Chapter 15

Technologies for Centralized Resource Recovery

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CHAPTER 5

Technologies for Centralized Resource Recovery

Introduction and Issues Addressed

Centralized resource recovery includes any process that can recover energy and/or recyclable materials from collected, mixed municipal solid waste (MSW). These processes are listed in table 28. In complexity they range from simple recovery of ferrous materials using magnets to complex systems that include the production of liquid or gaseous fuels by pyrolysis and the recovery of ferrous metals, aluminum, glass, and other nonferrous metals. While centralized resource recovery is sometimes viewed as being in the class of high-technology aerospace spinoffs, it includes small-scale modular incineration, simple mechanical processes such as shredding, and such biological processes as comporting and anaerobic digestion.

Table 28.—Municipal Solid Waste Energy and Materials Recovery Systems

Energy recovery systems
Mass combustion of raw MSW
Waterwall incineration
Small-scale modular incineration with heat recovery
Refuse derived fuel (RDF)
Dry processes
Fluff RDF
Dust or powdered RDF
Densified RDF
Wet processes
Pyrolysis systems
Low Btu gas
Medium Btu gas
Liquid fuel
Biological systems
Landfill methane recovery
Anaerobic digestion
Hydrolysis
Materials recovery systems
Comporting
Ferrous metals
Aluminum
Glass
Fiber
Wet separation
Dry separation
Nonferrous metals

SOURCE Off Ice of Tecnology Assessment

In this chapter the following questions and issues are addressed:

- What centralized resource recovery technologies are available?
- What is the status of these technologies and how well do they perform the tasks of waste disposal and resource recovery?
- What environmental, health, and safety problems may exist or emerge with centralized resource recovery?
- How does the question of plant size or , scale affect decisions about centralized resource recovery systems?
- What should be the Federal role in meeting research, development, and demonstration needs?

In this chapter, the status of the technologies and their effectiveness in resource recovery and waste reduction are examined. Issues related to environmental and workplace health and safety, the question of scale in resource recovery systems, and the Federal role in research, development, and demonstration are addressed. Other issue-oriented questions regarding markets, economics, institutional problems, and selection of overall waste management strategies are discussed in other chapters.

The technologies listed in table 28 are described briefly in appendix C. More technical detail is available in the additional readings listed at the end of appendix C.

The problem of technology selection and system design to serve a particular community is a difficult one, It requires consideration indepth of local conditions and of technological capabilities. The purpose of this report is not to provide sufficient detail to make such local decisions but only to assist in making the policy decisions associated with resource recovery programs.

Status of the Technologies

This section includes an inventory of resource recovery facilities in the United States. The various technologies are then compared in terms of (i) degree of proven commercialization, (ii) waste reduction efficiency, (iii) material recovery efficiency, and (iv) energy recovery efficiency. Estimates are presented of the maximum potential energy savings from the recovery of energy and materials from MSW. Finally, information on the status of European systems is reviewed.

Inventory of Centralized Resource Recovery Facilities in the United States

Table 29, which lists centralized resource recovery facilities now operating or under construction in the United States based on a recent Environmental Protection Agency (EPA) publication,(l) is an update of an earlier table published by EPA in 1976 in its Fourth Report to Congress.(2) It lists 17 plants in operation (down from 21 in 1976) with a total capacity of 6,730 tons per day (tpd) (down from 9,880 in 1976). The main differences between table 29 and the earlier EPA table are the addition of Baltimore and Baltimore County, Md., and Milwaukee, Wis., to the operational list; the deletion of experimental facilities in St. Louis, Me., and Washington, D, C.; and the deletion of five waste incinerators in Chicago, Ill., (two plants), Harrisburg, Pa., Merrick, N. Y., and Miami, Fla.

Table 29 also lists 12 facilities in startup or under construction (up from 10 in 1976] with a total capacity of 11,860 tpd (down from 12,560 in 1976). The major differences in this category include shifting Baltimore, Baltimore County, and Milwaukee to the operational list; adding Akron, Ohio,; Bridgeport, Corm.; Lane County, Oreg.: Monroe County and Niagara Falls, N. Y.; and North Little Rock, Ark.; and deleting the 6,000-tpd proposal for St. Louis.

In the Fourth Report to Congress,(2) EPA listed a number of communities engaged in various stages of planning for centralized resource recovery. Since 1976, neither EPA nor OTA has updated this list. Subsequent events suggest that it is not a reliable guide to the current situation nationwide.

In October 1978, the Department of Energy (DOE) announced that 20 communities would receive grants to conduct studies for demonstrating the feasibility of recovering energy from waste.(3) None of these grants is to be used for construction purposes.

It is difficult to classify the operational status of the facilities in table 29 because many of them are experimental or demonstration facilities whose status can change quickly. The term "operational" does not necessarily mean "commercial. " Several of the facilities in the operational phase have been based on significant public or private subsidy. Others are similarly subsidized demonstration plants. The San Diego County pyrolysis facility is shut down for major modification.(4)

Table 29 shows a trend toward large-scale plants among those under construction or in startup. Over half have a capacity of 1,000 tpd or more. A possible shift away from this early trend toward building large plants is discussed in this chapter. The table also shows that the most popular systems are waterwall incineration and refuse-derived fuel (RDF), but that there is interest in small modular combustion units such as those in

Table 29.– Resource Recovery Facilities in the United States

Location	Type'	Capacity (tons/day)	Products/markets	Startup date
In operation:				
Altoona, Pa.	Compost	200	Humus	1963
Ames, Iowa.	RDF	400	RDF-utility, Fe,Al	1975
Baltimore, Md. (D)	Pyrolysis	700	Steam heating&cooling. Fe	1975
Baltimore County, Md. (D).	RDF	550	RDF,Fe,ALglass	1976
Blytheville, Ark.	MCU	50	Steam process	1975
Braintree, Mass..	WWC	240	Steam process	1971
E. Bridgewater, Mass. (D)	RDF	160	RDF-utility	1974
Franklin, Ohio (D).	Wet pulp	150	Fiber, Fe. glass, Al	1971
Groveton, N.H.	MCU	30	Steam process	1975
Milwaukee, Was.	RDF	1,000	RDF-utility, paper Fe, Al	1977
Nashville, Term.	WWC	720	Steam heating & cooling	1974
Norfolk. Va.	WWC	360	Steam (Navy base)	1967
Oceanside. N.Y.	RWI/WWC	750	Steam	1965/74
Pales Verdes, Cal if.	Methane recovery		Gas-utility & Fe	1975
Saugus. Mass.	WWC	1,200	Steam process	1976
Siloam Springs, Ark.	MCU	20	Steam process	1975
South Charleston, W. Va.(D)	Pyrolysis	200	Gas. Fe	1974
Under construction; startup:				
Akron, Ohio	RDF/WWC	1,000	Steam heating & cooling	1978
Bridgeport.Corm.	RDF	1.800	RDF utility. Fe, Al, glass	1978
Chicago, ill.	RDF	1,000	RDF-utility, Fe	1976
Hempstead, N.Y.	Wet pulp/WWC	2,000	Electricity, Fe. Al, glass	1978
LaneCounty, Ore.	RDF/WWC	750	RDF-institution, Fe	1978
Monroe County, N.Y.,	RDF	2.000	RDF-utility. Fe, Al, glass	1978
Mountain View.Calif (D).	Methane recovery		Gas/utility	1977
NewOrleans, La.(D)	Materials	650	Nonferrous, Fe, glass, paper	1976
Niagara Falls, N.Y...	RDF/WWC	2,200	Steam industry, Fe	—
North Little Rock, Ark.,.	MCU	100	Steam process	1977
Portsmouth, Va..	WWC	160	Steam loop	1976
San Deigo, Calif (D)....	Pyrolysis	200	Liquid fuel/utility, Fe, Al, glass	1977

