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Air Pollution Control Technology for Municipal Solid Waste-to-Energy Conversion Facilities: Capabilities and Research Needs

September 1980

Prepared for:

U.S. Department of Energy
Assistant Secretary for Environment
Office of Environmental Compliance and Overview
Environmental and Safety Engineering Division

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INTRODUCTION

Substantial public and private research effort recently has been invested in developing processes for converting municipal solid waste (MSW) to useable energy. The technology has progressed through demonstration phases into the designing, building and successful operation of full scale facilities that, in many cases, are providing economically attractive utilization of municipal solid waste. As fuel prices continue to increase, waste-to-energy conversion will become even more competitive with landfills as an economical and energy-conserving waste disposal method. The potential then exists for increased use of waste-to-energy processes for disposal of MSW in closer proximity to urban sources of wastes.

The design and operation of much currently used air pollution equipment is based on the burning of fossil fuels and not municipal solid waste. It therefore follows that assessment of the ability of conventional air pollution control technology to meet current and proposed air quality standards at municipal waste-to-energy facilities is appropriate. Both the U.S. Environmental Protection Agency (EPA) and Department of Energy (DOE) made such assessments a priority early in their waste-to-energy programs. Much of this work was done with pilot or demonstration scale plants, or under less-than-ideal test conditions at "operating" facilities; and some recently developed and promising concepts, designs or operating alternatives have not been evaluated. Also it seems that a sufficient number of measurements may not have been made in previous tests to provide statistically valid data bases. This report presents the results of a survey of waste-to-energy facilities conducted:

1. To produce an updated status report on capabilities of current air pollution control technology to meet existing and proposed air quality standards when municipal solid wastes are used as part or all of the energy input to a generating facility;
2. To identify significant findings in recent research and development projects that may suggest that air pollution control technology constraints may limit the feasibility of wide-spread use of municipal solid waste as an energy source; and
3. To identify additional air pollution control technology research and development needs associated with waste-to-energy conversion.

This report presents the results of this survey. Section I contains a brief general description of the three prominent types of waste-to-energy conversion processes in use at the present time, a brief history of federal government funded research on these processes, and a summary of significant research needs. Section II contains an update of the operating status and significant air pollution control operating experiences and associated research findings for existing waste-to-energy conversion facilities on a case by case basis.

CONCLUSIONS AND RECOMMENDATIONS

The observations and facts presented in this report point clearly to the need for a comprehensive program to conduct an industry-wide assessment of particulate, trace element, and hydrocarbon air emission levels from each waste-to-energy process to provide a data base for decision making purposes. Research is needed to determine suitable methods for controlling particulate, gaseous and metals emissions from the three major types of waste-to-energy conversion processes so that environmental control and waste disposal policy makers will have adequate information to help make system choices. While a significant amount of research has been conducted concerning the capabilities of conventional air pollution control equipment to meet current and proposed air quality standards, unanswered questions still remain. Specific research and development needs are summarized as follows:

General Research Needs Applicable to all Waste-to-Energy Systems

1. Documentation of trace metals emissions from waste-to-energy processes is sparce at best and is almost non-existent for organic materials. Thus further tests to quantify these parameters is needed. The limited data available, while not providing an adequate statistical base for drawing firm conclusions, do indicate the potential for hazardous metals emissions from some of the operating, full-scale waste-to-energy processes. U.S. EPA also recently has reported that findings of trace hazardous organic in stack gases from some of these processes definitely show the need for further investigation although certified documentation of these observations has not been published to date (12).

2. Air pollution emissions from various waste-to-energy conversion processes now in operation should be compared on a common basis (ton for ton or BTU for BTU) including particulates, trace metals, chlorides (or HCl) and hazardous organics. This has not been done to date. Air pollution control processes with significant advantages should be identified. This survey should include processes co-firing coal and RDF, indirect and direct heated pyrolysis units and conventional mass-incineration and fluidized-bed incineration processes.
3. Air emission investigations like those mentioned in 1 and 2 above should be extended to look at possible co-disposal of sewage sludge and hazardous wastes with MSW. Although there seems to be little published documentation of any such attempts at co-disposal especially involving hazardous industrial wastes, the potential may be significant. Any such emission work should include searching for emission products that may result from co-disposal that would not appear when burning the municipal solid waste separately or when co-firing MSW with coal or oil.
4. An overall system analyses of the environmental/economic/operational aspects of waste-to-energy conversion should be performed to provide a basis for selecting combinations of processing and air pollution control technologies which will optimize energy recovery efficiency and minimize undesirable emissions.
5. Bacterial and viral emissions from the exhausts of dust control equipment used on front-end processes (grinding, screening, etc.) should be investigated and compared to emissions from other disposal sites such as landfills, sewage treatment processes, transfer stations,

animal feed lot or confinement buildings so that hazards specific to municipal solid waste processing can be identified.

