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Municipal Incinerator Residues

by

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

This study involved the composition and current disposal practices applicable to the residue from the incineration of municipal refuse. The economic and technical potential of utilizing these residues has also been studied.

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ABSTRACT

The composition and current disposal practices for the residue resulting from the incineration of urban refuse have been studied. In addition, the characteristics of urban refuse are described, and the location and capacity of the nation's municipal incinerators specified. The economic and technical potential for utilizing materials recovered from the residue have also been studied.

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SUMMARY

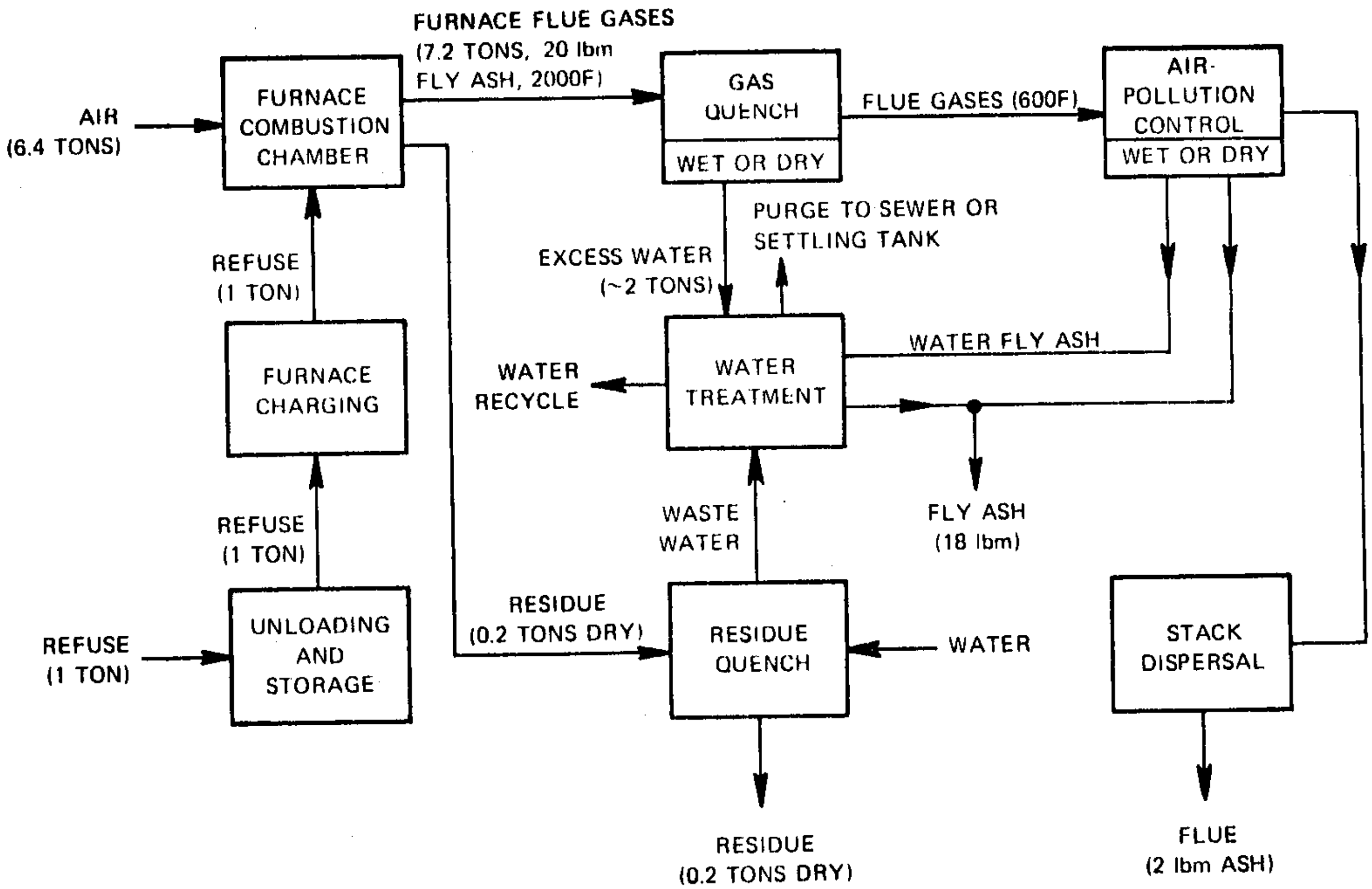
Incineration is utilized for the disposal of approximately ten percent of the collected municipal refuse, on a national basis. Annually, from 16 to 18 million tons of refuse are incinerated. A schematic representation of the basic components for incineration is shown in Figure 1. It is estimated that in 1972 about 193 incinerators were operating in the U.S. providing a total capacity for approximately 71,000 tons of refuse per 24 hour day. From the reported data, it appears that most incinerator facilities operate at about 70% of their rated capacity. Most of the incinerators are located in the eastern U.S. with New York, Massachusetts, Connecticut, Florida, and Ohio having the largest number of incinerators. Since 1969, construction of new incinerators or rebuilding of existing facilities has decreased significantly. It appears that the major factors for this decrease are the higher costs of incinerator construction, and higher operation costs due to the institution of stricter pollution regulations for incinerator operations. Capital costs for an incinerator range between \$6,000 and \$10,000 per daily ton and operating costs range between \$5 and \$20 per daily ton.

During incineration, furnace temperatures are between 1800°F and 2000°F with flame temperatures at approximately 2500°F. This process results in the reduction of the refuse incinerated to between 25 to 35% of its original weight; and, on the average, to less than 10% of its volume. The resultant residue after quenching is a wet, complex mixture of metal, glass, slag, charred and unburned paper, and ash. The typical range of values obtained for the various residue components is presented below.

RESIDUE COMPOSITION (%)

Material	Range
metals	20 - 40
glass	10 - 55
ceramics, stones	1 - 5
clinker	15 - 25
ash	10 - 20
organics	1 - 10

On a national basis, 4 to 6½ million tons of incinerated residue are generated annually, containing about 1½ to 2 million tons of ferrous metal, 100,000 to 200,000 tons of nonferrous metal and 2 to 3 million tons of glass. In addition to the residue, about 1% of the refuse exits with the exhaust gases leaving the furnace chamber. The particulate matter (or fly ash) retained, is predominately minus 200 microns in size, and consists of wood and paper ash, aluminum foil, carbon particles, metal pins and wire, glass, sand and iron scale. The chemical analysis of this material is very similar to fly ash from coal burning boilers.



NOTE: Quantities in parentheses are rough measures of flow rates and temperatures.

Figure 1. Basic Components of an Incinerator. (10)

The majority of the incinerator residue and fly ash is disposed of by burying. However, some problems are associated with this method of disposal because of potential water pollution from the water soluble portion of the residue. Depending on the specific residue, from 1 to 6% is water soluble. In addition to land fill, some communities are using the residue as a filler for road construction (road bed). The City of Baltimore is screening out the fine fraction for use as aggregate in asphalt. Several cities are salvaging the metal cans from the residue for the copper smelting industry and for use in the manufacture of Rebar. Several studies are now in progress to develop the technology for recovering the glass and metal fractions from incinerator residue. A pilot project by the Bureau of Mines has been relatively successful in developing a system for recovering the glass, ferrous metal, aluminum and other nonferrous metals from the residue. A schematic of this system is presented in Figure 2, and a breakdown of the various products which would be recovered from a 250 ton per day facility is presented below:

QUANTITIES OF THE VARIOUS PRODUCTS RECOVERED FROM THE BUREAU OF MINES' INCINERATOR RESIDUE RECOVERY PROJECT*

Project	Tons/Day
+4 mesh iron	41
-4 mesh iron	35
aluminum	4
copper and zinc	3
colorless glass	69
colored glass	50
waste solids	48

*for a plant processing 250 tons/day

A demonstration facility for residue recovery is scheduled for operation by 1975, at Lowell, Mass. The quality of the products recovered from the residue and the economics of recovery have not been well determined. Preliminary estimates indicate that a plant to process 50 tons per day in an eight hour shift would cost about 2 million dollars and operating costs would be 9 to 11 dollars per ton of residue processed.

The degradation of the metal and glass resulting from the incineration operation may limit the market acceptance of these materials. During incineration the ferrous metal is contaminated by copper and tin and undergoes considerable oxidation. The glass is subjected to slagging and contamination from metal and other minerals. Estimates for the revenue from the products of a ton of residue have varied from $6 to $15. For distant markets, freight rates become a major factor in the economics of the recovery process; and this is further compounded by the higher rates for secondary materials. In the final

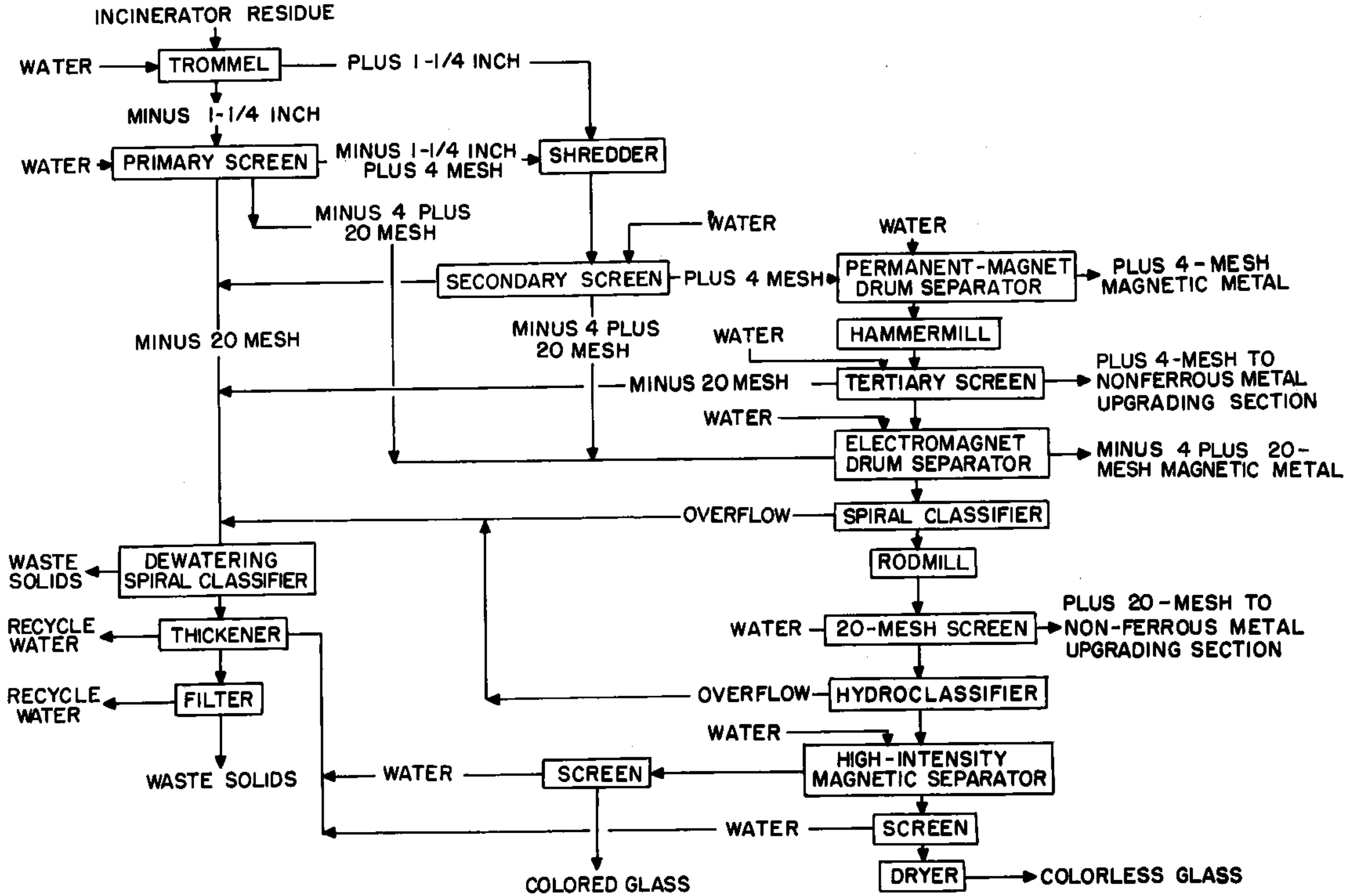


Figure 2. Continuous Incinerator Residue Processing Plant Flowsheet.

analysis, the economic viability for these recovery processes has yet to be firmly established and until an actual unit is in operation, it will not be possible to make a final determination on this matter.