*RDF= refuse derived fuel WWC= waterfall combustion, RWI= refractory wall incinerator with waste heat boiler MCU = modular combustion unit RDF/WWC= Waterfall combustion using processed waste D= Pilot demonstration facility
SOURCE H Freeman of EPA(l)

operation at Blytheville, Ark,; Groveton, N. H.; and Siloam Springs, Ark. Industrial and institutional interest in these same small waste heat recovery incinerators appears to be strong and growing. A late-1976 survey identified 1 municipal, I school, 19 hospital, and 22 industrial incinerators not listed in table 29.(5)

Comparative Performance of Various Technologies

In order to gain some insight into how well these systems work, they are compared here in terms of four performance measures: (i) degree of proven commercialization, (ii) waste reduction efficiency, (iii) material recovery efficiency, and (iv) energy recovery efficiency. It should be noted at the outset that in many instances because of the emerging nature or proprietary status of these technologies, it is difficult to obtain adequate data for these comparisons.

DEGREE OF PROVEN COMMERCIALIZATION

EPA has assessed the "degree of proven commercialization" of each of the materials and energy recovery technologies.(6) Such classification is necessarily judgmental and is useful only as a general guide to commercialization status. Their classification scheme is augmented here with an additional category, "Research Technologies, " which includes processes that have not yet reached the pilot plant or demonstration stage, EPA's assessments have been reevaluated by 0TA and a few differences have emerged. The four categories are defined as follows:

- **Commercially Operational Technologies.**—Existing full-scale commercial plants that operate continuously. Consequently, there are some operating data available from communities and engineers already involved in the use of the process. Although such systems are being commercially utilized, they may be technically complex. To operate properly, they will require maximum use of available information leading to careful design and operation by knowledgeable professionals. There may be only limited operating experience with some parts of these plants. Thus, technological uncertainties may still exist.
- Developmental Technologies.—These are technologies that have been proven in pilot operations or in related but different applications (for example, using raw materials other than mixed MSW). There is sufficient experience to predict full-scale system performance, but such performance has not been confirmed. System design requires considerable engineering judgment about scale-up parameters and performance projections; consequently, the level of technical and economic uncertainty is generally greater than with commercially operational technologies.
- Experimental Technologies.—These include new technologies still being tested in laboratories and pilot plants. Because there is not sufficient information to predict technical or economic feasibility, such technologies should not be considered by cities contemplating immediate construction.
- Research Technologies.—These technologies, which are only in the laboratory testing stages with no pilot plant activity underway, are most technologically and commercially uncertain.

Tables 30 and 31 show OTA'S version of the EPA assessment of the degree of proven commercialization for energy and material recovery technologies. The only commercially proven technologies for energy recovery are waterwall combustion, modular incineration with heat recovery, and solid fuel RDF (wet and dry processes). Table 30 includes the waste-fired gas turbine concept. Considerable Federal research funds have been expended on this system which uses waste combustion gases to drive a gas turbine. It has not been included in this assessment because of serious corrosion and other problems.(6)

The only commercially proven material recovery technologies are humus production by comporting, magnetic recovery of ferrous metals, and low-grade fiber recovery by wet pulping. Other approaches have yet to be proven in an operational, economically sound project.

Aluminum recovery is classed as developmental because no plants are currently producing a steady stream of recovered alu-

Table 30.—Degree of Proven Commercialization of Energy Recovery Technologies

Commercially operational technologies
Waterwall combustion
Small-scale modular incineration with heat recovery
Solid fuel RDF (wet and dry processes)
Developmental technologies
Low Btu gas pyrolysis
Medium Btu gas pyrolysis
Liquid pyrolysis
Biological landfill conversion
Experimental technologies
Biological anaerobic digestion
Waste-fired gas turbine
Research technologies
Hydrolysis systems

SOURCE Office of Technology Assessment

Table 31.— Degree of Proven Commercialization of Materials Recovery Technologies

Commercially Operational Technologies
Comporting
Magnet ic recovery of ferrous metals
Fiber recovery by wet separation
Developmental technologies
Aluminum recovery
Glass recovery
Experiment/ technologies
Nonferrous recovery
Paper recovery by dry processes

SOURCE Off Ice of Technology Assessment

minum. The New Orleans facility recovered its first aluminum cans in March 1978. Samples were sent to Reynolds Metals Corporation for testing. Additional tests will be necessary before large quantities of aluminum can be recovered.(4) The Ames, Iowa, aluminum magnet was damaged in a winter freeze and only returned to operational status in mid-April 1978. The plant management had not yet (spring 1978) concluded the purchase agreement because the system had not been accepted from its manufacturer as operating satisfactorily. The Baltimore County facility aluminum magnet does not run on a continuous basis, but only when small amounts of RDF are being produced for an EPA contract calling for 3,000 tons for experimental cement kiln firing. Normally the shredded waste is used for landfill after the recovery of ferrous material, and aluminum is not recovered when the plant is running in this configuration. The Americology plant in Milwaukee, after correcting several problems, is in roughly the same situation as the New Orleans plant. Thus, none of these plants has yet demonstrated the sustained recovery of aluminum that is necessary before such recovery can be considered a commercially operational technology.

The status of glass recovery technology is similar to that of aluminum. It is, therefore, also considered to be in the developmental stage.

WASTE REDUCTION EFFICIENCIES

Reducing the amount of waste that must be landfilled is a major concern of municipal decisionmakers. Table 32 shows literature estimates of the residual fraction of MSW that must be disposed of by landfill or other means following resource recovery by the various technologies. As can be seen from this table, all of the systems reduce the landfill burden. Recovering both materials and energy helps reduce the disposal load. It is generally believed that residues that have been subjected to high temperatures in incineration or pyrolysis will be less hazardous in landfill because most pathogens cannot survive the high temperature and because incinerator residue should be less subject to subsidence. However, the products of combustion and pyrolysis must be examined to determine whether they create new kinds of toxic landfill effluents.

Table 32.—Estimated Waste Reduction Efficiencies of Resource Recovery Technologies

Technology	Residue as percent of input waste: Weight percent	Residue as percent of input waste: Volume percent	Reference
Waterwall combustion	25-30a	10	(6)
	20-35a	5-15	(7)
	25-30a	—	(8)
Small-scale incineration	30a	10	(9)
Dry fluff RDF	l0-15 [b]	—	(8)
	20C	—	(lo)
Low Btu pyrolysis	15-20a	3-5	(lo)
Medium Btu pyrolysis	17C	2	(lo)
Liquid pyrolysis	27b	—	(lo)
	7b, d	1-2	(11)
Anaerobic digestion	17b	—	(11)

[a]with metals not recovered
[b]with metal recovery
[c]With ferrous recovery
dAssumes the char would have economic value and would not be landfilled

MATERIAL RECOVERY EFFICIENCIES

Table 33 shows the materials recovery efficiencies of various processes based on data from the literature. The National Center for Resource Recovery [NCRR) reports efficiencies of up to 99 percent when the aluminum magnet is run at extremely slow (not commercially feasible) speeds. Product contamination is a problem with aluminum recovery. To reduce contamination an "air knife" can be installed following the aluminum separator. As mentioned earlier, the quality of paper fiber and glass recovered by the technologies listed in table 33 is low. Ferrous recovery is the most commercially feasible of all the systems reviewed here. [Additional attention is given to the quality of recovered materials in chapter 3.] Other dry paper recovery processes such as the Flakt process are being explored in Europe where wood stock for paper is not as abundant as in the United States.