Specific Mass-Incineration Research Needed

1. Methods are needed for controlling waste feed and excess air rates so that incinerator operating conditions can be adjusted to minimize particulate emissions and maximize the effectiveness of air pollution control equipment. For example, some modular combustion units use a two-stage combustion chamber to help reduce particulate emissions.
2. Trace element and chloride emissions from fluidized-bed incineration of MSW should be investigated to determine if this process has significantly reduced emissions as compared to conventional incinerations.
3. The following supplements to conventional incinerator air pollution control equipment should be investigated:
   a. Addition of alkaline material to the refuse bed to promote binding of chloride into the bottom ash.
   b. Partial recirculation of flue gas as a means of reducing emissions of particulate and nitrogen oxides.

Specific Co-Firing Research Needs

1. Tests should be extended to determine the effect of firing port placement on particulate emissions when co-firing coal and refuse-derived fuel (RDF) suspension-fired boilers. For example, at Ames, Iowa, RDF injection ports were placed below the coal firing ports and particulate standards were met; Wisconsin Electric placed the RDF ports above the coal ports and particulate emission standards were not met.

2. Tests when co-firing coal and RDF should be conducted to determine the long-term effects on the performance of air pollution control equipment. Tests at Wisconsin Electric indicated detrimental long-term effects; but when RDF co-firing was stopped, the ESP performance returned to normal (36).
3. Tests should be conducted to investigate the effects of changes in the operation of stoker-fired boilers in organic emissions when co-firing RDF, specifically, when fly ash reinjection is no longer practiced.
4. The potential for co-firing RDF in small stoker-fired boilers having mechanical collectors should be investigated further. Studies at Ames show that it may be feasible to meet current air quality standards with high efficiency cyclones if operating parameters are controlled properly and RDF processing is designed to minimize the amount of dust and fines reaching the boiler.
5. Tests should be conducted to determine the relationship between front-end processing methodology and trace element and particulate emissions and boiler operating problems, such as slagging and ash handling.
6. Densified RDF (d-RDF) processing and co-firing with coal or oil should be investigated in detail to see if it has significant advantages over regular (fluff) RDF from an air pollution standpoint and to determine if costs can be reduced to a level competitive with RDF to take advantage of improved burnout, increased storage time characteristics, and burning without boiler modification. There is some evidence that co-firing d-RDF with coal or oil improves the

resistivity of ash for ESP collection purposes and may also cause some of the sulfur from fuel oil to be contained with the ash.

7. The effect of boiler heat release rate on particulate emissions when co-firing coal and RDF should be investigated.
8. The ability of fluidized-bed furnaces to tie up metals and to help minimize toxic metals emissions should be investigated.

Specific Pyrolysis Research Needs

1. The extent to which heavy metals and other potential pollutants are bound into the char or slag produced by pyrolysis should be determined. If significant binding is found, methods should be examined to exploit this phenomenon.
2. Gaseous emissions from pyrolysis processes should be examined to determine the potential for release of undesirable trace elements or hazardous organic materials.
3. Because fixed carbon in the char produced in some pyrolysis processes can comprise 18% by weight and 30% of the heat content of MSW (28), steps should be taken to develop methods for recovering this energy. These methods must be acceptable from an air pollution standpoint and also must be economically feasible.

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SECTION I

DESCRIPTION OF WASTE-TO-ENERGY PROCESSES

Waste-to-energy conversion processes in full-scale operation or advanced demonstration stages in the U.S. can be divided into three major categories: co-combustion, mass incineration and pyrolysis. Co-combustion consists of 1) some combination of shredding, classifying or other "front-end" processing of MSW into a recycleable (heavy) fraction and a burnable (light) fraction known as refuse-derived fuel (RDF), and 2) firing of the RDF in combination with a fossil fuel in a conventional fossil fuel boiler modified for this purpose (Figure 1, Table 1). The "front-end" processing varies significantly from facility to facility with each producing an RDF having unique characteristics, such as particle size, that affect its endpoint use. This processing can be carried further to include densification of RDF into powder, granules or briquettes that are expected to have significantly improved storage qualities and can be mixed directly with coal or oil and fired in existing power plants without having to make extensive boiler modifications.

Mass incineration recovers energy from MSW by burning unprocessed waste in large, thermally efficient waterwall incinerators (Figure 2, Table 2). Most energy recovery incinerators are similar to coal-fired stoker generating units in that they employ moving grates for charging and ash removal. Waterwall boilers typically are used to recover flue gas heat and generate steam. Individual units may have a capacity in excess of 1000 TPD of MSW. There are a few other types of facilities in various stages of design, construction and operation which either shred or wet pulp MSW for use in fluidized bed, suspension-fired or stoker-fired boilers.