The high cost of incineration, the institution of stricter pollution codes, and the increased need for the conservation of national resources suggests an uncertain future for conventional incineration, as indicated by the reduction in the construction of new facilities. The development of advanced combustion processes for urban refuse would appear to have a more promising potential. The advanced processes under development include: waste heat recovery for steam generation; high temperature incineration; fluidized bed incineration; pyrolysis and hydrogenation of refuse and the processing of refuse for use as a low-sulfur fuel supplement for coal burning furnaces and boilers. The residue from many of these processes will be considerably different from that obtained by conventional incineration. In high temperature incineration, combustion is more complete. All the organics are eliminated and the glass and metal is melted forming a slag, which after quenching is a good aggregrate material. In the fluidized bed process, the refuse is usually shredded and the metal removed prior to combustion. The residue is a powdery inorganic ash. Waste heat recovery for steam generation can be incorporated with conventional incineration as well as with high temperature and fluidized bed incineration. The nature of the residue will be determined by the precombustion processes (metal, glass removal, etc.) and the temperatue of combustion. In the various pyrolysis processes the refuse is shredded and the metal and glass removed prior to the destructive distillation of the organic materials. One ton of refuse will yield from 154 to 230 pounds of char residue by this process. The shredded refuse with the glass and metal removed can also be effectively used as a low-sulfur fuel supplement. The residue from the refuse in this case would be combined with the coal ash and recovered from the pit (bottom ash) and from the air pollution equipment (fly ash). In all of these advanced processes, the residue produced is primarily recovered as ash which can be used as fill in various construction applications. Removal of the glass and metal prior to combustion results in a residue that is easier to utilize and provides metal and glass fractions of higher quality. The economics for the different refuse disposal and recovery processes have been compiled by Midwest Research and are presented next for purposes of comparison. These data were compiled in 1972 and are based on the economic conditions at that time. Although the specific numbers quoted are now out of date the economic ratio between systems is still relatively valid.

SUMMARY OF ECONOMIC ANALYSIS FOR REFUSE DISPOSAL OR RECOVERY SYSTEMS

System	Capital Cost per Daily Ton	Operating Cost per Ton	Revenue per Ton	Net Cost per Ton
1. Incineration*	$ 9,299	$ 7.68	-0-	$7.68
2. Incineration and Steam Recovery*	$11,607	$10.39	$3.34	$7.05
3. Incineration and Residue Recovery*	$10,676	$ 8.96	$1.78	$7.18
4. Incineration, with Steam and Residue Recovery*	$12,784	$11.69	$5.12	$6.57
5. Incineration and Electrical Energy Recovery*	$17,717	$12.97	$4.00	$8.97
6. High Temperature Incineration with Steam Recovery**	$17,000	$ 6.42	$3.01	$3.41
7. Fluidized-Bed Incineration***	$12,000	$10.00	$2.50	$7.50
8. Pyrolysis*	$12,334	$10.95	$5.54	$5.42
9. Fuel Recovery*	$ 7,577	$ 5.77	$3.07	$2.70
10. Sanitary Land Fill Close-In*	$ 2,472	$ 2.57	-0-	$2.57
11. Sanitary Land Fill Remote*	$ 2,817	$ 5.94	-0-	$5.94
12. Composting*	$17,100	$ 9.96	$3.68	$6.28

*Based on municipally-owned 1000 TPD plant with a 20-year economic life operating 300 days per year.

**Based on the American Thermogen system for a plant with 1650 TPD capacity, economic data supplied by American Thermogen.

***Based on a 600 TPD plant.

From the foregoing compilation it is apparent that except for electrical energy generation all of the systems cited have lower net operating cost per ton than incineration. Fuel recovery, sanitary land fill, and high temperature incineration also have lower total operating costs than conventional incineration. However, the total operating cost of $6.42 listed for high temperature incineration would appear low since the operation is similar to conventional incineration and it requires the additions of lime for slagging and supplemental fuel (coal, oil or gas) for achieving the higher temperatures. Similarly, the estimated revenues for the products recovered from the refuse may also be somewhat high. In addition, it can be seen from the data presented that fuel recovery and sanitary land fill facilities require lower capital costs than conventional incineration. The data also show that recovery of metal and glass from the refuse and the use of the organic fraction for a low-sulfur fuel supplement are economically competitive with close-in sanitary land fill, when the facility is processing more than 1000 tons per day. In addition to its good economy, fuel recovery is a more desirable means for solid waste management because it is more consistent with the need for conservation of energy and natural resources and the improvement of the environmental quality of the community.

Conclusions and Recommendations

On a national level, incinerator residue is not a major solid waste as only 4 - $6\frac{1}{2}$ million tons per year are generated by some 193 incinerators. Most of these incinerators are located in the eastern United States, with New York, Massachusetts, Connecticut, Florida, Ohio, and Pennsylvania having the largest numbers. However, for communities with incinerators, there are problems in disposing of the residue. Almost all of the residue is buried; however, because of the potential for ground water pollution due to leaching, better land fill disposal procedures are necessary. Techniques have been developed for recovering the metal and glass from the residue; however, the economics may not be favorable for their implementation.

From this study, it is apparent that conventional incineration is the least desirable means for refuse disposal. The process is expensive and unless very sophisticated equipment is employed, the process contributes to air and water pollution. In addition, incineration is not consistent with the national need for conservation of natural resources. Whenever possible, resource recovery processes, consistent with the needs of the community, should be employed. When incineration is the only viable option for refuse disposal, the feasibility of shredding the refuse and recovering the glass and ferrous metal, prior to incineration, should be investigated. The shredded refuse will burn more completely reducing the leachate in the residue. In addition, the metal and glass recovered will be of higher quality and have higher market value.

It is recommended that the demonstration programs to evaluate the economic and technical viability of recovering useful commodities from incinerator residue be closely monitored. If these programs are successful, efforts to implement them in other communities should be actively pursued.

INCINERATOR RESIDUE CHARACTERIZATION

The incineration of urban refuse results in the generation of a residue derived from the noncombustible constituents of the refuse, and those materials which are not completely burned during incineration. The residue composition will be dictated by the composition of the refuse, the type of incinerator, and the efficiency of the incinerator. In addition to the residue produced and collected from the bottom of the furnace, the incineration process also generates particulate matter which is entrained in the effluent and is termed fly ash. About 25-35 weight percent of the refuse remains as residue when complete burnout is achieved. Incineration of refuse results in a volume reduction of 80 to 98% depending on the particular process employed. About 1 weight percent of the refuse incinerated is entrained in the effluent as fly ash.

Since the incinerator residue and fly ash composition are largely dictated by the refuse composition, the nature of urban refuse should first be evaluated. The average composition of refuse and its description, on an "as discarded" basis, is shown in Table I. The composition of refuse will vary both with seasons of the year and locality as reflected by the differences reported in the published literature. A summary of some of the more recent data compiled by the National Center for Resource Recovery is in Table II. An estimated ultimate analysis for each of the refuse categories is presented in Table III. An estimated proximate analysis and ultimate analysis for refuse is presented in Table IV. It can be anticipated that the refuse composition will be changing with time. A projected analysis of refuse composition and properties from 1968 to 2000 is presented in Table V. The projections indicate that the fraction of glass in refuse will not change significantly in the next 30 years. However, the glass fraction would be significantly reduced if low-cost beverage and food grade, plastic containers are successfully developed. The projections in Table V show a slight drop in the metal fraction of the refuse and an increase in the paper and plastics fractions. The very rapid growth expected for plastics may have some serious effects on incinerator operations (1,2,3).

Projected compositional changes will also alter the physical characteristics of the refuse as shown in Table VI. Projected heating rates (BTU/lb.) are expected to increase as the paper and plastic fractions increase. Increased heating value of the refuse will correspondingly result in a decrease in the incinerator furnace capacity. Similarly, the indicated drop in moisture will result in higher flue gas temperatures with corresponding decrease in effective incinerator capacity.

The average per capita rate for the generation of municipal solid wastes in the United States has been estimated at 3.32 pounds/day for 1971. It has been estimated that in 1968 only 69% of the refuse generated was collected by municipal agencies for disposal, and in 1969 about 76% was collected. The

TABLE I

AVERAGE REFUSE COMPOSITION

AS DISCARDED

Category	Wt %	Description
Glass	10.0	Bottles, jars, crockery, & other ceramic products
Metal	10.1	Cans, Wire, Foil, broken furniture and appliances
Paper	37.8	Newspapers, books, magazines corrugated & other packaging materials
Plastics	3.8	Polyvinyl Chloride, Polyethylene, Styrene, etc. as Found in Packaging, Housewares, Furniture, Toys and Non-woven Synthetics
Leather & Rubber	2.7	Shoes, Tires, Toys, etc.
Textiles	1.6	Cellulosic, Protein, and Woven Synthetics
Wood	3.7	Wooden Packaging, Furniture, Logs, and Twigs
Food Wastes	14.2	Garbage animal & vegetable waste from food preparation
Miscellaneous	1.5	Inorganic Ash, Stones, Dust, Dirt
Yard Wastes	14.6	Grass, Brush, Shrub Trimmings
	100.0	

TABLE II

AVERAGE REFUSE COMPOSITION

Surveys of the Composition of Municipal Solid Waste in the United States

Study	Food	Yard	Misc.	Glass	Metal	Est. Ferrous	Ferrous	Al	Non-Ferrous	Paper	Plastics	Textiles	Wood	Leather Rubber
Oceanside, N. Y.	9.6	33.3		9.7	8.0	7.0				37.8		3.0	1.2	
	10.2	19.0		9.5	8.2	7.2				39.8		3.3	6.6	
Cincinnati, Ohio	28.9	6.4		7.5	8.7	7.7				42.0	1.6	1.4	2.7	
Oceanside, N. Y.	16.7	0.3		11.9	10.6	9.6				53.3		2.2	1.5	
Flint, Mich.	29.1	26.7		12.7	14.5	13.5				13.0		0.3	1.0	
Johnson City, Tenn.	21.1	0.9	0.6	7.0	7.5	6.5				59.8	0.9		0.3	0.6
San Diego, Cal.	0.8	21.1		8.3	7.7	6.7				46.1	0.3	3.5	6.4	4.7
Berkeley, Cal.	12.5	12.5	7.1	11.3	8.7	7.7				44.6	1.9	1.1		0.3
Raleigh, N. C	31.8	8.4		11.9	9.2	8.2				38.9				
Santa Clara Co., Cal.	2.1	34.5	0.5	10.9	7.4	6.4				36.2	1.5	1.3		1.1
Flint, Mich.	35.0	0.3	0.7	23.2	14.5	13.5				21.1		0.8	0.8	
Weber Co., Utah	8.5	4.2	5.9	4.6	8.4	7.4				61.8		2.0	2.2	
Johnson City, Tenn.	34.6	2.3	0.2	9.0	10.4	9.4				34.9	3.4	2.0	0.8	2.4
New Orleans, La.	18.9	9.2		18.2	12.2	11.2				39.4		2.6		
Alexandria, Va.	7.5	9.5	3.4	7.5	8.2	7.2				55.3		3.7	1.7	
Atlanta, Ga.	12.3	1.6	3.4	10.3	8.6	7.6				58.6		1.8	0.4	
	17.5	2.8	3.4	6.5	8.8	7.8				53.2		2.0	3.2	
New Orleans, La.	18.9	9.2	1.5	16.2	12.2	11.2				39.4		2.6		
				13.0			8.8	1.0			3.8			
Tampa, Fla.	9.1	41.5	6.1	6.0			4.8	0.8	0.3	24.1	2.4	2.8	1.5	0.6
Wilmington, Del.	16.5	9.0	2.9	14.7			5.7	0.6	0.3	33.7	3.3	8.9	2.5	1.9
San Diego, Cal.	0.8	21.1		8.3	7.6	6.6				46.2	0.3	3.5	7.5	4.7
Madison, Wisc.	15.3	13.8	6.0	10.1	6.7	5.7				42.4		1.6	1.1	
Purdue. U. of	12.0	12.0	15.4	6.0	8.0	7.0				42.0	0.7	0.6	2.4	0.9
Kaiser, E. R.	8.4	6.9	12.0	7.7	6.9	5.9				53.5	0.8	0.8	2.3	0.8
Little, A. D.	16.6	12.6	1.7	8.5	8.7	7.7				44.2	1.2	2.3	2.5	1.7
Battelle Inst.	14.0	5.0	3.0	9.0			7.5	1.0	0.5	55.0	1.0		4.0	
Averages	14.6	12.5	4.5	10.3	9.2	8.2	6.7	0.9	0.4	42.7	1.7	2.4	2.5	1.8

TABLE III

ESTIMATE FOR ULTIMATE ANALYSIS OF REFUSE CATEGORIES (%) (DRY BASIS) (2)