Table 33.—Materials Recovery Efficiencies

Technology	Percent of the waste stream content of each material recovered	Reference
Ferrous-magnetic	90-97	(6)
Paper fiber—dry[a]	23	(6)
Paper fiber—wet	50	(12)
Aluminum magnet[b]	65	(15)
Glass-froth flotation	65-70	(11)
Glass-optical sorting	50	(12)

[a]CECCHINI Process in Italy
[b]shredded cans at a 1 ton per hour feedstock rate

Table 34.—Energy Recovery Efficiencies of Resource Recovery Processes

Process	Efficiency basis: Energy in fuel produced[a]	Efficiency basis: Energy available as steam[b]
Fluff RDF	70[c]	49[c]
Dust RDF	80	63
Wet RDF	76	48
Waterwall combustion furnace	—	59
Modular incinerators	—	25-50
Purox gasifier	64	58
Monsanto gasifier	78	42
Torrax gasifier	84[c]	58[c]
Occidental Petroleum Co. pyrolysis	**26**	**23**
Biological gasification	**33[c]**	**29[c]**

[a] Higher heating value of the fuel product, less the heating value of the energy used to operate the system expressed as a percent of the heating value of the input solid waste It was assumed that electricity is produced onsite using the system's fuel product
[b]In order to compare all the processes on an equivalent thermodynamic basis, the energy available as steam was calculated using an appropriate boiler efficiency for each fuel product
[c]Corrected figures are based on communications with EPA and an EPA contractor (18,23).
[d]Includes energy recovered from sewage sludge which also goes into the digester. This calculation also assumes that the filter cake residue from the digester is burned to recover heat
SOURCE EPA Fourth Report to Congress, p 59, with corrections by OTA as noted All calculations are based on higher heating value of Input solid waste of 5,000 Btu per pound, with some inorganic materials removed

ENERGY RECOVERY EFFICIENCIES

There is currently no standard accepted way to evaluate the energy recovery efficiency of resource recovery systems. This problem is illustrated by one study that cites seven different efficiency figures from the literature, ranging from 29 to 49 percent, for the Occidental liquid pyrolysis process. Different efficiencies result from alternative ways of treating energy used by the process itself, from the choice of system boundaries for which the calculation is made, from the choice of higher or lower heating value of the waste, and from including or excluding the energy content of nonfuel materials. As the situation presently stands, it is possible to produce energy recovery efficiency figures to either enhance or detract from the apparent attractiveness of a particular system. The American Society for Testing and Materials (ASTM) Committee E-38 on Resource Recovery is examining energy efficiency calculations, but because of more pressing matters it has a low priority according to the committee chairman.(17)

Table 34 shows system energy efficiencies in terms of the energy content of the fuel produced, and in terms of the output energy available as steam. While comparison on the basis of available steam makes thermodynamic sense in terms of standard system boundaries, it ignores such important economic characteristics of the various waste-derived fuels as the quality of the fuel product and its transportability. The temperature of the steam produced by various technologies may differ considerably.

The basis for table 34 is a similar table in EPA's Fourth Report to Congress. However, several typographical errors in EPA's report have been corrected. In addition, data for small-scale incinerators have been added based on conversations with an EPA contractor, The energy savings from materials recovery have not been included. EPA's use of the term "net energy" in their version of table 34 differs from best practice in such calculations because of arbitrary limits on the system boundary.

The energy efficiency figures in table 34 are not based on tests from actual working systems. Rather, they were calculated from data available in the literature and from contacts with vendors. Therefore, care should be exercised in drawing inferences from this table, particularly where efficiency differences are relatively small.

Potential Energy Savings From Centralized Resource Recovery

Resource recovery can save energy in two ways: by substituting fuels or heat recovered from waste for nonrenewable energy sources: and by substituting recovered materials for their counterpart virgin materials.

Less energy is required to produce most industrial materials from scrap than from virgin sources. Therefore, recovering materials from MSW for recycling represents an energy savings. Using data from the literature(19,20,21 ,22) the potential energy savings were calculated assuming that in 1975 all the iron and steel, aluminum, copper, and glass were recovered from the MSW stream. The results of this calculation are summarized in table 35. Complete recovery of these materials would have saved 0.3 x 10^{15} Btu or 0.3 Quad. * This is equivalent to about 0,4 percent of the Nation's energy use in 1975.

To calculate the amount of nonrenewable energy that could be saved by recovery of fuel or energy from MSW it was assumed: (i) that 100 percent of the combustible waste (including paper) could either be recovered as fuel or burned, (ii) that the substitution would be on a Btu for Btu basis, and (iii) that raw MSW has an energy content as fuel of 5,000 Btu per pound. Thus, for the base year selected, 1975, the energy content of the 136.1 million tons of MSW generated would have been 1.36 x 10^{15} Btu or 1.36 Quads. This is equivalent to about 1.9 percent of the Nation's energy use in that year.

Thus, the maximum energy that could have been saved by centralized recovery of both energy and materials in 1975 is 1.66 x 10^{15} Btu or 2,3 percent of the energy used by the Nation in that year. In actual practice, however, the maximum amount of energy saved would be considerably less than calculated in these estimates. Technical, economic, and institutional barriers would act to limit the contribution of resources recoverable from MSW to the Nation's energy pool,

*One Quad = 10^{15} Btu = 1.055 exajoule.

Table 35.—Potential Annual Energy Savings From Recovery and Recycling of 100 Percent of Various Materials From MSW

Material	Energy savings (10^{15} Btu/year)
Iron and steel	0.08
Aluminum	0.19
Copper	0.01
Glass	0.02
Total	0.30

SOURCE Office of Technology Assessment

Resource Recovery Experience in Western Europe

Resource recovery, especially for energy production, is more widespread in Western Europe than in the United States. A recent study for DOE of 14 countries identified 181 plants containing 243 separate units. The 181 plants include a total of 413 furnaces.** Most of these units recover steam in waterwall or fire-tube boilers. Typical applications are electricity generation, steam for district heating and industrial use, and sewage sludge drying. Several plants preshred the refuse and recover ferrous metals before burning, and many have pollution control devices. Tables 36 and 37 show the geographic distribution of units, both furnaces and plants. (Furnace sizes are given in metric tons, which are equivalent to 2,205 pounds. The U.S. short ton is 2,000 pounds.)

In comparison with Western Europe, EPA identified seven waterwall combustion plants and three small-scale modular combustion units for MSW completed and operational in the United States in 1976. Not all of these seven large waterwall systems were able to market their steam. Thus, in terms of numbers of units, Western Europe is considerably ahead of the United States.

