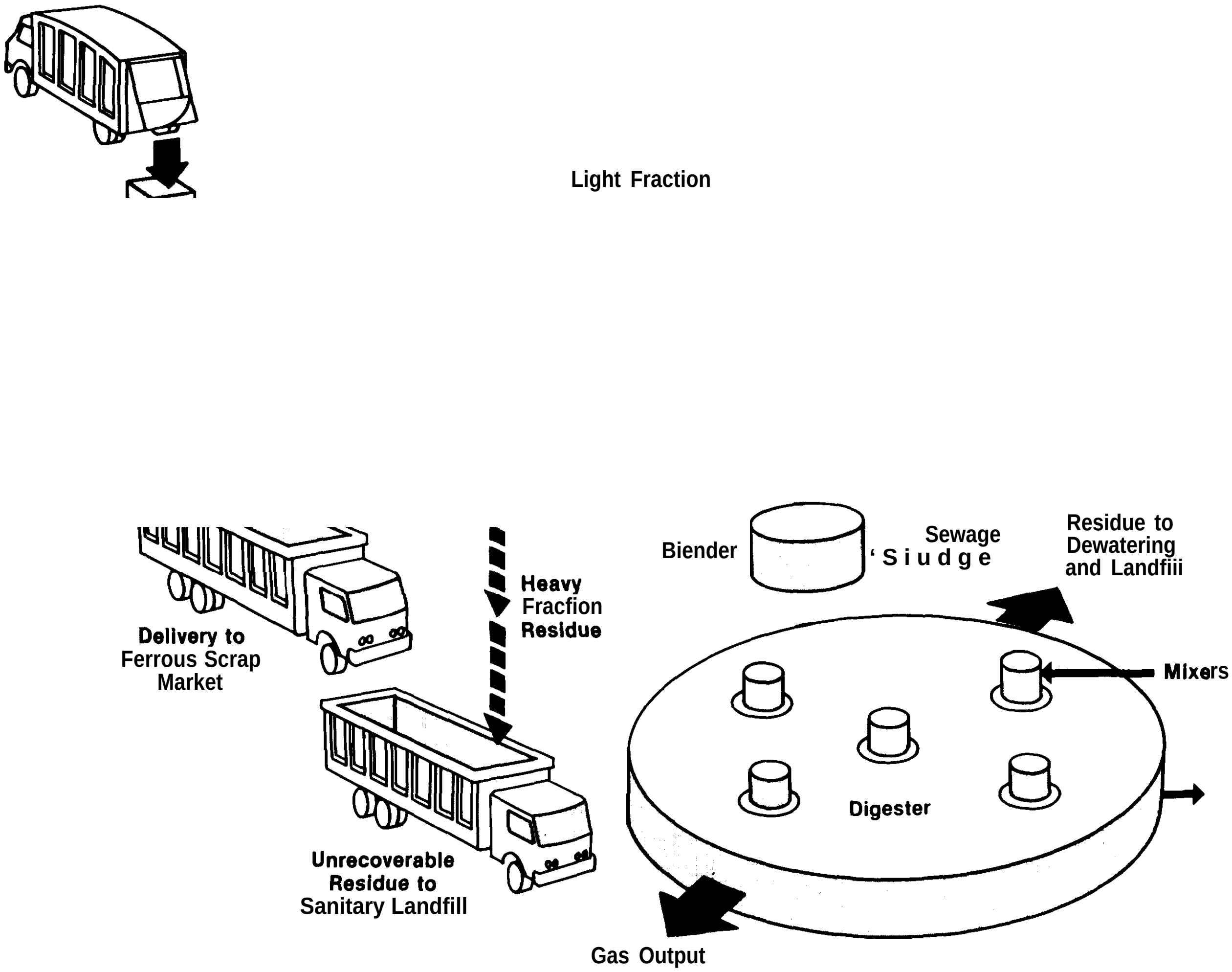


SOURCE (1)

generation is that MSW sometimes contains toxic components that can kill the methane-producing bacteria, Successful methane production from sewage sludge and animal manure can in part be attributed to the homogeneity of these substances and to the absence of bacteria-killing toxic contaminants.