Category	C	H	O	N	Ash	S	Fe	Al	Cu	Zn	Pb	Sn	P**	Cl⁻	Se	% Fixed Carbon (Dry Basis)	Heating Value (BTU/lb.) (Dry Basis)
Metal	4.5	0.6	4.3	0.06	90.5	0.01	77.3	20.1	2.0		0.02	0.6	0.03	---	---	0.5	740
Paper	45.4	6.1	42.1	0.3	6.0	0.12	----	----	---	---	---	---	---	---	Trace	11.3	7930
Plastics	59.8	8.3	19.0	1.0	11.6	0.3	----	----	---	---	---	---	0.01	6.0	---	5.1	11,500
Leather and Rubber	59.8	8.3	19.0	1.0	11.6	0.3	----	----	---	2.0	---	---	---	---	---	6.4	10,175
Textiles	46.2	6.4	41.8	2.2	3.2	0.2	----	----	---	---	---	---	0.03	---	---	3.9	8030
Wood	48.3	6.0	42.4	0.3	2.9	0.11	----	----	---	---	---	---	0.06	---	---	14.1	8400
Food Wastes	41.7	5.8	27.6	2.8	21.9	0.25	----	----	---	---	---	---	0.24	---	---	5.3	8540
Yard Wastes	49.2	6.5	36.1	2.9	5.0	0.36	----	----	---	---	---	---	0.04	---	---	19.3	7300
Glass	0.52	0.07	0.36	0.03	99.02	---	----	----	---	---	---	---	----	---	---	0.4	65
Miscel.	13.0*	2.0*	12.0*	3.0*	70.0	---	----	----	---	---	---	---	---	---	---	7.5	3500

* Estimated (varies widely)

** Excludes phosphorus in $CaPO_4$

TABLE IV

ESTIMATED PROXIMATE AND ULTIMATE ANALYSIS OF REFUSE [4]

Proximate Analysis	Kaiser, et al. [7]	Kaiser [6]	Golueke [8]	Niessen, et al.* [2]
Moisture	28.0	20.0	-	28.3
Volatile Matter	43.4	52.7	-	50.9
Fixed Carbon	6.6	7.3	-	6.3
Glass, Ash, Metal	22.0	20.0	-	20.8
Ultimate Analysis				
Moisture	28.0	20.0	20.7	28.3
Carbon	25.0	29.8	28.0	25.6
Hydrogen	3.3	4.0	3.5	3.4
Oxygen	21.1	25.7	22.4	21.2
Nitrogen	0.5	0.4	0.3	0.6
Sulfur	0.1	0.1	0.2	0.1
Glass Ceramics, Stones	9.3	-	-	-
Metals	7.2	20.0	24.9	20.8
Ash, Other Inerts	5.5	-	-	-
Heating Value (HHV)	4500	5442	4917	4450
Stoichiometric Air required, lb air/lb refuse	-	3.78	-	3.18

*For 15.5% yard waste

TABLE V

PROJECTED REFUSE COMPOSITIONS (%)*[4]

Refuse Category	1968			1970			1975			1980			1990			2000		
	Seasonal	Semi-Seasonal	Non Seasonal	Seasonal	Semi-Seasonal	Non Seasonal	Seasonal	Semi-Seasonal	Non Seasonal	Seasonal	Semi-Seasonal	Non Seasonal	Seasonal	Semi-Seasonal	Non Seasonal	Seasonal	Semi-Seasonal	Non Seasonal
Glass	8.8	8.1	7.6	9.1	8.4	7.9	9.9	9.2	8.7	10.3	9.6	9.0	9.5	8.9	8.4	8.1	7.6	7.2
Metal	8.7	8.1	7.5	8.3	8.2	7.6	9.0	8.4	7.8	9.4	8.7	8.1	9.0	8.4	7.9	7.4	6.9	6.5
Paper	38.2	35.1	32.6	39.1	35.8	33.5	40.8	37.6	35.2	41.5	38.4	36.1	45.0	41.7	39.3	49.7	46.0	43.5
Plastics	1.1	1.1	1.0	1.3	1.3	1.1	1.9	1.8	1.7	2.8	2.7	2.5	3.5	3.5	3.1	4.2	4.2	3.8
Leather, rubber	1.5	1.4	1.3	1.5	1.4	1.3	1.5	1.4	1.3	1.5	1.4	1.3	1.5	1.4	1.3	1.6	1.5	1.4
Textiles	2.0	1.9	1.8	2.0	1.9	1.8	2.1	2.0	1.9	2.1	2.0	1.9	2.5	2.3	2.2	2.8	2.6	2.5
Wood	2.7	2.4	2.3	2.5	2.3	2.2	2.2	2.0	1.9	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2
Food Wastes	21.1	19.5	18.2	20.2	18.7	17.4	17.9	16.6	15.5	16.2	15.0	14.1	14.0	13.1	12.3	12.1	11.4	10.7
Miscellaneous	1.8	1.7	1.6	1.7	1.6	1.5	1.5	1.4	1.3	1.4	1.3	1.2	1.2	1.1	1.1	1.0	1.0	0.9
Yard Wastes	14.1	20.7	26.1	13.8	20.4	25.7	13.2	19.6	24.7	12.9	19.2	24.1	12.2	18.1	23.0	11.8	17.6	22.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

*Percentages shown are on an "as-discarded" basis.

TABLE VI

PHYSICAL CHARACTERISTICS OF REFUSE (4)

Refuse Properties and Statistics	1968			1970			1975			1980			1990			2000		
	Seasonal	Semi-Seasonal	Non Seasonal	Seasonal	Semi-Seasonal	Non Seasonal	Seasonal	Semi Seasonal	Non Seasonal	Seasonal	Semi-Seasonal	Non Seasonal	Seasonal	Semi-Seasonal	Non Seasonal	Seasonal	Semi-Seasonal	Non Seasonal
Heating value (HHV, Btu/lb)	4582	4505	4449	4628	4550	4493	4719	4640	4582	4811	4730	4627	5040	4956	4849	5407	5271	5161
Percent moisture	25.9	27.8	29.3	25.2	27.1	28.6	23.4	25.3	26.9	22.1	21.0	25.7	20.5	22.4	24.1	19.3	21.3	22.9
Percent volatile carbon	19.8	19.4	19.1	19.9	19.5	19.2	20.4	20.0	19.7	20.8	20.4	20.1	22.0	21.5	21.1	23.6	23.0	22.5
Percent ash content	21.8	20.3	19.1	22.1	20.7	19.5	22.9	21.5	20.3	23.5	22.0	20.3	22.4	21.1	20.0	19.7	18.6	17.7
Percent ash (excluding glass, metals)	5.5	5.3	5.1	5.5	5.2	5.1	5.3	5.1	4.9	5.2	5.0	4.9	5.2	5.0	4.9	5.3	5.2	5.0
Per-capita growth multiplier	1.0	1.0	1.0	1.05	1.05	1.05	1.19	1.18	1.18	1.32	1.32	1.31	1.52	1.51	1.50	1.76	1.74	1.72
National-population-growth multiplier	1.0	1.0	1.0	1.02	1.02	1.02	1.07	1.07	1.07	1.13	1.13	1.13	1.33	1.33	1.33	1.54	1.54	1.54
Total waste-load multiplier	1.0	1.0	1.0	1.07	1.07	1.07	1.27	1.26	1.26	1.49	1.49	1.48	2.02	2.01	2.00	2.71	2.68	2.65
Per-capita heat-rate multiplier (Btu/person/day)	1.0	1.0	1.0	1.06	1.06	1.06	1.23	1.22	1.22	1.39	1.39	1.36	1.67	1.66	1.64	2.08	2.04	2.00
Total heat-rate multiplier (Btu/day)	1.0	1.0	1.0	1.08	1.08	1.08	1.32	1.31	1.31	1.57	1.57	1.54	2.22	2.21	2.18	3.20	3.14	3.08

amount of solid waste collected and categorized as to origin is summarized in Table VII (4).

In 1971, approximately 125 million tons of refuse were generated and it is expected that by 1980 more than 170 million tons of refuse will be generated. The amount of refuse collected will increase due to three major factors: (a) increasing population; (b) improved municipal collection practices; and (c) continued increase in national consumption of manufactured products coupled with a trend toward reduced service life.

It is projected that solid waste generation would have an annual growth rate of 3.5% per year. At the present time, the bulk of the refuse collected is disposed of in land fills. However, approximately 13 percent of the urban refuse collected is disposed of in municipal incinerators (10,11).

The basic components of an incinerator are shown schematically in Figure 1. Incinerators operate on both a continuous and/or a periodic batch basis. Continuous feed incinerators, e.g., the traveling-grate, reciprocating-grate, ram-feed, and rotary-kiln are more commonly used for municipal incineration. Several incinerators in the United States recover the waste heat generated during incineration. The waste heat can be recovered by the use of high and low pressure boilers or with waterwall systems. A summary evaluation, by Niessen, of incinerator concepts based on existing technology is presented in Table VIII (2,4,9,10,11,12,13,14).

From a compilation by Achinger & Baker(1), it was determined that since 1920 about 322 municipal-scale incinerators were built and about 193 of them, having a total daily capacity of 70,667 tons, were reported operational as of May 1972.

A summary of operating municipal incinerators in the United States is presented in Table IX. From these data it would appear that most incinerator facilities are operating at about 70% of rated capacity.(2)

Most of the incinerators are located in the eastern United States, with New York, Massachusetts, Connecticut, Florida, and Ohio having the largest number of incinerators. Since 1964, the number of new incinerators built and the number of incinerators rebuilt or added to has decreased significantly, as shown in Figures 3 and 4. Although total added annual capacity has decreased, the average incinerator plant size has increased and is approaching 400 tons per day. A major factor for decrease in incinerator construction may be the higher costs resulting from the institution of stricter pollution regulations for incinerator operations (2).

The proximate analysis and ultimate analysis for the combustible components is presented in Table X. During incineration, furnace temperature is usually between 1800^{o}F and 2000^{o}F and flame temperature is approximately 2500^{o}F.

TABLE VII

ORIGIN OF SOLID WASTES FOR MUNICIPAL COLLECTION[9]

Source	Pounds/Person/Day
Combined Household & Commercial Refuse	2.64
Demolition & Construction	0.23
Street and Alley	0.19
Miscellaneous	0.09
Tree & Landscaping Refuse	0.02
Park & Beach Refuse	0.01
Catch Basin Refuse	0.14
TOTAL	3.32

TABLE VIII

SUMMARY EVALUATION OF INCINERATION CONCEPTS BASED ON EXISTING TECHNOLOGY (2)

	Criteria of Performance						
	Furnace Emissions						
	Mineral Particulate	Combustible	Reliability	Residue Quality	Safety	Cost	Potential for By-Product Credits
Batch Feed							
Rectangular and cylindrical	4	1	4	2	OK	4	----
Continuous Feed							
Retangular construction	3	3	3	3	OK	3	----
Horizontal-Cylindrical construction	3	3	3	3	OK	3	----
Ignition grate plus burnout grate	2	4	3	4	OK	2	----
Volatilizing kiln and burnout grate construction	3	3	4	4	OK	2	----
3-stage, rotary-kiln construction	2	3	4	4	OK	2	----
Waterwall construction (grate burning)	4	4	5	3	OK	2	YES
Waterwall construction (suspension burning)	2	5	5	4	OK	2	YES
Semi-Continuous Feed							
Package system	3	3	3	3	OK	5	----
Rotary grate	2	3	3	3	OK	4	----
Continuous feed with residue fusion	2	4	3	5	OK	3	----

Range: 1 = high unfavorable; 5= highly favorable

TABLE IX

SUMMARY OF OPERATING MUNICIPAL INCINERATORS - MAY 1972[1]

Region	Number of incinerators	Daily design capacity (tons)	Average tonnage processed	
			Daily (tons)	Yearly (10^6 tons)
National Summary	193	70,667	49,932	16.66
Region I	45	12,518	5,700	2.16
Maine	0	0	0	0
Vermont	0	0	0	0
New Hampshire	3	250	68	0.02
Rhode Island	4	960	560	0.23
Massachusetts	21	5,994	2,410	0.88
Connecticut	17	5,314	2,662	1.03
Region II	50	18,570	14,058	5.00
New York	45	17,240	13,167	4.80
New Jersey	5	1,330	891	0.20
Region III	22	11,012	8,138	2.48
Pennsylvania	11	4,272	3,529	1.14
West Virginia	0	0	0	0
Virginia	6	2,320	1,550	0.44
District of Columbia	1	1,500	1,000	0.26
Maryland	4	2,920	2,059	0.64
Delaware	0	0	0	0
Region IV	23	8,025	6,034	1.98
Kentucky	7	1,525	1,525	0.38
Tennessee	0	0	0	0
Georgia	2	1,100	990	0.32
Florida	14	5,400	3,519	1.28
North Carolina	0	0	0	0
South Carolina	0	0	0	0
Mississippi	0	0	0	0
Alabama	0	0	0	0
Region V	37	15,392	12,279	3.92
Ohio	14	5,050	3,887	1.11
Illinois	8	6,200	6,311	2.15
Indiana	1	450	100	0.03
Michigan	4	1,750	1,180	0.41
Wisconsin	10	1,942	801	0.22
Minnesota	0	0	0	0
Region VI	10	3,450	2,355	0.65
New Mexico	0	0	0	0
Texas	2	1,150	850	0.24
Oklahoma	0	0	0	0
Arkansas	0	0	0	0
Louisiana	8	2,300	1,505	0.41
Region VII	2	800	1,000	0.26
Kansas	0	0	0	0
Nebraska	0	0	0	0
Missouri	2	800	1,000	0.26
Iowa	0	0	0	0
Region VIII	1	300	300	0.06
South Dakota	0	0	0	0
Montana	0	0	0	0
Utah	1	300	300	0.06
Colorado	0	0	0	0
North Dakota	0	0	0	0
Region IX	3	600	600	0.16
Arizona	0	0	0	0
California	0	0	0	0
Hawaii	3	600	600	0.16
Nevada	0	0	0	0
Region X	0	0	0	0
Idaho	0	0	0	0
Washington	0	0	0	0
Oregon	0	0	0	0
Alaska	0	0	0	0