Individual furnaces in Europe are smaller than the large-sized units being installed in the United States. Thirty-four percent of the European furnaces are smaller than 5 metric

**EPA is currently examining European systems in a detailed study.

Table 36.— Waste-to-Energy Systems in Western Europe

Country	Number of units[a]	Number of plants[b]
Austria	2	2
Belgium	3	3
Denmark	45	31
Finland	2	2
France	29	20
Italy	16	14
Luxembourg	1	1
Netherlands	7	6
Norway	13	8
Spain	3	2
Sweden	22	16
Switzerland	33	29
United Kingdom	9	9
WestGermany	58	38
Total	243	181

aAUnit os a facility built at one time in a single locaton
bA plant is building which one or more waste-to-engery units is installed
SOURCE (24)

tons per hour, and 60 percent are smaller than 10 metric per hour. In contrast, for example, the Resco plant at Saugus, Mass., uses two waterwall combustion furnaces, each rated at682 metric tpd or 28 metrictons per hour. The only units larger than these operating in Western Europe are two 50-metric-ton per hour furnaces in the Paris, France IVRYII plant and a few 40-metric-ton per hour furnaces installed in West Germany.*

With the exception of the large furnaces in France and West Germany, other European plants use a modular approach to achieve large plant capacity. The French plant at Lyon Zeme achieves a daily capacityof 960 metric tons with four, l0-ton per hour furnaces. The Sorain Cecchini plant in Rome, Italy reaches 576 metric tpd with six, 4-ton perhourunits.

Most of the incineration units in Europe are in large cities that often have more than one facility. However, several small towns in Denmark have small units with capacities less than 5 metric tons per hour. Almost all these plants are used for hot water and district heating. In Switzerland, centrally located facilities serve rural areas. The plant at Monthey, for example, generates electricity from the solid waste of 57 villages.

There are institutional differences between European and U.S. society that affect resource recovery systems. Denmark has a law requiring source separation that removes a large portion of the organic combustibles from MSW and thus discourages certain kinds of centralized waste-to-energy systems. Comporting is successful in the Netherlands, whereas it usually fails in the United States. The Netherlands subsidizes comporting operations. Markets for the composted product, humus, are good in the flower and bulb industries.

Some of the factors that might explain European adoption of energy recovery incinerators are: (i) relatively high population densities with less land available for dumping, (ii) high fossil-fuel prices, (iii) cold climates in which district heating systems have long flourished, (iv) strong manufacturing firms including several furnace grate manufacturers, and (v) localized electricity production, which makes the sale of electricity easier (except in France and Italy, which have state monopolies) .(24)

Environmental and Workplace Health and Safety

This section examines the environmental and workplace health and safety aspects of resource recovery systems in order to determine whether problems exist that might require attention by Congress, the regulatory agencies, or the R&D community. The topics addressed include air, liquid, and solid emissions from resource recovery facilities, and workplace conditions such as noise, pathogens, dust, toxic substances, explosion and fire hazards, and the safety of mechanical and electrical equipment. Few, if any, of the problems discussed appear to be insoluble,

*One DOE official believes that the French will not again build and try to operate systems with large furnace units but would achieve large scale by using a modular approach with several smaller furnace units,(25)

Table 37.—Distribution of Waste-to-Energy Furnaces, by Capacity and Country in Western Europe

Country	Furnace size (metric tons/hour)[a]						
	0-5	5-10	10-15	15-20	20-25	Over 25	Total
Austria	—	3	—	2	—	—	5
Belgium	1	5	—	—	—	—	6
Denmark	35	10	7	1	—	—	53
Finland	—	4	—	—	—	—	4
France	13	26	10	4	—	2	55
Italy	18	10	9	—	—	—	37
Luxembourg	—	—	2	—	—	—	2
Netherlands	—	5	8	4	6	—	23
Norway	12	1	—	—	—	—	13
Spain	—	1	3	—	—	—	4
Sweden	20	8	3	4	—	—	35
Switzerland	31	9	10	3	—	—	53
United Kingdom	2	5	12	—	—	—	19
West Germany	9	20	37	20	13	5	104
Total	141	107	101	38	19	7	413[b]

[a]To convert metric tons to short tons, multiply by 1.1.
[b]Many units have more than one furnace.
SOURCE: (24).

but they could add to the cost of building and operating resource recovery plants and constrain the range of practical technologies.

Environmental Factors

Questions have been raised about potential air and water pollution from resource recovery plants. Emission standards exist for such air emissions as particulate matter, sulfur dioxide, nitrous oxides, carbon monoxide, and hydrocarbons. Because MSW contains larger concentrations of some heavy metals and other hazardous substances than coal and oil, there is increasing interest in assessing the potential health and environmental hazards of these substances. However, very little good data are available for this purpose. A report by the Midwest Research Institute (MRI) for EPA lists 84 substances known to be in MSW; many of which are known to be hazardous. Research is cited which indicates that a number of hazardous inorganic substances are found in higher concentrations in RDF than in coal.

EPA has recently initiated research to build a data base on the environmental aspects of resource recovery systems. This should enable development of control technology, if necessary. The consequences of hazardous substances in resource recovery systems are currently not understood and there are no regulatory standards applicable to their emission into the air or water, or as solid waste. EPA has proposed an ambient air quality standard for lead and is considering regulation of other hazardous materials.

AIR EMISSIONS

Some data exist on emissions of the five "criteria pollutants" (particulate, sulfur oxides, nitrogen dioxide, carbon monoxide, and photochemical oxidants) from incineration and from combined RDF/coal-fired systems. Little data on the emission of these pollutants from pyrolysis or biological systems are available. Air emissions from pyrolysis plants can contain particulate matter as well as hydrocarbons and such gases as hydrogen chloride, hydrogen sulfide, and nitrous oxides. Air pollution from biological systems can result from the incineration of digester filter cake residues. Other air emissions can result from cleaning methane digester gas. The characteristics of these potential pollutants are unknown.

Air pollution control equipment is necessary for incineration systems. * Average uncontrolled particulate emissions from a modern waterwall incinerator were found to be 1.24 grains per standard cubic foot (SCF) (2.84 grams per standard cubic meter, g per SCM) compared to the EPA standard of 0.08 grains per SCF (O. 18 g per SCM).(7) However, air pollution control technology, when properly selected, installed, and operated appears to bring particulate emissions within EPA standards.(7) Since waste has a higher ash content than fossil fuels, burning RDF with coal may increase the load on air pollution control equipment. The efficiency of electrostatic precipitators may be reduced when MSW is burned with coal at high boiler utilization rates.(10)

Research indicates that sulfur dioxide, oxides of nitrogen, carbon monoxide, and hydrocarbons are not likely to cause problems when MSW is burned. Since MSW has a much lower sulfur content than most coals, cofiring RDF and coal could reduce sulfur dioxide emissions per unit of electric energy produced. In cofiring RDF and coal, for which there are more data than for waterwall incineration, there is evidence of increased air emissions of such heavy metals as beryllium, copper, lead, cadmium, and mercury. Based on very limited tests, researchers at Iowa State University reported increases in copper and lead air emissions from the powerplant at Ames when RDF was added to the coal.**

*Incinerators of less than so tpd are excluded from Federal air quality standards.(28) There is great variability among States and between State and Federal standards for incinerators. For example, in the Baltimore and Washington metropolitan areas of Maryland, single-stage incinerators with a capacity of less than 5 tons per hour are prohibited. (29l) It is not clear whether this ban would apply to small, two-stage incinerators of the kind under discussion here.

**A furor was caused in the fall of 1977 when researchers erroneously reported very high concentrations of toxic substances in the RDF from the Ames, Iowa RDF plant. The error was subsequently corrected.

Hydrogen chloride gas produced by burning plastics in MSW can combine with water to form hydrochloric acid and may create potential health and corrosion problems. Hydrochloric acid, if it is found to be a significant health problem, should not be difficult to control with scrubber technology.

Little is known about air pollution from cofiring liquid pyrolysis fuel with oil, since the Occidental pyrolysis plant in California is not in operation.