A demonstration project to assess the feasibility of a 100-tpd anaerobic digestion system for MSW is being supported by the Department of Energy (DOE) at Pompano Beach, Fla., with startup expected in late-1978. At the Pompano Beach facility, MSW will be preprocessed to produce fluff RDF and recover ferrous metal, The wet RDF process could also be used. The RDF will be mixed with raw sewage sludge and introduced into digester tanks where it is mixed. The MSW-sludge mix will stay in the reactor around 10 days to capture the largest portion of the methane; longer retention times will produce more gas but at a rapidly decreasing rate. The gas produced by this process will contain approximately 50-percent methane and 50-percent carbon dioxide with a heating value of 540 to 700 Btu per cubic foot. The gas can be burned as is, without purification, or with further processing the carbon dioxide and traces of hydrogen sulfide can be removed to yield methane with a heating value of about 1,000 Btu per cubic foot. The digestion process produces large quantities of a liquid effluent, the majority of which will be recycled to the mix-

Figure C-8.—Biological Gasification of Solid Waste in Reactors



ing tanks, with the remainder discharged to a city sanitary sewer system, The remaining solids, about 17 percent of the refuse feed, must be either landfilled or burned in specially designed boilers. Schulz (6) estimates that approximately 3,700 cubic feet of methane will be produced per ton of MSW.

HYDROLYSIS

There are two processes for the production of ethyl alcohol (ethanol) from the organic portion of MSW by hydrolysis: (i) acid hydrolysis, which is a well-developed industrial technology for nonwaste applications, and (ii) enzyme hydrolysis, a recent process still in the research stage. To convert cellulosic material to ethanol, it must first be hydrolyzed to produce sugar which then ferments to yield dilute ethanol that can be recovered by distillation. The production of ethanol from MSW by hydrolysis is not currently in the commercial or demonstration stage to our knowledge. Wilson (7) reports that Black Clawson is currently researching this area.

Considerable pioneering research in enzyme hydrolysis has been carried out at the U.S. Army Natick Development Center in Massachusetts. Natick's work in this area arose out of attempts to prevent biological decay of textile materials. Since 1972, they have been authorized to conduct studies of enzyme hydrolysis processes for converting cellulose wastes of military bases into useful products. The fungus Trichoderrna viride has been identified as having considerable enzyme productivity, with a potential for commercially feasible conversion processes.(8)

In addition, the Gulf Chemical Company is presently exploring the feasibility of constructing a demonstration plant (50 tpd of biomass feedstock) for the production of ethanol from municipal, agricultural, and industrial waste by enzymatic hydrolysis.(g)

Materials Recovery Systems

Several of the energy recovery systems just described include ferrous metal, aluminum, or glass recovery technologies. Other materials that can be recovered are paper fiber, compost, and other nonferrous metals.

Aluminum

The process for aluminum recovery is based on an eddy current separation system commonly called an aluminum magnet. With this technology, nonferrous conducting metals mixed with other wastes are conveyed through a magnetic field in such a way that an eddy current is induced in the metals. This current causes the metallic conductors to be repelled from the region of the magnetic field and thus out of the conveyor path. Nonmetallic are unaffected and are carried on. The device is quite sensitive and can be tuned to repel various shapes, densities, or materials. For example, it can be tuned, or optimized, to recover aluminum cans, the largest part of the aluminum waste. Eddy current separation equipment is currently installed at the following locations: National Center for Resource Recovery (NCRR) experimental test facility in Washington, D. C.; Ames, Iowa; Baltimore County, Md.; Occidental pyrolysis plant in San Diego, Calif.; the Americology plant in Milwaukee, Wis.; and in New Orleans, La. As reported in chapter **5**, as of April 1978, none of these facilities was in steady production with a sustained commercial run.

Electrostatic separation is another method for separating nonferrous metals from organic materials. Mixed wastes pass between charged plates and are given an electric charge. Conducting materials such as aluminum lose their charge on an electrically grounded drum and fall off. Nonconductors retain their electrical charge and adhere to the drum. None of these systems is in use in full-scale plants. To further assist in cleaning contaminants from metals, a device called an "air knife" is sometimes used.

Glass

Two systems are being experimented with for the recovery of waste glass from MSW. Research is preceding on froth flotation, a standard mineral processing technique, for the recovery of glass. In this process the "heavy" portion of the waste stream, rich in finely ground glass, is slurried in water along with chemicals that cause the glass to become attached to air bubbles on the surface of the water. The glass floats out of the mix with the bubbles and is then washed and dried. Froth flotation is being explored at the NCRR facility in Washington, D. C.; in New Orleans, La.; and at the Occidental pyrolysis plant in San Diego. It is being installed in both the Monroe County, N. Y., and the Bridgeport, Corm., plants.