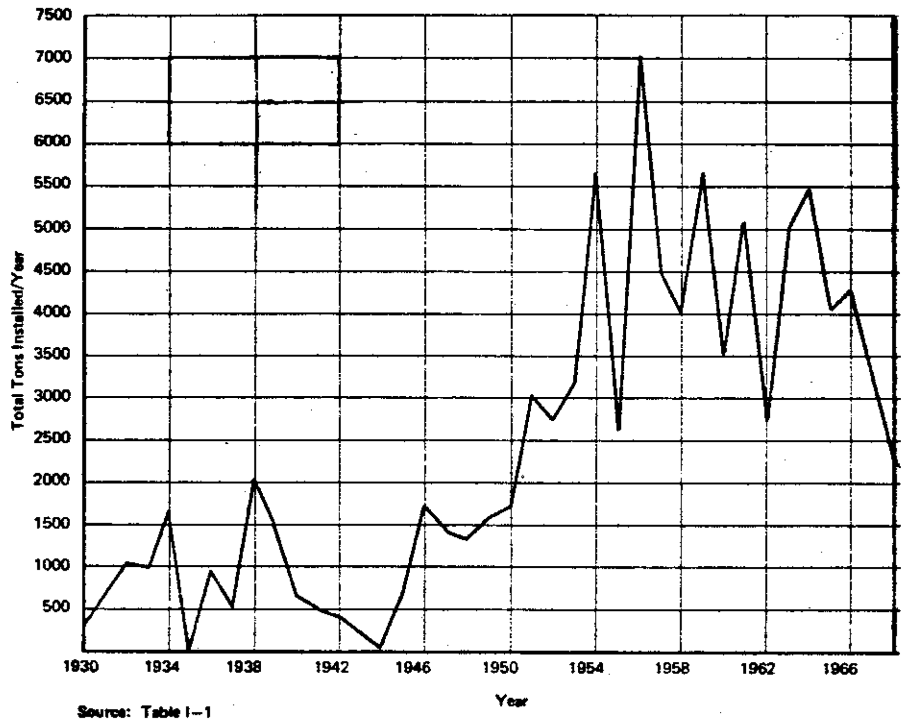


Figure 3. Total Annual Additions to United States Incinerator Capacity (2)

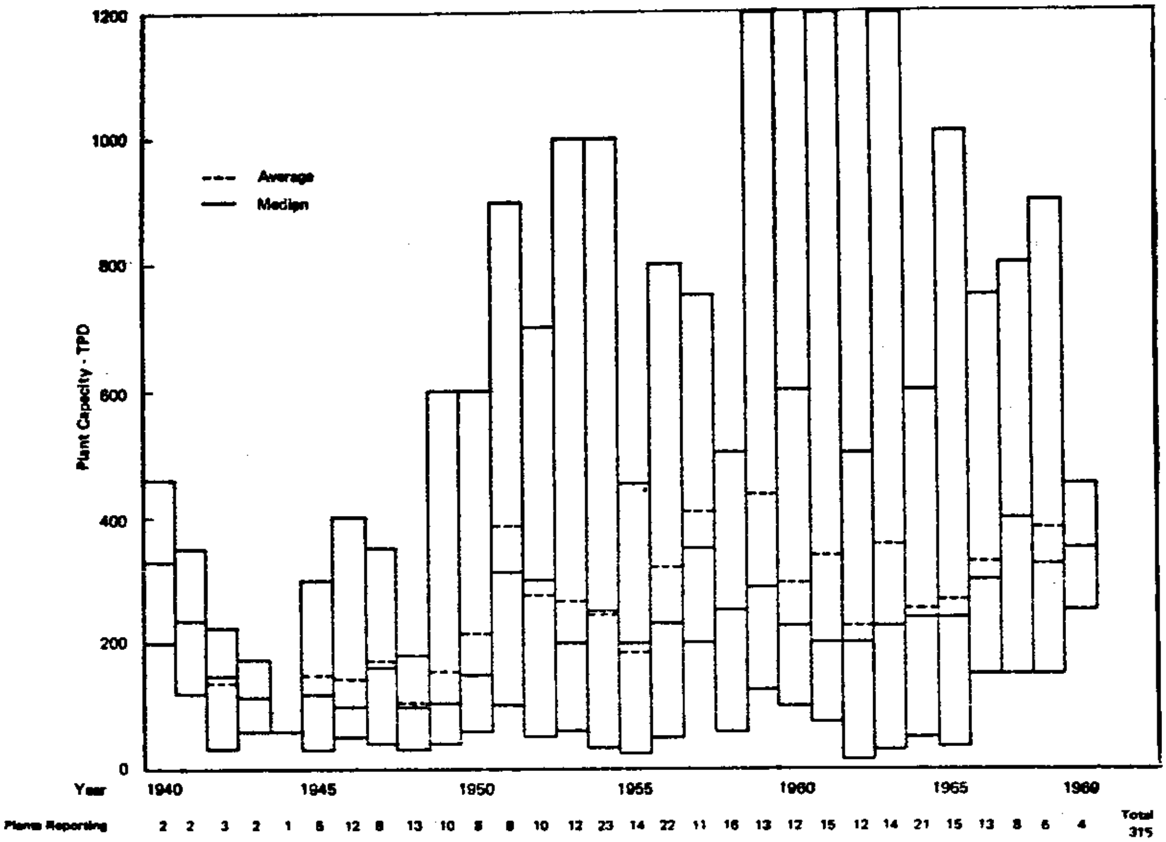


Figure 4. Range of Plant Capacities: New Rebuilt, and Additions (2)

TABLE X[9]

Refuse component	A. Proximate Analysis of Combustible Components of Municipal Refuse as Discarded by Householders (percent by weight): Moisture	Volatile matter	Fixed carbon	Ash	Btu/lb: As discarded	Btu/lb: Dry basis	B. Ultimate Analysis of Combustible Components Of Municipal Refuse, Dry Basis (percent by weight): Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Newspaper	5.97	81.12	11.48	1.43	7,974	8,480	49.14	6.10	43.03	0.05	0.16	1.52
Brown paper	5.83	83.92	9.24	1.01	7,256	7,700	44.90	6.08	47.84	0.00	0.11	1.07
Trade magazine	4.11	66.39	7.03	22.47	5,254	5,480	32.91	4.95	38.55	0.07	0.09	23.43
Corrugated paper boxes	5.20	77.47	12.27	5.06	7,043	7,429	43.73	5.70	44.93	0.09	0.21	5.34
Plastic coated paper	4.71	84.20	8.45	2.64	7,341	7,703	45.30	6.17	45.50	0.18	0.08	2.77
Waxed milk cartons	3.45	90.92	4.46	1.17	11,327	11,732	59.18	9.25	30.13	0.12	0.10	1.22
Paper food cartons	6.11	75.50	11.80	6.50	7,258	7,730	44.74	6.10	41.92	0.15	0.16	6.93
Junk mail	4.56	73.32	9.03	13.09	6,088	6,378	37.87	5.41	42.74	0.17	0.09	13.72
Vegetable food wastes	78.29	17.10	3.55	1.06	1,795	8,270	49.06	6.62	37.55	1.68	0.20	4.89
Citrus rinds and seeds	78.70	16.55	4.01	0.74	1,707	8,015	47.96	5.68	41.67	1.11	0.12	3.46
Meat scraps, cooked	38.74	56.34	1.81	3.11	7,623	12,443	59.59	9.47	24.65	1.02	0.19	5.08
Fried fats	0.00	97.64	2.36	0.00	16,466	16,466	73.14	11.54	14.82	0.43	0.07	0.00
Leather shoe	7.46	57.12	14.26	21.16	7,243	7,826	42.01	5.32	22.83	5.98	1.00	22.86
Heel and sole composition	1.15	67.03	2.08	29.74	10,899	11,026	53.22	7.09	7.76	0.50	1.34	30.09
Vacuum cleaner catch	5.47	55.63	8.51	30.34	6,386	6,756	35.69	4.73	20.08	6.26	1.15	32.09
Evergreen trimmings	69.00	25.18	5.01	0.81	2,708	8,735	48.51	6.54	40.44	1.71	0.19	2.61
Balsam spruce	74.35	20.70	4.13	0.82	2,447	9,541	53.30	6.66	35.17	1.49	0.20	3.18
Flower garden plants	53.94	35.64	8.08	2.34	3,697	8,027	46.65	6.61	40.18	1.21	0.26	5.09
Lawn grass, green	75.24	18.64	4.50	1.62	2,058	8,312	46.18	5.96	36.43	4.46	0.42	6.55
Ripe tree leaves	9.97	66.92	19.29	3.82	7,984	8,869	52.15	6.11	30.34	6.99	0.16	4.25

The resultant residue taken from the quench pit is a wet complex mixture of metal, glass, slag, charred and unburned paper, and ash. The typical range of values obtained for these various residue components is shown in Table XI (9,15,16, 17).

On a national basis from 4 to $6\frac{1}{2}$ million tons of incinerated residue are generated annually, containing about $1\frac{1}{2}$ to 2 million tons of ferrous metal, 100,000 to 200,000 tons of nonferrous metal, and 2 to 3 million tons of glass. A detailed compilation of the inorganic oxides (mineral) and metallic phases resulting from the incineration of municipal refuse is presented in Table XII. A comparison of residue analysis from a rotary-kiln incinerator and a grate-type incinerator is presented in Table XIII. The differences in composition are due to the higher temperatures attained in the rotary-kiln and hence greater burn-out (3,20).

Potential water pollution from residue buried in land fill sites is of concern since from 1 to 6% of the residue for a batch and continuous feed incinerator is presented in Table XIV. Process water from incineration is also of concern since both the quench water and the scrubber water come into contact with the residue and fly ash and pick up pollutants. An analysis of the scrubber water for a batch-feed incinerator is presented in Table XV and an estimate of the total waste water discharges from U.S. municipal incinerators is presented in Table XVI (7,9,17,21,22,23,24,25,26).

The exhaust gases leaving the furnace chamber contain not only the products of combustion but also considerable particulate matter and other gasous components released during refuse burning. A compilation of the typical emissions from the furnace chamber and from the stack is presented in Table XVII. Projected annual emissions estimated for U.S. municipal incinerator systems from 1968 to the year 2000 are presented in Figure 5. An estimate of air pollution from U.S. municipal incinerators in 1972 is presented in Table XVIII.

The particulate matter retained by the air pollution control unit (the fly ash) is one of the fractions from incinerator emissions of interest. The particulate matter retained, which is primarily less than 200μ in size, consists of wood and paper ash, aluminum foil, carbon particles, metal pins and wires, glass and iron scale. A general analysis of the inorganic components found in fly ash is presented in Table XIX. A comprehensive elemental analysis for eight different municipal incinerator fly ashes is presented in Table XX and the screen analysis for these fly ashes is presented in Table XXI (27,28) It has also been reported that small amounts of cadmium, lead and mercury have been found in fly ash samples. (1)

The future of municipal incineration is somewhat uncertain at the present time. Although the projected quantity of urban refuse generated is expected to increase and the availability of land fill sites around urban areas is rapidly decreasing, the high cost of incineration, the extensive maintenance.