Dry process refuse-derived-fuel plants may emit dust, odor, and noise to the plant environment, but these can be confined to the plantsite with proper design. (See the following section for a discussion of these substances in the workplace environment.)

LIQUID EMISSIONS

Important characteristics of waste water from resource recovery systems, some of which could require control, are: high temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), hydrogen ion concentration (pH), alkalinity, hardness, total solids, total dissolved solids, suspended solids, settleable solids, phosphates, nitrates, chlorides, fluorides, heavy metals, odor, and color.(8)

Not much is known about the characteristics of water pollutants from incineration processes, in which one potential source of waste water is from ash slurrying. Studies at the St. Louis RDF/coal-fired plant indicate increased levels of BOD, COD, and total dissolved solids. Characteristics of waste water from pyrolysis plants are not well known, but it may be high in BOD, COD, alcohols, phenols, and other organic compounds. Biological systems present waste water pollution problems because the process requires large quantities of water in the digesters, part of which is recycled, but part of which must be discharged. Little information is available on these emissions since the demonstration plant at Pompano Beach is still under construction.

SOLID RESIDUALS

Solid wastes from resource recovery plants include combustion ash, pyrolysis residues, and particulate matter recovered by air pollution control devices, all of which can produce undesirable leachates when used as landfill. Although data are scarce, fly ash particulate from waste incineration may contain trace elements such as cadmium, lead, beryllium, and mercury (30)) The solid sludge from biological processes may contain bacteria that could create leachate problems if landfill is chosen for its disposal.

Occupational Health and Safety Factors

Persons working in and around resource recovery plants may be subjected to potential health and safety hazards such as bacteriological and virological pathogens, dust, toxic substances, noise, explosions and fires, and mechanical and electrical equipment. Since these systems are new, little is known about the characteristics of the hazards they pose, This section describes these hazards and reviews some of the ongoing research and regulatory activity associated with them.

NOISE

Resource recovery processes such as shredders, air classifiers, trommels, and cyclones can produce noise in excess of present Occupational Safety and Health Administration (OSHA) standards. A study of a small, 3-ton per hour resource recovery system reported noise levels in excess of 90 dBA* near these devices. Control of noise in such equipment by engineering design will probably be costly. Consequently, administrative controls (limiting the time exposure of employees in high noise areas) and personal protective equipment may be needed to control exposure. Noise levels in larger commercialized shredders will undoubtedly exacerbate the problem. Current OSHA regulatory activity should be adequate to control noise exposure unless the plant is operated by a municipality in a State in which municipal employees are not covered by OSHA.

PATHOGENS

As MSW is shredded, air-classified, and transported within resource recovery facilities, workers are exposed to bacterial, fungal, and virological pathogens contained in the waste stream. Air sampling indicates that total bacterial counts in the Ames plant are around 100 times greater than in normal nonplant environments.(34) MSW contains human and animal fecal matter due, for example, to the use of disposable diapers and the disposal of animal litter. Fecal coliforms and fecal staphylococci at the Ames facility are about 5 percent of total bacteria. Good data on the impact of these pathogens on the health of workers are not available. No standards exist for microbiological contaminants in the workplace except for hospital operating rooms—a standard not applicable to resource recovery plants.

The data base for viral contaminants in resource recovery plants is even less adequate. Even though viruses would be expected in such plants, air sampling studies done by MRI for EPA have not detected any. The sampling method may be inadequate, and further tests are underway at Ames .(34)

Epidemiological studies of persons with long-term exposures to environments typical of resource recovery plants do not exist. One study of New York City uniformed sanitationmen found no evidence of an increased amount of chronic pulmonary disease when compared to other job titles in the department.(35) The same author reported that these sanitationmen have a rate of coronary heart disease almost twice that of other groups of males in similar age categories. He is unable to explain this finding, and urges that epidemiological studies are needed to identify causes.

Some research is underway on pathogens in resource recovery plants. EPA is funding a

*Ninety decibels on the A scale (90 dBA) is the maximum noise level permitted for an 8-hour day by present OSHA standards. This level is thought to be too high by some organizations who prefer an 85 dBA standard.

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study in this area by MRI. The National Institute of Occupational Safety and Health (NIOSH) is presently funding research at the Stanford Research Institute on occupational health and safety (emphasis on health) in emerging energy industries. One of the tasks being carried out is an assessment of health and safety problems in resource recovery facilities. This limited preliminary study is expected to produce a qualitative assessment of potential problems with pathogens and to suggest what needs to be done. Related work is being done at the Ames Laboratories of DOE. ASTM has formed a subcommittee on health and safety of its Committee E-38 on Resource Recovery. One of this subcommittee's tasks is to develop standardized methods for sampling microbiological aerosols. Some researchers in this field indicate that if information on bacteriological and virological experiments done by the military could be declassified, research on resource recovery plants might be expedited.

DUSTS AND TOXIC SUBSTANCES

Processing MSW produces considerable dust—another potential health hazard. OSHA standards for dust specify maximum permissible concentrations of dirt or nuisance dust. However, because of the variety of materials in MSW there is additional concern about specific substances such as asbestos, metal dusts, and other toxic substances. In one test at a resource recovery plant asbestos fibers were not found in the air, and a single test for aluminum and cadmium dust gave negative results. Roughly half the dust on a particle count basis at the Ames plant is composed of particles less than 4 microns in diameter. Similar results are reported elsewhere.(33) Retention of dust in the lungs is highest for particles of about 2 microns, so it appears that MSW dust retention may present a problem. The National Center for Resource Recovery reports that an average of dust samples in their experimental test facility showed only 12 percent of the dust to be in the respirable range.(37) Their dust measurements were made on a weight basis, rather than the particle count basis used at Ames. Dust particles too large to enter the lungs can be captured in mucous membranes and ultimately carried into the digestive tract. This is another source of infectious potential of unknown significance.

Obviously, dust control measures and personal protective equipment for workers in resource recovery plants need considerable attention on the part of workers, managers, and regulators. In the long term more work needs to be done to characterize the nature of dust in resource recovery plants and to assess the health effects of long-term exposure to this kind of dust.

EXPLOSIONS AND FIRES

MSW occasionally contains dynamite; gunpowder; flammable liquids and gases; aerosol cans; propane, butane, and gasoline fuel containers; and other explosive substances. When such substances are shredded an explosion can occur. A 1976 study of explosion hazards in refuse shredders reported 95 explosions in the 45 MSW-shredding plants included in the survey. Thirty-four of the shredding operations had experienced at least one explosion. Injuries were reported in only three incidents. No fatalities occurred. Only five of the explosions produced more than $25,000 property damage or put the shredder out of operation for more than 1 week. Because shredders are designed to withstand mild explosions, shredder explosions usually damage peripheral equipment such as ducts and conveyors.

Protection from shredder explosions can be achieved by manual or automated surveillance of input material, explosion venting, explosion suppression/extinguishing systems, water spray, or equipment isolation. Manual screening to remove explosive material is already being practiced, but cannot be expected to remove all explosive substances. The feasibility of automatic detection of such materials is questionable. Shredders can be designed with hinged walls and tops to allow rapid venting of exploding gases. This method can minimize shredder damage, but requires careful attention to the protection of personnel and adjacent equipment. Explosion extinguishing systems detect the pressure increase at the beginning of an explosion and trigger the release of chemical explosion-suppressing agents into the shredder. When operating properly these devices can control shredder explosions and extinguish flames. However, such devices cannot control explosions of self-oxidizing explosives such as ordnance. Continuous water sprays in the shredding operation can reduce explosion and fire hazard, but water in the shredded refuse reduces its heating value, reduces the efficiency of ferrous separation, and can cause shredder corrosion. Finally, personal injury from shredder explosions can be controlled by isolating the shredder and keeping employees away from it while in operation.