Since glass recovered by froth flotation produces mixed colored cullet, which has a limited market, the process of "optical sorting" is being examined. Glass particles around one-fourth inch in size are sorted, on the basis of their light transmission properties, into three colors, clear (flint), green, and amber. This process currently faces problems with high costs and its inability to reject a sufficiently large fraction of contained ceramics and stones to meet the quality standards required by glass producers. It also cannot recover particles smaller than one-fourth inch in size. Color sorting is being installed at the Hempstead plant in New York and has been used on a pilot plant basis at the Franklin, Ohio, facility.

Ferrous Metals

Ferrous metals have been removed from MSW by magnetic separators for a number of years. A recent study by the American Iron and Steel Institute identified nearly 40 such commercial installations in the United States. (I()) Some experience has been gained more recently in magnetic recovery of incinerated ferrous metals from the residue or ash from MSW incinerators. Such a device is currently in regular operation at the Saugus incinerator, but the recovered ferrous material is not currently being marketed. The U.S. Bureau of Mines has experimented with a complex mineral-technology-based process for "back-end" recovery of a variety of materials from incinerator residue.(11) Incinerated ferrous may be less marketable than the unincinerated product.

Compost

Comporting permits organic matter to decay to humus, which can be used for fertilizer or soil conditioner. Generally, comporting has not been economically successful because of difficulty in selling the humus product. According to EPA, only one comporting plant was operating as a commercial facility in 1976, the 50-tpd plant at Altoona, Pa.(3) A 1969 survey identified 18 plants with a total capacity of 2,250 tpd, indicating a major decline in U.S. comporting operations in this 7-year period.(12)

Comporting is successful in some European countries. In the Netherlands where markets for humus in the flower and bulb industries are good, the Government runs comporting operations. A technique for briquetting and joint comporting of MSW and sewage sludge has been developed in Germany. Its developers claim that the dried briquets can be used in food for pigs, as a soil conditioner, as a stable element in landfills, or as fuel.(2)

Fiber

Not many centralized resource recovery facilities can reclaim fiber from MSW for recycling as fiber. A 150-tpd demonstration fiber recovery facility has been operating since 1971 at Franklin, Ohio, using the Black Clawson wet process described earlier. Fiber recovered with this process is of poor quality, and it is sold to a nearby manufacturer of asphalt-impregnated roofing shingles. Two wet process plants, the Hempstead, .N.Y., facility now under construction, and the plant in Dade County, Fla., about to begin construction, will recover the fiber for use as a fuel, not for paper production.

A dry process for recovering paper fiber and light plastics has been developed by the Cecchini Company in Rome, Italy. Paper from this process is used with straw to make a low-grade paperboard. In general, the quality of the recovered paper is low and it has limited marketability. Roughly 23 percent of the paper in the input waste stream is recovered.(l) Other dry paper recovery processes, such as the Flakt process, which are being explored on a pilot plant basis in Western Europe, are described by Alter.(13)

Finally, some of the most recent plants (Milwaukee and New Orleans) feature limited paper recovery by hand-packing of bundled paper from the resource recovery plant input conveyor. This method has both economic and quality limitations.

Other Materials Recovery Technologies

There are many other materials recovery technologies which have not been addressed in this brief overview. The most important contemporary processes, however, have been touched upon. Readers wishing to explore further might do well to start with a review of the extensive research in this area carried out over the years by the U.S. Bureau of Mines.(11)