(Text continues on Page 35)

TABLE XI

RESIDUE COMPOSITION [9]
(PERCENT)

Material	Range
Metals	19 to 30
Glass	9 to 44
Ceramics, Stones	1 to 5
Clinkers	17 to 24
Ash*	14 to 16
Organic	1.5 to 9

*Exclusive of other materials listed

TABLE XII

MINERAL RESIDUE FROM INCINERATION OF MUNICIPAL REFUSE [20]
(POUNDS/TON OF REFUSE)

	Corrug. Boxboard	Newspaper and Wood	Misc. Paper	Textiles	Plastics etc.	Food Waste	Grass Dirt	Inorganics from Organic Wastes Total	Metal With Partial Oxidation	Glass Ceramics Stones	Total Metal and Minerals	less Fly Ash	= Metal and Mineral in Grate Residue
P_2O_5	0.01	---	0.12	tr	0.01	0.33	1.47	1.94		0.18	2.12	----	2.12
SiO_2	1.44	2.30	14.50	0.70	2.73	7.17	39.80	68.64		142.29	210.93	9.40	201.53
TiO_2	0.22	0.06	2.60	0.16	0.74	0.12	1.18	5.08		tr	5.08	0.24	4.84
Al_2O_3	0.21	0.80	2.10	0.10	0.50	0.52	4.51	8.74	0.90	9.55	19.19	4.68	14.51
Al									8.95		8.95	----	8.95
MgO	0.29	0.30	2.68	0.17	0.71	1.40	4.91	10.46		15.68	26.14	0.46	25.68
ZnO	0.01	----	0.12	tr	0.15	0.04	0.35	0.67	0.18	0.06	0.91	tr	0.91
Zn									1.79		1.79	----	1.79
CuO									0.10		0.10	tr	0.10
Cu									0.50		0.50	----	0.50
FeO	0.12	0.46	0.97	0.06	0.17	0.36	1.09	3.23	33.00	0.18	36.41	1.28	35.13
Fe									133.58		133.58	----	133.58
MnO		0.11						0.11			0.11	tr	0.11
CaO	0.54	1.82	3.51	0.43	2.51	3.08	8.31	20.20		18.00	38.20	1.76	36.44
BaO	0.01	----	0.01	tr	tr	0.01	0.24	0.27		0.14	0.41	tr	0.41
Na_2O	0.10	0.60	1.77	0.07	0.33	0.61	1.35	4.83		4.02	8.85	0.76	8.09
K_2O	0.01	0.15	1.29	0.09	0.08	0.58	0.73	2.93		0.10	3.03	0.62	2.41
Other	0.04	0.60	0.33	0.02	0.07	0.18	0.66	1.90		1.80	3.70	0.80	2.90
	3.00	7.20	30.00	1.80	8.00	14.00	64.60	129.00	179.00	192.00	500.00	20.00	480.00

TABLE XIII

COMPOSITION OF ROTARY-KILN INCINERATOR RESIDUES

Component	Average % *
Fines minus 8-mesh (ash, slag, glass) **	35.8
Glass and slag, plus 8-mesh ***	21.2
Shredded tin cans	19.3
Mill scale and small iron	10.7
Nonmetallics from shredded tin cans	6.5
Charcoal	3.4
Massive iron	1.9
Iron wire	0.5
Ceramics	0.2
Handpicked nonferrous metals	0.1
TOTAL	99.6

COMPOSITION OF GRATE-TYPE INCINERATOR RESIDUES

Component	Average % *
Glass	44.1
Tin cans	17.2
Mill scale and small iron	6.8
Iron wire	0.7
Massive iron	3.5
Nonferrous metals	1.4
Stone and bricks	1.3
Ceramics	0.9
Unburned paper and chemical	8.3
Partially burned organics	0.7
Ash	15.4
TOTAL	100.3

*Dry weight basis

**Of the total weight of this fraction 1.8% is recoverable nonferrous metal.

***Of the total weight of this fraction 1.4% is recoverable nonferrous metal.

TABLE XIV

AVERAGE ANALYSIS OF WATER-SOLUBLE

PORTION OF RESIDUE[9]
(percent by dry weight of sample)

	Batch-feed incinerator	Continuous-feed incinerator
Hydrocarbon concentration	6.17	9.17
Alkalinity	0.12	0.19
Nitrate nitrogen x 10^{-4}	4.01	3.48
Phosphate x 10^{-4}	2.75	4.42
Chloride	0.12	0.08
Sulfate	0.08	0.24
Sodium	0.047	0.20
Potassium	0.04	0.045
Iron	0.01	0.012

TABLE XV

ANALYSIS OF SCRUBBER WATER

FOR A

BATCH-FEED INCINERATOR [9]

Chemical constituent	Raw water	Scrubber effluent	Contribution from incineration
Iron (Fe) (mg/l)	0.35	2.00	1.65
Barium (Ba) (mg/l)	0.0	5.0	5.0
Cyanide (CN) (mg/l)	0.210	5.4	5.19
Chromium (Cr) (mg/l)	0.0	0.13	0.13
Lead (Pb) (mg/l)	0.0	1.30	1.30
Phenols (mg/l)	0.005	1.73	1.72
Copper (Cu) (mg/l)	0.08	0.18	0.10
Zinc (Zn) (mg/l)	0.0	2.40	2.40
Manganese (Mn) (mg/l)	0.0	0.30	0.30
Aluminum (Al) (mg/l)	0.18	20.80	20.62

TABLE XVI[1]

ESTIMATE OF WASTEWATER DISCHARGES FROM MUNICIPAL-SCALE INCINERATORS - 1972*

Region	Solid waste processed (10^6 tons)	Water used (10^9 gal)	Suspended solids (tons)	Dissolved solids (tons)	Chlorides as Cl (tons)	Sulfates as SO_4 (tons)	Phosphates as PO_4 (tons)
I	2.16	4.10	3,600	20,300	7,800	6,700	240
II	5.00	9.50	8,300	47,100	18,000	15,400	550
III	2.48	4.71	4,100	23,300	8,900	7,700	270
IV	1.98	3.76	3,300	18,700	7,100	6,100	220
V	3.92	7.45	6,500	37,000	14,100	12,100	430
VI	0.65	1.24	1,100	6,200	2,400	2,000	70
VII	0.26	0.49	400	2,400	930	800	30
VIII	0.06	0.11	100	600	210	180	10
IX	0.16	0.30	300	1,490	570	490	20
X	None						
Total	16.67	30.86	27,700	170,500	60,010	51,470	1,840

* Calculated using emission factors, quantities of solid waste processed, and quantity of water used. Emission factors and quantities of water used are based on assumptions indicated in text.

TABLE XVII

TYPICAL EMISSION FACTORS FOR U.S. INCINERATORS ACTIVE IN 1968[2]

Pollutant	Furnace Emission Factor (lb/ton of refuse)	Stack Emission Factor (lb/ton of refuse)
1. Mineral Particulate	15.1	9.5
2. Combustible Particulate	4.6	4.1
3. Total Particulate	19.7	13.6
4. Carbon Monoxide	34.8	34.8
5. Nitrogen Oxides (as NO_2)	3.0	2.6
6. Hydrocarbons	2.7	2.7
7. Sulfur Oxides (as SO_2)	3.9	3.9
8. Hydrogen Chloride	1.0	0.8
9. Polynuclear Hydrocarbons	5.0×10^{-3}	3.2×10^{-3}
10. Volatile Metals (lead)	0.03	0.03

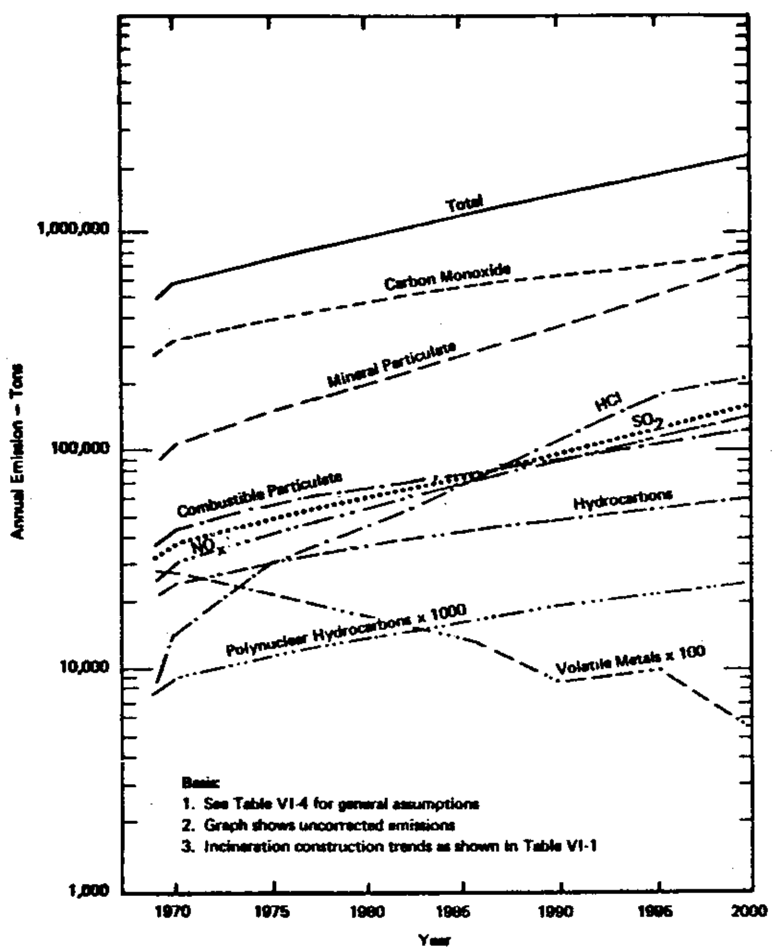


Figure 5. Total Annual Furnace Emission Estimates For U.S. Municipal Incineration Systems (2)

TABLE XVIII [1]

ESTIMATE OF AIR POLLUTION EMISSIONS FROM MUNICIPAL-SCALE INCINERATORS, 1972*

Region	Solid Waste Processed	Pollutant						Total
		Particulate	SOx	HC	NOx	HCl	CO	
I	2,160,000	18,500	1,600	1,600	2,100	6,300	36,800	66,900
II	5,000,000	45,800	3,800	3,800	5,000	15,000	87,500	160,900
III	2,480,000	19,800	1,900	1,900	2,500	7,500	43,400	77,000
IV	1,980,000	12,000	1,500	1,500	2,000	6,000	34,700	57,700
V	3,920,000	24,100	3,000	3,000	4,000	11,900	69,500	115,500
VI	650,000	3,700	500	500	700	2,000	11,400	18,800
VII	260,000	1,800	200	200	260	800	4,600	7,860
VIII	60,000	500	50	50	60	200	1,100	1,960
IX	160,000	1,100	120	120	160	500	2,700	4,700
X	None							
Total	16,670,000	127,300	12,670	12,670	16,780	50,200	291,700	511,320 -50,200 HCl** 461,120

* Calculated using emission factors and quantities of solid waste processed.
** Subtracted so that these data can be compared to the data in Table 3.

TABLE XIX

OXIDE ANALYSIS OF INCINERATOR FLY ASH [27]

Component	Computed for Typical Refuse	NYC Incinerators	
		73rd St.	So. Shore
SiO_2	53.0	46.4	55.1
Al_2O_3	8.2	28.2	20.5
Fe_2O_3	2.6	7.1	6.0
CaO	14.8	10.6	7.8
MgO	9.3	2.9	1.9
Na_2O	4.3	3.0	7.0
K_2O	3.5	2.3	-----
TiO_2	4.2	3.0	-----
SO_3	0.1	2.7	2.3
P_2O_5	1.5	----	-----
ZnO	0.4	----	-----
BaO	0.1	----	----
	100.0		

TABLE XX

ELEMENTAL HEAD SAMPLE ANALYSES OF MUNICIPAL INCINERATOR FLYASHES (% by weight) (28)

Sample	Ag %	Al %	Ba %	C %	Ca %	Cu %	Cr %	Fe %	K %	Mg %	Mn %
F-1	0.02	11.63	0.11	5.16	5.23	0.08	0.11	3.22	1.66	0.99	0.40
F-2	0.01	11.03	0.09	0.68	6.09	0.13	0.06	3.21	1.76	0.94	0.11
F-3	0.07	13.31	0.23	0.42	4.25	0.06	0.05	2.05	1.12	0.99	0.07
$F\text{-}4_1$	0.01	11.51	0.11	11.18	4.16	0.05	0.06	2.11	1.92	0.92	0.15
$F\text{-}4_2$	0.01	8.68	0.16	0.89	6.89	0.08	0.05	4.08	1.83	1.01	0.18
F-5	0.02	13.20	0.16	1.50	6.44	0.09	0.09	1.53	1.62	1.06	0.13
F-6	0.01	9.02	0.12	0.55	7.92	0.05	0.06	4.52	1.86	1.19	0.15
F-7	0.01	10.46	0.14	3.75	7.82	0.09	0.07	2.67	1.44	0.76	0.14
$F\text{-}8_1$	0.01	11.87	0.10	0.78	5.11	0.14	0.06	2.38	1.88	0.98	0.09
$F\text{-}8_2$	0.02	13.85	0.11	0.79	5.15	0.06	0.06	1.40	1.85	0.96	0.06

Sample	Na %	Ni %	P %	Pb %	S %	Si %	Sn %	Ti %	Zn %	Au %
F-1	1.93	0.04	0.76	0.50	0.47	17.98	0.18	1.54	0.74	0.01
F-2	2.28	0.03	0.63	0.40	0.40	22.88	0.14	1.13	0.60	0.01
F-3	1.55	0.03	0.60	0.26	0.51	20.57	0.13	1.88	1.50	0.01
$F\text{-}4_1$	1.09	0.02	0.63	0.38	0.32	18.03	0.18	1.41	0.63	0.01
$F\text{-}4_2$	2.30	0.02	0.46	0.25	0.97	21.89	0.21	1.20	0.80	0.01
F-5	2.33	0.01	0.29	0.51	0.93	17.83	0.16	1.83	0.70	0.01
F-6	2.28	0.02	0.37	0.36	0.99	20.17	0.12	1.02	0.79	0.01
F-7	1.66	0.01	0.63	1.84	3.18	12.84	0.45	1.11	1.65	0.01
$F\text{-}8_1$	1.68	0.01	0.41	0.48	0.76	19.45	0.22	0.17	0.64	0.01
$F\text{-}8_2$	1.81	0.01	0.48	0.35	0.46	17.64	0.09	2.25	0.62	0.01