It appears possible to reduce the incidence of shredder explosions by substituting a rotary drum air classifier for the shredder as the first step in waste processing. Using this approach, only the light fraction of the waste is shredded while most of the potentially explosive components become part of the heavy fraction, which is not shredded. Such a system has been tested at the waste shredding facility in New Castle, Del.

Dust from MSW shredding does not appear to be a great explosion hazard. However, mixtures of combustible dust and flammable gas or vapor may explode even though neither the dust nor the gas by itself is in an explosive concentration range. In addition, dust can be a contributing factor in fires caused by explosions.

Dust explosions may be more likely where fine powder RDF is produced. An explosion with a fatality occurred at the ECOFUEL II" plant in East Bridgewater, Mass., in the fall of 1977. According to the plant owners, Combustion Equipment Associates (CEA), the cause of this explosion is still undetermined. (39) CEA claims that their powdered RDF is less explosive than grain or starch dust or pulverized coal.

MECHANICAL AND ELECTRICAL HAZARDS

Resource recovery systems contain an array of mechanical and electrical devices ranging from equipment for handling materials (front-end loaders, cranes, and conveyors) to the separation and combustion processes discussed earlier. This environment exposes employees to a variety of potential accidents. However, most of these devices fall under existing OSHA safety regulations. Assuming that these regulations are enforced and that workers are covered, control of these hazards maybe adequate.

Conclusions

Several potential environmental and occupational health and safety problem areas in resource recovery need further investigation. Many questions about the environmental impacts of waste-to-energy systems remain unanswered. EPA is now monitoring and studying control of pollution from resource recovery facilities as they come online. If construction of resource recovery facilities continues, this activity may need to be accelerated to ensure against the emergence of environmental problems in the future. Exploration of control technologies for heavy metals in air emissions and for toxic leachates from solid residuals of resource recovery in landfill, is particularly important.

Some of the occupational health and safety problems such as noise and mechanical and electrical hazards can probably be controlled by OSHA'S existing regulatory apparatus. However, work on pathogens as health hazards should be accelerated. NIOSH has recently announced an interest in developing a criteria document on occupational safety and health standards for incineration systems. Under this procedure, 1982 is the earliest date for promulgation of a health and safety standard for incinerators. NIOSH should consider issuing a criteria document for all the resource recovery technologies, not just incineration, on an accelerated time schedule. Finally, relevant military research on pathogenic agents should be made available.

Plant Size and System Design: The Question of Scale

Overview

Most of the resource recovery technologies in the United States examined in this chapter are currently being designed and built as large-scale plants, with capacities in the 1,000- to 3,000-tpd range. The exceptions are small-scale modular incinerators and biological conversion processes. Such large plants are attractive because they promise significant economies of scale in processing (average costs decline as plant size grows—see chapter 6) and because they can include economical systems for the recovery of materials as well as energy.

Recently, however, strong interest has emerged in small-scale, modular incinerators with heat recovery. This interest is stimulated by the realization that the institutional, financial, and technological barriers to large-scale systems discussed in chapters 6 and 7 are real, especially in view of the uncertainty about the capability and reliability of available technologies.

Interest in small-scale systems has also paralleled the attention being given to the concepts of "decentralized," "appropriate," or "soft" technology. These concepts are being examined for many technologies such as energy supply, sewage treatment, and provision of government services. For resource recovery systems these concepts suggest that the scale of a technology should match the scale of its users.

In the remainder of this section, the implications of scale matching are explored for resource recovery system design. The sizes of potential producers and consumers of recovered energy are examined, and some of the advantages and disadvantages of small- and large-scale systems are addressed.

Matching producers With Consumers

ENERGY CUSTOMERS

Resource recovery plants can be viewed as factories that produce energy from a raw material—MSW. The larger such a plant, the more waste it can process from more people, and the larger the energy customer it requires. For example, a plant with 1,000-tpd average capacity can process the waste of approximately 570,000 people. The energy content of that waste as fuel is about 9 billion Btu per day, or the equivalent of the energy required to support a 37-megawatt electric (MWe) powerplant. * Such a powerplant would, in turn, serve about 3 percent of the electric power needs of the 570,000 people; who would use a total of about 1,200 MWe.

Electric powerplants are often considerably larger than 37 MWe; in fact, plants of 1,000 MWe are not unusual. Because electric powerplants are large consumers of fuel, they have been suggested as major potential customers for the fuel or energy output of resource recovery projects. However, to date utilities have been reluctant to use fuel from these sources, in part for the financial and institutional reasons discussed in chapter 7. In addition, however, utilities may be less than enthusiastic because solid waste as a fuel source is just too small. The potential financial, regulatory, technical, and political problems of burning solid waste may not be worth the effort for only 3 percent of a utility's fuel needs.

On the other hand, the energy output from a l,000-tpd" plant is much too large for most alternative customers for energy as steam or hot water. For example, the space heating and cooling energy demand of office buildings is estimated to be on the order of 850 Btu per ft^2 per day.(42) Thus, a 1,000-tpd plant might

*This calculation is based on an MSW heating value of 9 million Btu per ton, a per capita waste generation rate of 3.5 pounds per day, and an electrical generation efficiency of one-third.

serve up to 5 million ft^2, * an area corresponding to a very large office building or multibuilding complex, such as the Pentagon, which has 6.55 million ft^2 of space. (43) One alternative is for a large, centrally located facility to serve a number of surrounding customers, This approach has been taken in Nashville, Term., and in a plant under construction in Akron, Ohio.

Another alternative is to build a number of small resource recovery plants that produce steam or hot water. These modular combustion units (MCUS) would serve such customers as small- to medium-sized manufacturing plants and office buildings, and large institutions. The number of such potential customers greatly exceeds the number of potential industrial customers for the output of the larger 1,000- to 3,000-tpd plants.

The large number of potential industrial, institutional, and commercial users of heat from MCUS is suggested by the following information from DOEO(44) Several institutions are already using MCUS to recover energy from their own wastes, and in 1972, about 25,000 small boilers comparable in size to MCUS were producing heat for industrial processes. This indicates considerable potential industrial interest in MCU heat, especially as energy costs rise. There are also some 7,200 hospitals, 3,026 public and private colleges and universities, and 108,676 public and private elementary and secondary schools, Although many of these institutions are too small to use the entire output of even a small MCU, only 2 percent of them would be 2,400 potential users. For commercial buildings, Friedricks(43) thinks there might be a "realistic potential" for 1,000 to 2,000 MCUS. The possibility of matching the output of small-scale modular incinerators for MSW to the many potential users of heat warrants more extensive examination.

WASTE PRODUCERS

Experience to date suggests that in the United States resource recovery plants can be implemented more easily to serve a single community, or part of a community, than to serve a multicommunity region. As noted in chapter 7, the institutional, political, and economic barriers to multicommunity projects are difficult to overcome.

The potential market for resource recovery plants of various sizes can be estimated by considering the size distribution either of individual communities or of Standard Metropolitan Statistical Areas (SMSAS). A bigger market is predicted for small plants when the first approach is used and for large plants using the second approach.