Additional Reading on Resource Recovery Technologies

1. Alter, H., and E. Horowitz, (editors) Resource Recovery and Utilization, (ASTM Special Technical Publication 592, proceedings of the National Materials Conservation Symposium, 29 April - 1 May 1974.
2. Environmental Protection Agency, The Resource Recovery Industry: A Survey of the Industry and its Capacity, report SW-50/c, 1976.
3. ______ Engineering and Economic Analysis of'Waste to Energy Systems, a report by the Ralph M. Parsons Company, June 1977.
4. ______, St. Louis Demonstration Final Report: Refuse Processing Plant—Assessment of Bacteria and Virus Emissions by Midwest Research Institute, Kansas City, Me., draft report August 1977. EPA Contract No. 68-02-1871, MRI Project No. 4033-L.
5. ______, St. Louis Demonstration Final Report: Refuse Processing Plant Equipment, Facilities, and Environmental Evaluations, by Midwest Research Institute, Kansas city, Mo,, September 1977. EPA-600 /2-77-155a.
6. ______ Evaluation of the Ames Solid Waste 'Recovery System, Part 1. Summary of Environmental Emissions: Equipment, Facilities, and Economic Evaluations, by Iowa State University and Midwest Research Institute, November 1977. EPA-600/2-77-205.
7. Levy, S. J., and H. G. Rigo, Resource Recovery Plant Implementation Guides for Municipal Officials, Technologies Report, U.S. EPA, SW-157.2, 1977.
8. Mantell, C. L., Solid Wastes: Origin, Collection, Processing, and Disposal, John Wiley, 1975.
9. Schulz, H., J. Benzier, B. Borte, M. Neomatalla, R. Szostax, and R. Westerhoff, Resource Recovery Technology for Urban Decision Makers, prepared for the National Science Foundation by the Urban Technology Center, School of Engineering and Applied Science, Columbia University, H. W. Schulz, et al., January 1976.
10. Pavoni, J,, J. Heer, and D, Hagerty, Handbook of Solid Waste Disposal, Van Nostrand, 1977.
11. Resource Recovery From Municipal Solid Waste, A State of the Art Study, National Center for Resource Recovery, Inc., Lexington Books, 1974.
12. U.S. Department of the Interior, Bureau of Mines Research on Resource Recovery Reclamation, Utilization, Disposal and Stabilization, Bureau of Mines Information Circular (IC 8750), 1977.
13. Weinstein, N. S., and R, F. Toro, Thermal Processing of Municipal Solid Waste for Resource and Energy Recovery, Ann Arbor Science Publishers, Inc., 1976.

References

1. Environmental Protection Agency, Resource Recovery *Plant* Implementation: Guides *for* Municipal *Officials*, Technologies Report, No. SW-157.2. Second printing 1977.
2. Department of Energy, European *Waste*-to-Energy Systems, An Overview. Report No. CONS-2103-6 prepared by Resource Planning Associates, Inc., June 1977.
3. Environmental Protection Agency, Office of Solid Waste Management, Fourth Report to the Congress, Resource Recovery and Waste Reduction, Publication SW-600, Aug. 1, 1977.
4. Hofmann, Ross, Associates, Evaluation *of Small* Modular Incinerators in Municipal Plants, Report SW-113c, done for EPA by Ross Hofmann Associates, Coral Gables, Fla., 1976.
5. Schwegler, Ron, Division Engineer, County Sanitation District of Los Angeles County, Calif., telephone communication, May 1978.
6. Schulz, H., J. Benziger, B. Bortz, M. Neomatalla, R. Szostak, G. Tong, G., and R. Westerhoff, Resource Recovery Technology *for* Urban Decision Makers, a report produced by the Urban Technology Center, Columbia University, for NSF, January 1976.
7. Wilson, E. M., J. Leavens, N. Snyder, J. Brehany, and R. Whitman, Engineering and Economic Analysis *of* Waste to Energy Systems, a report prepared by Ralph M. Parsons Co. for the EPA Industrial Environmental Research Laboratory, Cincinnati, Ohio, June 1977. (Available as EPA- 600/7-78-086, May 1978.)
8. Gaden, E. L., M. H. Mandels, E. T. Reese, L. A. Spano, (editors) Enzymatic Conversion *of Cellulosic* Materials: Technology and Applications, Symposium Proceedings held at Newton and Natick, Mass., Sept. 8-10, 1975. John Wiley and Sons, . 1976.
9. *Solid* Waste Report, July 31, 1978, p. 125.
10. American Iron and Steel Institute, "Summary Report of Solid Waste Processing Facilities" AISI, Washington, D. C., 1977.
11. U.S. Bureau of Mines, Bureau *of* Mines Research on Resource Recovery Reclamation, Utilization, Disposal, and Stabilization, U.S. Dept. of the Interior, Bureau of Mines Information Circular 8750, 1977.
12. Pavoni, J., J. Heer, and D. Hagerty, Handbook *of Solid* Waste Disposal, Van Nostrand, 1977.
13. Alter, H., "European Materials Recovery Systems, " Environmental Science and Technology, vol. 11, no. 5, May 1977.