TABLE XXI

SCREEN SIZE SEPARATION OF INCINERATOR FLYASHES[28]

Type Fly ash	+20 Wt. %	20 x 40 Wt. %	40 x 60 Wt. %	60 x 100 Wt. %	100 x 200 Wt. %	200 x 325 Wt. %	-325 Wt. %	Total Wt. %
F-1	5.3	6.8	11.9	18.7	23.4	14.6	19.3	100.0
F-2	12.0	17.2	19.4	21.1	15.8	9.3	5.2	100.0
F-3	5.6	12.5	18.1	22.9	19.9	9.0	12.0	100.0
$F\text{-}4_1$	4.9	8.3	12.5	12.8	24.4	12.8	24.3	100.0
$F\text{-}4_2$	9.8	21.4	21.5	19.2	13.7	6.6	7.8	100.0
F-5	1.8	4.8	10.2	17.5	37.8	19.0	8.9	100.0
F-6	6.4	8.9	16.7	21.8	23.2	10.2	12.8	100.0
F-7	12.2	10.4	9.7	12.6	16.6	24.5	14.5	100.0
$F\text{-}8_1$	7.9	14.3	20.6	22.1	20.0	9.6	5.5	100.0
$F\text{-}8_2$	4.0	9.9	17.6	20.8	16.7	9.9	21.1	100.0

and the institution of pollution regulations severely limit the potential for conventional municipal incineration. Daily operating costs vary from $5 to $20 per ton of refuse incinerated versus $2 to $6 per ton for disposal at a sanitary land fill. This price differential permits the hauling of refuse to distant land fills, before incineration becomes competitive. Although conventional municipal incinerators do not appear to be the wave of the future, it does appear that the use of special incinerators for industrial wastes and the development of advanced combustion processes for urban refuse have potential.

A number of processes have been developed for recovering the thermal energy available from solid waste. Depending on their composition and morphology, municipal solid wastes will have between 4000 and 9000 BTU/lb. The utilization of solid waste as a fuel has been the most effective means to date for recovering this thermal energy. Municipal solid waste can be processed into many different fuel forms and used in a variety of furnaces. The refuse can be used "as-received" or processed into a solid fuel, a liquid fuel or a fuel gas. In most cases, the fuel produced is used for steam generation; however, this fuel can be used in industrial furnaces as well. The most commonly used process for the recovery of the thermal energy in municipal solid waste is steam generation by incineration of the refuse "as-received". These steam raising municipal incinerators are quite common in Europe, Japan, and Canada, and have been used to a limited extent in the United States.

The "as-received" refuse can be further processed to produce an upgraded fuel for use in boilers and industrial furnaces. The refuse can be shredded and most of the noncombustibles can be removed. The refuse can also be dried to improve the heating value and ease of handling. Combustion Equipment Associates (CEA) and Raytheon have reported the development of processes for removing most of the inert fillers from the wastes and commutation of the wastes to a fine powder. Liquid fuels can be produced from the refuse by pyrolysis, hydrogenation or a combination of these processes. The liquid fuel is usually compared to a heavy fuel oil. Gasification can be accomplished by a number of thermochemical and anaerobic digestive processes (38).

Although the refuse represents an energy source at a time when energy is in high demand, there are a number of problems associated with its use. The major problem is the day to day (if not minute to minute) variation of the waste composition. Moisture content will fluctuate from 15 to 50 weight percent of the refuse, greatly affecting the BTU content and the processibility of the material. Yard waste with its seasonal fluctuations is also a problem. Compared with other fuels, the fuels from wastes are more difficult to transport, store, and process and they have very low energy densities. Even when shredded refuse is briquetted its energy density is only 1/4 that of coal. Most of the waste fuels are in a dilute or partly oxidized form and as a result have relatively low energy levels and produce lower maximum flame temperatures. The lower flame temperatures result in lower heat transfer rates and increased total gas volumes. The greater gas volumes necessitate larger combustion zones.

Two other problems associated with the use of waste fuels are the ash generation and corrosion. High temperature liquid phase corrosion (above 900°F) and low temperature dew point corrosion are the two main problems reported from the use of waste fuels. Corrosion due to localized reduction has also been reported. Although the low-alloy steels are more susceptible to the corrosion by the alkalies and chlorides in the refuse, the stainless alloys are also severely attacked at the higher temperatures (42). Most of the waste derived solid fuels have relatively high ash content (approximately 20 weight percent on a BTU replacement basis) and have to be fired in furnaces with ash handling systems. However, CEA reports only 2% ash (by weight) in its new "Eco Fuel II". Higher ash content will increase the soot blowing and air pollution control equipment requirements. Also the ash builds up on the boiler tubes, and will reduce heat transfer rates and limit operating capacities. However, the ash may have a synergistic effect and reduce the sulfur emissions and some of the corrosion.

Because of these problems with waste fuels and the associated economic considerations, it would appear that using the refuse as a supplemental fuel may be more desirable then using it as the primary fuel in boiler units. The solid waste fuel can effectively be used as a 10 to 35% BTU replacement for coal and the compositional variations, corrosion, and ash handling problems would be minimized. It should also be noted that the average community only produces about 25 to 30% of the BTU requirements of the local electrical generating system.

Some of the more advanced combustion processes for recovering the thermal energy from refuse under development include: a) pyrolysis and hydrogenation of refuse, b) high temperature incineration, c) fluidized-bed incineration, and d) direct use of refuse as a fuel supplement for steam generation.

A number of current pilot and advanced development projects are directed toward the pyrolysis of urban refuse from which the metal and glass fractions have been previously removed. By this process of destructive distillation gaseous hydrocarbons, oils, tars, alcohols, and carbon-rich chars are produced. A schematic arrangement of the refuse pyrolysis process is shown in Figure 6. One ton of refuse will yield 154 to 230 lbs. of char residue, 1/2 to 5 gallons tar and pitch, $1\frac{1}{2}$ to 2 gallons light oil, 18 to 25 lbs. of ammonium sulfate, 80 to 133 gallons liquor and 1,000 to 17,000 cu. ft. of gas. A more detailed analysis of the yield from the pyrolysis of municipal and industrial refuse is presented in Table XXII. (2,29,30,31,32,33,41)

High temperature incineration (above 2500°F) is another advanced combustion process receiving considerable attention. With high temperature incineration, more complete combustion occurs, resulting in the elimination

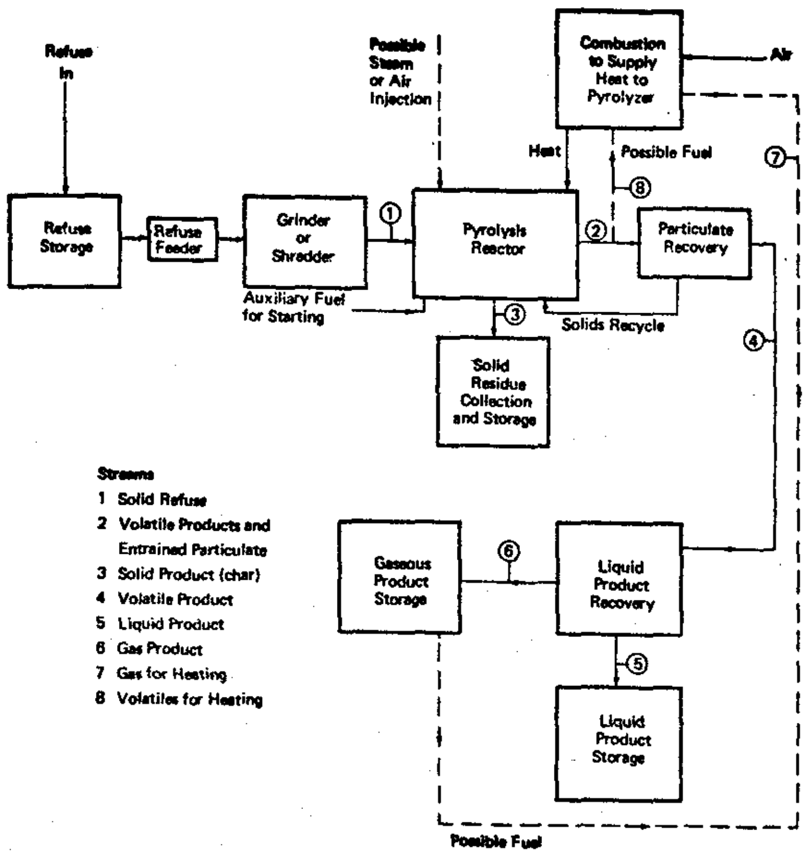


Figure 6. Schematic Arrangement of Refuse Pyrolysis Process. (2)

TABLE XXII

YIELD OF PRODUCTIONS FROM PYROLYSIS OF MUNICIPAL AND INDUSTRIAL REFUSE [29]

Refuse	Pyrolysis Temp. °C	Yield, weight-percent of refuse							Yields per ton of refuse				
		Residue	Gas	Tar	Oil in Gas	ammo-nia	Liquor	Total	Gas Cubic Feet	Tar Gal-lons	Light oil in Gas gallons	Liquor gallons	Ammunium Sulfate, pounds
Raw municipal	500-900	9.3	26.7	2.2	0.5	0.05	55.8	94.6	11,509	4.8	1.5	133.4	17.9
	750	11.5	23.7	1.2	0.9	0.03	55.0	92.3	9,628	2.6	2.5	131.6	23.7
	900	7.7	39.5	0.2	---	0.03	47.8	95.2	17,741	0.5	---	113.9	25.1
Processed municipal containing plastic film	500-900	21.2	27.7	2.3	1.3	0.05	40.6	93.2	11,545	5.6	3.7	96.7	16.2
	750	19.5	18.3	1.0	0.9	0.02	51.5	91.2	7,380	2.2	2.6	122.6	28.4
	900	19.1	40.1	0.6	0.2	0.04	35.3	95.3	18,058	1.4	0.6	97.4	31.5
Heil mill industrial	500-900	36.1	23.7	1.9	0.5	0.05	31 6	93.9	9,563	4.1	1.4	75.2	12.5
	750	37.5	22.8	0.7	0.9	0.03	30.6	92.5	9,760	1.5	2.6	73.0	19.5
	900	38.8	29.4	0.2	0.6	0.04	21.8	90.8	12,318	0.5	1.6	51.1	21.7
Gondard mill industrial	500-900	41.9	21.8	0.8	0.6	0.03	29.5	94.6	9,270	1.7	1.6	70.2	20.4
	750	31.4	25.5	0.8	0.8	0.03	31.5	90.0	10,952	1.8	2.2	74.9	21.2
	900	30.9	31.5	0.1	0.5	0.03	29.0	92.0	14,065	0.02	1.4	68.5	22.9

of all organic phases and increased volume reduction of the slag-like residue (up to 98% volume reduction of the refuse). The residue can be used for soil or road stabilization with little danger of ground water pollution. At the higher incineration temperatures (>300°F) phase separation between the metal and glass components has been reported. Phase separation would significantly increase the recovery potential of the slag consituents. A classification of the various high temperature incinerators is presented in Table XXIII. A compilation of the slag analyses for the different high temperature incinerators is presented in Table XXIV (2,34,35,42).

Although fluidized-bed furnaces have been used extensively for a number of industrial processes, they are now being tested for refuse incineration. The process offers a number of advantages, however, the projected per ton cost is reported to be higher than conventional incineration (10).

Heat recovery incineration is the most commonly employed method for directly utilizing the thermal energy from waste products. European countries have pioneered in heat recovery from incineration of municipal solid waste (MSW) and European engineers have led in the development of the refuse-fired boiler plant utilizing waterwall furnaces. While demonstrated to be highly successful in many installations in Europe, one difficulty has been boiler-tube corrosion due to sulfates or chlorides on the fire side of the tubes. This attack has appeared to be a function of steam, increasing as temperatures increase above 1000°F.

European technology has been utilized in the design of incinerators recently installed in the United States (Norfolk Naval Base, 1967; Braintree, Massachusetts, 1971; Chicago, Illinois, 1971; Harrisburg, Pennsylvania, 1973).

A variety of furnace designs have been developed for burning refuse. Most of the units are designed for mass burning the raw refuse and no special refuse processing is required. The refuse is conveyed through the furnace by some type of stoker system, which also agitates the bed permitting more complete combustion. Air is introduced from both under the stoker and over the refuse. The residue from combustion is normally carried by the stoker to a water quench.