Table 38 shows the size distribution of American cities along with estimated waste generation rates, neglecting any change in per capita waste generation with a change in city size. Only 23 cities are large enough to support a 1,000 + tpd plant on their own. Another 34 cities fall in the 500- to 1,000-tpd range. On the other hand, over 800 cities might use resource recovery plants in the 50- to 500-tpd range, and an additional 1,200 cities are in the 15- to 50-tpd group. These numbers suggest that there may be a large potential market for "small" resource recovery plants.

A somewhat different view of the potential for large plants is suggested by table 39, which shows the distribution of U.S. population in the SMSAS. These areas typically in-

*Assumes roduction of 4 million Btu of steam or hot water energy per ton of MSW.

Table 38.—U.S. City Size, Population, and Waste Production in 1975

City size range (thousands)	Number of cities[a]	Population[a] (million)	Average population per city (thousands)	Average municipal solid waste per city (tons/day)[b]
5-10 . . . .: . ;	‘1,463	10.3	7.1	12
10-20 .., ...	977	13.8	14.1	25
20-25	238	5.3	22.0	39
25-50	514	17.9	34.9	61
50-100	230	16.1	70.0	122
100-250	105	14.9	142,0	248
250-500	34	11.8	348.0	609
500-1,000	17	11.3	664.0	1,160
over 1,000. . . .	6	17.8	2,970.0	5,200

[a] SOURCE (45)
bEstimated by OTA based on 3.5 pounds, of MSW per capita Per day

Table 39.—U.S. Standard Metropolitan Statistical Areas (SMSAS) Size, Population, and Waste Production in 1975

SMSA size (thousands)	Number of SMSAS'	Population[a] (m!llion)	Average population per SMSA (thousands)	Average municipal solid waste per SMSAb (tOns/rjay)
un-der-l OO .-. .	27	2.5	92	160
100-250	97	16.6	171	300
250-500	63	22.7	361	630
500-1,000. . . .	37	27.1	733	1,280
1,000 -2,000..	20	28.3	1,417	2,480
2,000-3,000. .	8	19.0	2,373	4,150
over 3,000 . . .	7	40.0	5,693	9,960

aSORCE (46).
bEstimated by OTA based on 3.5 pounds of MSW per capita Per day

elude several cities and contiguous unincorporated areas. Table 39 shows that seven SMSAS produce around 10,000 tpd of MSW, 28 more are in the 3,000-tpd range, and another 37 are in the 1,200-tpd" range.

Advantages and Disadvantages of Small and Large Plants

Large resource recovery plants can achieve significant economies of scale and can include economical systems for recovery of both materials and energy. They represent large financial investments and may thus serve as a dramatic focus for the attention of citizens, industry, and government officials.

The disadvantages of large plants include: (i) their high first cost; (ii) the inflexibility they create by their requirements for future utilization in order to meet debt obligations, (iii) the difficulty of identifying a suitable energy customer; (iv) the problems of regionalization; (v) their vulnerability to strikes, sabotage, and mechanical failure; and (vi) the logistics and cost of delivering such large amounts of waste to a single site.

The advantages of small-scale systems include: (i) the fact that a large community or region can start small and add units or facilities incrementally; (ii) their compatibility with smaller waste producers and energy consumers; (iii) the system reliability inherent in operating several dispersed units; (iv) the fact that they can help avoid the political problems of regionalization; (v) their potential for reducing siting problems by locating them on customer property; and (vi) the fact that they can be produced in relatively large numbers with factory technology according to standard plans and installed relatively quickly with greater use of local skills.

The disadvantages of small-scale systems include: (i) potentially higher direct costs per unit of waste processed, (ii) the need to control a large number of relatively small air pollution sources, (iii) the requirements of small waste incinerators for auxiliary oil or gas fuel, and (iv) the fact that materials recovery in small-scale systems may be uneconomic since shredding and classifying would be very expensive at small scale. However, little or no thought has been given to small-scale materials recovery systems, or for that matter to small-scale cogeneration of electric power from MSW.

In comparing the advantages and disadvantages of small and large resource recovery plants, two characteristics warrant further elaboration: reliability and redundancy considerations, and implications for technological innovation.

The consequences of system failure are potentially more serious with one large plant than with several small plants. This fact creates the need in large plants to build in costly storage space, backup landfill, or equipment redundancy. To illustrate, consider two alternative ways of providing for resource recovery in a given city: one 1,000-tpd facility without storage or landfill, or five dispersed 200-tpd plants. If the waste that goes to any one of the 200-tpd plants could be temporarily redistributed to the others in the event of failure in any one plant, then the system of five plants possesses a kind of built-in redundancy. It can be shown with reliability theory that the reliability [probability of successful operation) of a single 1,000-tpd plant would have to be 0.9997' to equal the reliability of the five plant system if the reliability of the individual 200-tpd" plants were only **0.80.**

Factory production of a larger number of smaller incinerators may also have implications for incremental technological innovation and for system performance standards, both of which relate to aspects of potential Federal involvement. With several producers of small systems competing for sales to numerous municipalities and other buyers, market forces might stimulate technological improvements with minimal Federal involvement. In the case of construction of a smaller number of large, custom-designed systems, however, which take a relatively long time to plan and construct, market forces may not be adequate to induce technological innovation, and there may thus be greater pressure for Federal assistance. But the presence of a large number of competing systems may tend to complicate the technology/vendor selection process for local officials. Under these conditions, Federal technical assistance to local governments might be as important as if larger systems were involved.

Research and Development in Resource Recovery: The Federal Role

Background

The Federal Government has sponsored research, development, and demonstration programs in resource recovery for the last 15 years; first in the Public Health Service and later in EPA, in the Energy Research and Development Administration (ERDA) (now DOE), in the National Bureau of Standards, in the Bureau of Mines, and in the National Science Foundation. A good part of the funds has been spent on several large-scale demonstration plants. Other work has been done on innovative separation technologies, environmental impacts of resource recovery, and characterization of recovered resources. The Federal Government has also funded a variety of economic evaluations and state-of-the-art review studies.

Federally funded demonstrations have limited usefulness as a means for promoting the diffusion of technology. A recent study by OTA on the role of demonstrations in Federal R&D policy(47) found that only a low rate of success can be expected. Furthermore, the evaluation of the success or failure of a demonstration will be difficult and subjective. In part, this is because there is frequent confusion over the goals of a demonstration project, and in part because the information received from a project is likely to be unclear and imperfect.

In the last decade there have been several vigorous private sector R&D programs, demonstrations, and commercial ventures, sometimes jointly with Federal agencies. A privately funded R&D center has been in operation at the National Center for Resource Recovery, which has also received Federal grant and contract funds.

The following discussion of Federal R&D needs for resource recovery is set within this context of vigorous private sector activity and an important but limited Federal role in technology demonstration.

R&D Needs

The technical problems that have occurred at many of the operational or demonstration plants are sufficient evidence that more R&D is needed to make the technologies work reliably and economically. Much of this work might be accomplished most effectively by private firms in the normal process of commercial development. In view of the considerable existing private activity, the need for a Federal role to further support pilot plant and large-scale demonstration activity is limited.

However, Federal R&D programs concerned with potential environmental and occupational problems of resource recovery are needed because the private sector usually underinvests in such research, and because it is unlikely to be done by State and local governments or labor organizations. Such research should be focused on identifying and clarifying hazards to health, and on developing methods for their control. At the same time, a vigorous program to enforce health, safety, and environmental standards would help to stimulate this kind of R&D in the private sector. A Federal R&D program for occupational and environmental problems is also needed in order to develop and maintain a reservoir of knowledgeable government personnel who can participate in the regulatory process.