The most efficient steam generation has been in water wall boilers operating with low excess air on a continuous basis. In general, to achieve satisfactory heat generation, it has been necessary to provide auxiliary fuel to maintain constant generation because of the varying moisture content and the varying composition of refuse. A major economic advantage has been the volume effect of the extraction of heat from exhaust gases in the furnace and the use of less excess air because of the completely water-cooled furnace.

The opportunities for marketing steam generated in heat recovery incinerators appear to be limited because: a) the incinerator/steam generator must be located continguous to the steam consumer; b)the steam generation and use patterns must coincide or the steam supplied by the incineration of MSW

TABLE XXIII

CLASSIFICATION OF HIGH TEMPERATURE INCINERATORS (42)

Function	Type	Examples
Heating System	1. Over draft	Melt-Zit Dravo
	2. Under draft	Torrax
	3. Side fired	Ferro-Tech
	4. Cyclone fired	Hartford
Feed Systems	1. Direct change	Melt-Zit Torrax
	2. Shredder	Hartford Dravo
	3. Conventional incinerator grates	Ferro-Tech
Combustion System	1. Self combustion	Melt-Zit Ferro-Tech
	2. Coke combustion	Melt-Zit Ferro-Tech
	3. Auxiliary heating	Torrax (silicon carbide tubes)
Incinerator Output	1. Granulated product	Melt-Zit Dravo Torrax
	2. Molten separation	Ferro-Tech
	3. Pre-incineration separation	Hartford (magnetic sep)

TABLE XXIV

CHEMICAL ANALYSES CITED FOR SLAGS FROM HIGH TEMPERATURE INCINERATION (2)

	Eggen & Powell	Melt-Zit	Ferro-Tech
SiO_2	61.9%	62.4	60
Al_2O_3	13.6	7.6	8
Fe_2O_3	3.7	FeO 5.2	4
TiO_2	-----	0.7	---
CaO	6.6	14.2	17
MgO	2.0	3.3	5
BaO	0.2	----	---
ZnO	1.7	----	---
PbO	0.5	----	---
CuO	0.4	----	---
MnO	----	0.2	1
$Na_2O + K_2O$	9.4	3.8	3
SO_3	----	----	---
P_2O_5	----	0.7	---
Other	----	1.9	2
	100.0%	100.0%	100.0%

must be a small fraction of the total steam requirements; and e) reliance on a single consumer or a small group of closely located consumers would be necessary.

Several pilot studies using refuse as a supplemental fuel with coal or oil in boilers have also been initiated. The most extensive of these has been at the Union Electric Company of St. Louis where a 125 MW pulverized coal firing unit has been modified to fire shredded refuse supplied by the city.

The city refuse processing facility, developed through an EPA demonstration grant program, shreds the refuse to minus $1\frac{1}{2}$ inch size and air classifies the refuse into a combustible fraction and a heavies fraction containing the metal, glass, rocks, heavy plastics, and rubber. The combustible fraction is trucked to Union Electric for use as a fuel supplement replacing up to 20% of the coal on a BTU basis. Ferrous metal is separated from the heavies for use as blast furnace charge and the residue is landfilled.

A schematic for this process is shown in Figure 7. At Commonwealth Edison of Chicago, bags of shredded refuse, with the ferrous metal removed, were manually fed into a cyclone unit at 10% BTU replacement rate with very encouraging results. At the General Motors Corporation plant in Pontiac, Michigan, a spreader stoker unit has been built with two separate air-swept chute feeders, using bark burners, for firing shredded refuse and coal simultaneously. Cubetted, shredded refuse has been used as a supplemental fuel in an underfed stoker-fired boiler at the Fort Wayne Municipal electric plant.

At Fort Wayne, the cubettes were prepared with an alfalfa cubetting machine. Although preliminary results were very encouraging, there are still questions to be resolved regarding the stability of these cubettes when subjected to coal handling processes (bin storage, conveying, etc.). Storage of cubettes would require extra facilities since the cubettes are half the density of coal and replace half the BTU content of an equivalent weight of coal.

In East Bridgewater, Massachusetts, Combustion Equipment Associates, Inc. is operating a recycling plant to produce fuel from shredded refuse. MSW is delivered directly to a receiving floor. Front-end loaders transport the waste to a conveying system feeding the primary shredder. After shredding, the material is sent to a dryer where the moisture content is reduced in order to facilitate processing and to provide a uniform moisture content. The solid refuse is then sent to a horizontal air classifier where the light combustible fraction is separated from the heavies fraction containing ferrous and non-ferrous metals, glass, heavy plastics, rubber, and miscellaneous dirt. The light fraction is reduced further in size and fed to a mechanical separator to remove most remaining fine noncombustibles. The fuel product can be stored for weeks without decay or odor and can be reclaimed readily from storage. The heavy fraction is further shredded and classified to separate

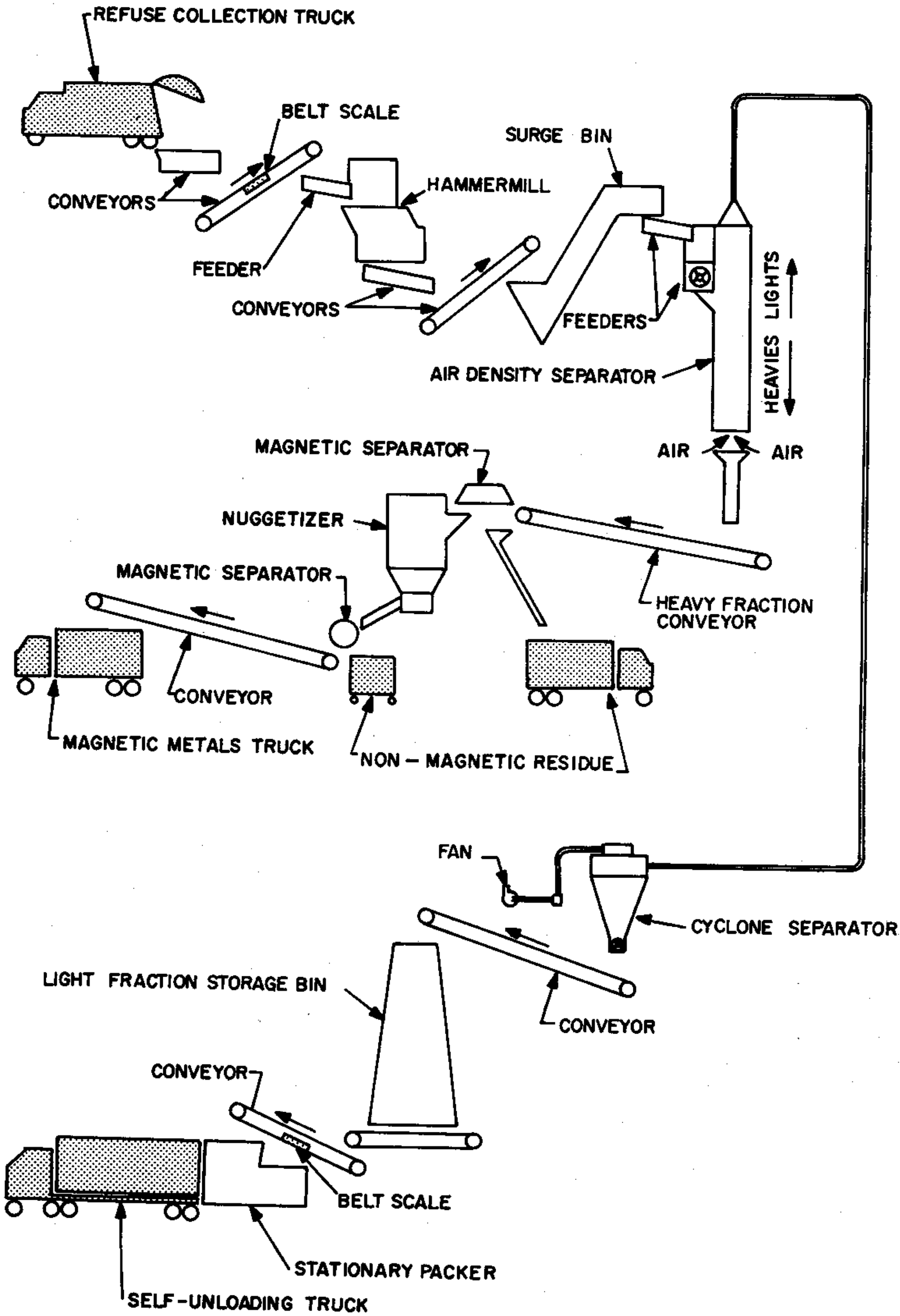


Figure 7. Solid Waste Processing Facilities.

any remaining combustibles which are recycled to the first air separator. The heavies are then combined with non-combustibles rejected from the mechanical separator and fed to a magnetic separator for recovery of the ferrous metals and the residue is discarded to land fill (38).

Hempstead Resource Recovery Corp., utilizing equipment developed by The Black Clawson Co., a sister subsidiary of Parsons & Whittemore Inc., plans on using the Kinney system for the 2,000 TPD,$44.6 million resource recovery plant to be built in Hempstead, L. I. The wet portion of the system has been developed in the Black Clawson Solid Waste Disposal Plant in Franklin, Ohio. The Kinney system utilizes a hydrapulper to convert all pulpable materials to an aqueous slurry. Nonpulpable materials are ejected continuously from the hydrapulper, conveyed to a drum washer and thence to a magnetic separator where ferrous metal is recovered. Following removal of nonfibrous materials in a liquid cyclone, the pulped slurry is dewatered and compressed into a cake with 50% solids content. The discharged cake is broken into small lumps and fed pneumatically into a fluid bed reactor for combustion. A waste heat boiler converts the heat from the reactor exhaust gases to steam. HRRC estimates the Hempstead facility will reduce municipal refuse to less than 3% of its original volume, generate 400,000 pounds of steam per hour and produce annually 40,000 tons of ferrous metals, 23,000 tons of color-sorted glass and 5,000 tons of aluminum (38).

The CPU-400 pilot plant system, developed by the Combustion Power Company of Menlo, California, recovers energy from MSW in the form of electric power through the use of a gas turbine driven electric generator. In this system, the refuse is shredded, conveyed to an air classifier where the lighter fibrous materials are carried upward and pneumatically transported to large cyclones where the lights are separated from the air stream and stored. The MSW fuel is burned in a high pressure fluid bed combuster, and the hot gases, after passing through a particle clean-up train, drive a gas turbine/generator to produce electricity. The heavies are processed for the magnetic separation of iron and the recovery of aluminum. At this point, the process is still in the pilot plant stage.

Based on the experiences to date, it would appear that refuse as a supplemental fuel will burn well in a boiler and will not change significantly the fly ash produced or the flue gases emitted. It would also appear that a safe upper limit for the replacement of coal by refuse, on a BTU equivalent basis, is about 25 percent to avoid additional boiler tube corrosion. It should also be noted that the use of refuse as a supplemental fuel results in the formation of boiler tube slag which can be more easily removed than the slag formed on boiler tubes in all-coal-fired units.

It also appears desirable to shred and air-classify the refuse prior to using it as a fuel supplement, since this facilitates recovery of the glass and metal fractions, reduces the handling and feed problems, reduces the amount of erosion encountered in the handling equipment, and results in a higher quality bottom ash (which is a saleable commodity). Shredding and air classification would also result in a reduction of the moisture content and elimination of the noncombustibles, resulting in a higher BTU content for the refuse (38,39,40).

A summary of the various energy recovery processes for refuse has been compiled by Midwest Research Institute and is presented in Table XXV. A comparison of the economics for the different resource recovery processes has been compiled by Midwest Research Institute and is shown schematically in Figure 8 and tabulated in Table XXVI. It is apparent from these data that processing the refuse for ferrous metal recovery and fuel recovery is the most economical and ecologically desirable approach provided sufficient steam generating facilities are locally available (43). It should be recognized that the Midwest data are based on 1972 economic conditions and the appropriate adjustments would be necessary for use at a later time. However, the relative economic relationship between recovery systems should be reasonably valid at some later time.

TABLE XXV

ENERGY RECOVERY PROCESSES (43)

No.	Name	Principal Product (s)	Other Products	Capacity (tons/day)	Capital + Costs ($/ton/day)	Operating + Costs ($/ton)	Revenue + ($/ton)	Net Costs + ($/ton)	Development Status
1	Horner and Shifrin	Fuel	Fe Metals	650	NA[h]	NA	NA	NA	Demonstration plant in operation since June 1972
2	A. M. Kinney	Fuel	Fe Metals	1000 (proposed)	5, 175	3. 92	2. 94	1. 43	Engineering design
3	CPU-400	Electricity	Fe Metals Other Metals Glass Sand Fly Ash	1000 (proposed)	9, 300	3. 23[a]	5. 78	-2. 55[a]	Pilot plant to be complete in late 1972
4	American Thermogen	Steam	Frit	1650 (proposed)	11, 800	6. 42	3. 01	3. 41	Pilot plant
5	Torax	Steam	Metals Slag	300 (proposed)	15, 000	NA	NA	NA	Demonstration plant in operation
6	Chicago N. W. Incinerator	Steam	Fe Metals	1600	14, 400	NA	NA	NA	Plant completed March 1971
7	Montreal Incinerator	Steam		1200	12, 500	7. 00	3. 50	3. 50	Plant completed February 1970
8	Issy-les-Moulineaux	Steam Electricity		1500	15, 300	7. 70	2. 88	4. 82	Plant completed in 1965
9	Munich North Incinerator	Electricity	Metal	1056	15. 400	13. 96	1. 96[b]	12. 00[b]	Plant completed in 1967
10	Munich Power Station	Electricity Steam		960	NA	NA	NA	NA	Plant completed in 1971

+ Economic Data Supplied by Vender

TABLE XXV (concluded)

ENERGY RECOVERY PROCESSES

No.	Name	Principal Product (s)	Other Products	Capacity (tons/day)	Capital Costs ($ton/day)	Operating Costs ($/ton)	Revenue ($/ton)	Net Costs ($/ton)	Development Status
11	Zurich II Incinerator	Electricity	Steam	520	NA	NA	NA	NA	Plant completed in 1966
12	Basel II Incinerator	Electricity	Steam	600	NA	NA	NA	NA	Plant completed in 1969
13	Osaka Plant	Electricity		400	NA	NA	NA	NA	Plant completed in 1966
14	Isago Plant	Steam		450	NA	NA	NA	NA	Plant completed in 1968
15	USBM Hydrogenation	Oil		100-500 gal/hr	NA	NA	NA	NA	Bench scale pilot plant
16	Garrett	Oil	Char Glass Fe Metals	150-2000	7000	3.86[f]	5.84	-1.98	Pilot plant. Demonstration plant to be built (San Diego, Cal.)
17	Union Carbide	Fuel Gas	Slag	200-1000	10,000	8.45	4.00	4.45	Pilot plant
18	Monsanto Landgard	Steam Metals	Char	500-1000	11,600	8.08	5.31	2.77	Pilot plant. Demonstration plant to be built (Baltimore, Md.)
19	USBM	Oil Gas	Tar Char	NA	NA	NA	NA	NA	Laboratory Tests
20	Battelle	Fuel Gas	Slag	100-200 (proposed)	NA	NA	NA	NA	Pilot plant

Notes:

a/ Amortized capital cost not included. b/ Does not include revenue from electricity. c/ Color sorted glass. d/ Does not include land or working capital. e/ Includes $5.50/ton disposal fee. f/ Excludes depreciation. g/ Input: sugar can bagasse. h/ NA = not available.

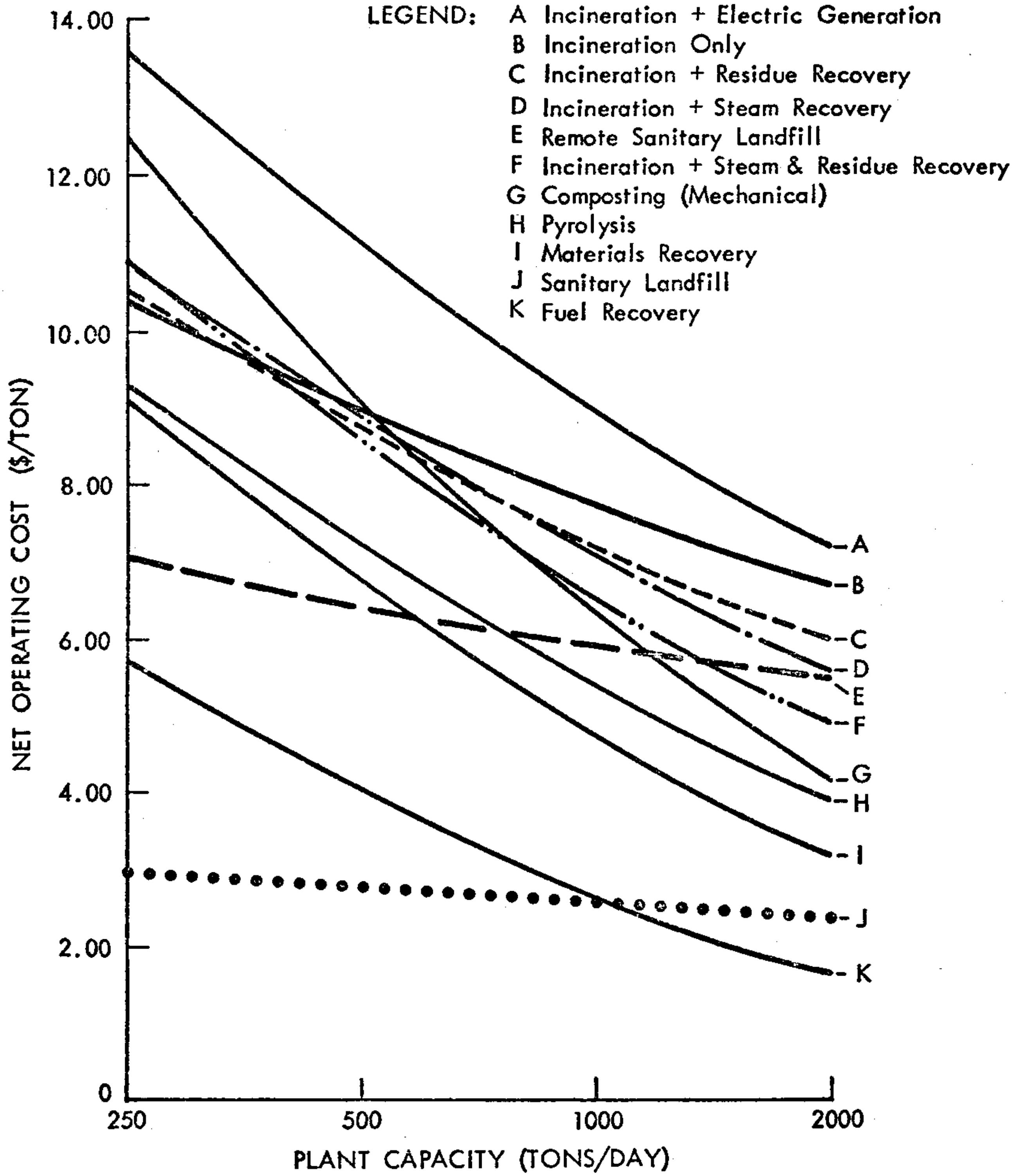


Figure 8. Net Operating Costs Associated with Municipally-Owned Resource Recovery Processes at Various Plant Capacities (20 year economic life; 300 days per year operation). (43)

TABLE XXVI

SUMMARY OF RESOURCE RECOVERY PROCESS ECONOMICS* (43)

Process Concept	Investment ($000)	Total Annual Cost ($000)	Resource Value ($000)	Net Annual Cost ($000)	Net Cost Per Input Ton ($)
Incineration Only	9,299	2,303	0	2,303	7.68
Incineration and Residue Recovery	10,676	2,689	535	2,154	7.18
Incineration and Steam Recovery	11,607	3,116	1,000	2,116	7.05
Incineration + Steam and Residue Recovery	12,784	3,508	1,535	1,973	6.57
Incineration and Electrical Energy Recovery	17,717	3,892	1,200	2,692	8.97
Pyrolysis	12,334	3,287	1,661	1,626	5.42
Composting (mechanical)	17,100	2,987	1,103	1,884	6.28
Materials Recovery	11,568	2,759	1,328	1,431	4.77
Fuel Recovery	7,577	1,731	920	811	2.70
Sanitary Landfill (close-in)	2,472	770	0	770	2.57
Sanitary Landfill (remote)	2,817	1,781	0	1,781	5.94

*Based on municipally-owned 1000 TPD plant with 20-year economic life, operating 300 days/year.

Source: Midwest Research Institute.

INCINERATOR RESIDUE UTILIZATION

Most of the incinerator residue is disposed of in land fills. However, some communities use the residue as a fill material in road construction (road bed). The city of Baltimore uses the fine fraction screened from the residue as a fill material in asphalt. Some incinerator plants also salvage the metal cans from the residue. Because of the high tin content a major use for this scrap iron is for copper ore refining. However, this is a very limited market since about 600,000 tons are used per year. The development of the electric arc furnaces may generate a greater market for scrap iron from urban refuse. Currently, only eleven incinerator plants and a few composting plants are recovering scrap iron. Ferrous metal from incinerator residue is usually contaminated by tin (from the plating) and copper during incineration and has undergone considerable oxidation. A project at the Bureau of Mines has shown that ammonia bleach can be used to remove the copper, and hydrochloric acid bleach or chloride roasting can be used to remove the tin in order to meet market specifications. The Bureau of Mines has also been very active in the development of a pilot process for the recovery of the various metal and glass fractions in the incinerator residue. A schematic of this process is shown in Figure 2. The quantities recovered for the various fractions are compiled on a ton per day basis in Table XXVII (3,16,18,19,44).
Three separate economic analyses have been prepared for the cost and operation of an incinerator residue recovery facility: one by the Bureau of Mines based on their pilot studies, one by Raytheon for its EPA demonstration grant at Lowell, Mass., (set up an operating residue recovery facility), and one by L.S. Wegman Co., for the town of North Hemstead, New York. The results of these studies are summarized in Table XXVIII. A review of the data used to compile this table showed that a good deal of the variation in costs was due to the use of different cost parameters in each analysis. The most comprehensive analysis appeared to be by the L.S. Wegman Company. From the data it would seem that a plant to process 250 TPD (in an 8 hour shift) would cost about $1,500,000 to build and about $9 per ton of residue to operate (1971 - 1972 figures). The revenue from the products generated (glass, ferrous metals, and nonferrous metals) will depend to a large degree on the quality of the recovered material, the local markets, and the transportation costs when distant markets have to be used. Estimates for the revenue from a ton of incoming residue may vary from $6 to $15. For distant markets, freight rates become a major factor in the economics of the recovery process. The higher freight rates for secondary materials (scrap metals, etc.) can seriously jeopardize the cost effectiveness of a recovery process. The quality of the recovered products and the standards that can be met have not been well established to date. The full-scale demonstration facility, scheduled for operation by 1975 at Lowell, Mass., should provide the most concete information about the economic and technical feasibility of incinerator residue recovery (45,46, 47, 48).
Preliminary discussions with representatives of the glass and metals industries have indicated considerable reluctance to accept the metal and glass

TABLE XXVII

QUANTITIES OF THE VARIOUS FRACTIONS RECOVERED BY THE BUREAU OF MINES PROCESS (16) (TONS PER DAY)*

	PLANT SIZE			
	250 tpd	400 tpd	670 tpd	1, 000 tpd
Plus 4-mesh ferrous metal	41	66	111	166
Minus 4-plus 20-mesh ferrous metal	35	56	93	139
Aluminum scrap	4	6	11	16
Copper-zinc scrap	3	5	8	12
Colorless glass	69	110	185	276
Colored glass	50	80	133	199
Waste solids	48	77	129	192

* Data Projected from Bureau of Mines Pilot Plant Studies

TABLE XXVIII

SUMMARY OF ECONOMIC ANALYSIS FOR RESIDUE RECOVERY***

No.	Organization	Plant Capacity*	Capital Cost	Process Cost**
1	Bureau of Mines[45]	250 tpd	$1,500,000	$4.03/Ton
2	Raytheon Co.[48]	230 tpd	$2,750,000	$10.60/Ton
3	L. S. Wegman[47]	150 tpd	$1,400,000	$9.21/Ton

*Plant capacity based on one 8 hour/day shift

**Process cost include plant operation and maintenance and amortization costs.

*** Data based on 1971-1972 Economics

fractions recovered from incinerator residue. The steel companies contacted, indicated no interest in the ferrous fraction of the residue. In fact, their interest in the ferrous fraction from raw refuse was limited. The only immediately apparent market for the ferrous fraction from residue is the copper industry. However, this market is limited to approximately 600,000 tons/year and not exclusively to incinerated ferrous metal. The use of color sorted glass recovered from the residue for cullet has not been very successful to date due to the difficulty in obtaining material of high enough quality. However, a number of effective secondary uses for this waste glass have been developed. The most effective products to date are structural block, mineral wool, aggregate for Portland cement concrete, Terrazzo, and "Glasphalt". However, the economic viability of these products is yet to be proven (44, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61).

A number of studies have also been initiated for utilization of incinerator fly ash. However, a major problem is the compositional variation in the fly ash samples studied. Aerated concrete, brick, lightweight aggregate and glass ceramics were produced from incinerator fly ash. Analysis of these products showed that the best potential for fly ash utilization was as lightweight aggregate (27, 28).

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16. ABSTRACT

The composition and current disposal practices for the residue resulting from the incineration of urban refuse have been studied. In addition, the characteristics of urban refuse are described, and the location and capacity of the nation's municipal incinerators specified. The economic and technical potential for utilizing materials recovered from the residue have also been studied.

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