R&D needs and problem areas in resource recovery technology have been presented in the literature. (10,48) The list in table 40 illustrates their range. It is beyond the scope of this assessment either to develop a comprehensive list or to set priorities.

Many of the problems listed in table 40 could be dealt with best in the process of commercial development by private firms. However, there may be a tendency to neglect the more fundamental research questions, such as: (i) materials characterization; (ii) processes of size reduction, separation, combustion, and chemical reaction; and (iii) exploratory design work on innovative systems for purifying and utilizing recovered materials, and for utilizing energy products, particularly at small scale. Consequently, there may also be a useful Federal role in dealing with these problems.

Table 40.—Selected Research, Development, and Demonstration Needs for Resource Recovery Technologies

HanLing and storage of RDF; fluff, densified, anD powdered.
—Material handling processes to cope with the abrasive, corrosive, and mixed nature of MSW.
—Ferrous, aluminum, nonferrous (nonaluminum), and glass recovery improvement and optilmization.
—Shredder optimization.
—Air classifier optimization.
— Resource recovery with mixed wastes such as: MSW with sewage, commercial waste, industrial waste, agricultural waste, forestry waste, etc.
—Fundamental parameters in MSW pyrolysis processes.
— Fundamental combustion parameters in firing all classes of RDF and raw MSW with traditional fuels.
— Fundamental MSW bioconversion parameters.
—Fundamental hydrolysis processes for MSW.
—CofiMing of MSW with sewage sludge.
—Corrosion in the combustion of MSW.
—New uses for glass aggregate, pyrolysis char, etc.
—Upgrading of fiber recovered from MSW.
—Improved recovery of materials from incinerated waste.
—Use of magnetic fraction from MSW in foundries.
—Systems optimization problems such as cost effectiveness of trammeling prior to shredding, particle size interaction with grate and boiler design, etc.
—Resource recovery processes in synergy with other nonwaste developments such as biomass energy conversion, cogeneration, industrial hydrolysis, etc.
—Small-scale materials recovery processes.
—Small-scale cogenerat ion.
—Small-scale combustion processes.
— Markets for small-scale energy output.

SOURCE Office of Technology-Assessment

Findings on Technologies for Centralized Resource Recovery

Widespread interest in the systematic recovery of materials and energy from MSW in the United States is just a decade old. The construction of centralized facilities for separating MSW into useful components has only recently been considered as one potentially important approach to the problems of waste management. The rationale for centralized resource recovery has been threefold: (i) effective and safe disposal of solid waste, (ii) recovery of materials for recycling, and (iii) production of energy from the combustible portion of the waste. These are also the major components of the potential revenues from resource recovery.

A number of technologies for burning the combustible portion of MSW or for converting it to solid, liquid, or gaseous fuels are at various stages of development. Techniques have also been developed, with differing success, for recovery of ferrous metals, aluminum, glass, nonferrous metals, and paper fiber. Waterwall combustion and small-scale modular incineration to produce steam, and the production of refuse-derived fuel (RDF) by wet and dry processes are currently the only commercially operational methods for recovering energy. The only commercially operational technologies for recovering materials from mixed MSW are the magnetic recovery of ferrous metals, the recovery of low-grade fiber by wet separation, and the production of compost by natural processes. Aluminum and glass recovery are being actively explored as is energy recovery by both anaerobic digestion and pyrolysis.

Energy can be recovered by centralized resource recovery either as fuel or as heat, and also as the savings that accrue from recycling materials. As an upper limit, the total recovery of all energy in MSW could supply about 1.9 percent of the Nation's current annual energy consumption. Recycling all of the iron and steel, aluminum, copper, and glass could save about 0.4 percent more for a total savings of 2.3 percent of current energy use, or the equivalent of about 800,000 barrels of oil or 200,000 tons of coal per day, Thus, centralized resource recovery might play a small, but not insignificant role in conserving energy. Technical, economic, and institutional factors, however, will keep the energy saved by resource recovery in the foreseeable future to a fraction of its potential.

Relatively little is known about the effluents from operating centralized resource recovery plants or about the nature and degree of workplace hazards they may present. This is largely because there has been little opportunity to gather data and because there is considerable variability in and ignorance about the composition of both MSW and the recovered products. A number of studies currently underway should produce some information and data about air and water emissions, bacteria and viruses in the plant environment, and toxic substances in all media including solid residuals. Authority exists for regulating these workplace and environmental problems, if needed. Should activity in centralized resource recovery accelerate, it will be desirable to step up research and to promulgate regulations to control any potentially harmful side effects.

Over the past 15 years, there have been a number of federally funded research, development, and demonstration projects concerned with centralized resource recovery, There has also been vigorous activity in the private sector. The Federal R&D presence would be most effective in identifying, evaluating, and controlling environmental and occupational problems: in characterizing materials; in basic studies of processes for size reduction, materials separation, combustion, and chemical reaction: and in exploratory designing—particularly of small-scale systems for processing and using recovered materials and energy, The remaining technical problems would probably be best solved in the course of commercial development by private firms.

Recently, there has been a substantial shift from materials recovery to energy production as a more significant driving force. This shift, which has taken place because energy prices have risen more rapidly and steadily than scrap materials prices over the last several years, may have important implications for resource recovery system planning, design, and operation:

- It creates the need to consider more carefully matching resource recovery plants with the potential customers for the energy produced.
- Attention to such matching may induce a shift from large, centralized to small, dispersed resource recovery plants.
- With smaller plants there may be less need to consider regionalization of solid waste disposal, with its attendant problems,
- There may be increased attention to direct incineration and to cofiring of waste with coal, as opposed to more exotic approaches.
- There may be less recovery of materials from waste than had been envisioned earlier since materials recovery may be less feasible in small plants.
- There may be an increased urgency to assess, regulate, and control potential environmental and workplace problems.
- There may be less concern that beverage container deposit legislation might impair resource recovery development, if material revenues become relatively less important.

- There may be increased flexibility for designing resource recovery systems that include source separation activities, and that can respond more readily to changing patterns of waste generation in the future.

Only electric powerplants, large factories, or large complexes of office buildings can consume all the energy output of a 1,000-tpd resource recovery facility. These kinds of potential customers have proven to be difficult for proposed resource recovery projects to reach. Electric utilities have been less than enthusiastic because it presents technical difficulties and because they have essentially no incentive to use refuse-derived energy and, if they do, face many problems. In a given service area, MSW can provide only a few percent of the fuel needs of an electric utility. Thus, a' utility must contend with numerous difficulties to obtain just a minor part of its total fuel supply.

On the other hand, for smaller quantities of refuse-derived energy there are a large number of potential customers such as office buildings, institutions, and smaller factories. Smaller resource recovery plants, say in the 25- to 200-tpd range, might adequately serve their energy needs. These would help to avoid some of the problems that arise when several communities attempt to regionalize in order to build large plants. Smaller resource recovery plants, which are more common in Europe, may feature direct incineration to produce steam or hot water and may forego materials recovery altogether. They may also allow for a more flexible approach in a community or region by making it possible to adopt resource recovery gradually rather than all at once.

However, a few cautionary words about smaller energy recovery systems are in order. Not enough is known about their reliability, or about the environmental and workplace health implications of operating a network of dispersed, small plants. Also, more needs to be known about the energy demand characteristics of the small customers mentioned above, in order to learn whether they can indeed become consumers of energy from waste.

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