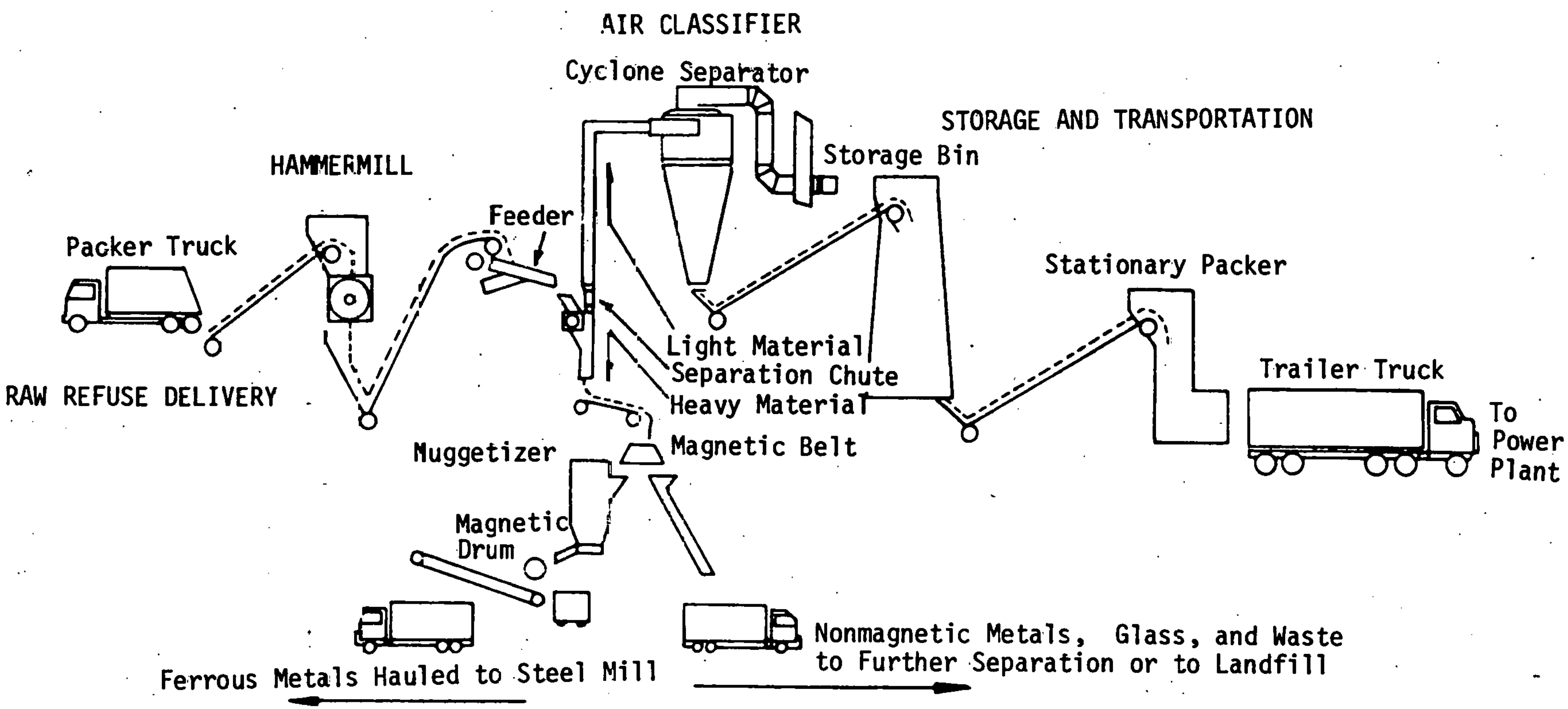

Fig. 1. Flow diagram of a solid waste processing plant designed to produce refuse-derived fuel for energy recovery (From Shannon, L.J., Shrag, M.P., Honea, F.I., and Bendersky, D., U.S. EPA Report No. 650/2-74-073, 1974).

Table 1. Refuse-derived fuel plants in the U.S. as of Nov. 1979 (11).

Location	Owner	Capacity, TPD Design	Capacity, TPD Operating	Products	Start-up Date	Status
Ames, Iowa	City of Ames, Iowa	200	170	RDF, ferrous	1975	Operational
Baltimore Co., Maryland	Maryland Environmental Service	1,200	750	RDF, ferrous	1976	Operational
Chicago, Illinois	City of Chicago	1,000	500	RDF, ferrous	--	Plant is currently undergoing shakedown (1980)
East Bridgewater, Massachusetts	Combustion Equipment Associates	160	160	ECO-FUEL II™	1973	Operational
Lane County, Oregon	Lane County	500	--	RDF, ferrous	--	Under construction
Milwaukee, Wisconsin	Americology Div. of American Can Co.	1,200	900	RDF, bundled paper, ferrous, aluminum, glass concentrate	--	Plant is currently undergoing shakedown (1980)
St. Louis, Missouri	Union Electric Company	150-300	--	RDF, ferrous	1972	Demonstration facility is now closed. Union Electric has abandoned its work in solid waste utilization due to local problems.
Madison, Wisconsin	City of Madison	400	200	RDF, ferrous	1979	Operational
Albany, New York	City of Albany	750	--	RDF, ferrous	1980	Under construction
Bridgeport, Connecticut	Connecticut Resources Recovery Authority	1,800	--	ECO-FUEL II™ ferrous, aluminum, glass	1979	In start-up phases
Monroe County, New York	Monroe County	2,000	--	RDF, ferrous, aluminum, glass	1979	Shakedown
Niagra Falls, New York	Hooker Chemicals and Plastics Corp.	2,286	--	Steam, electricity, ferrous	1980	Under construction
Appleton, Wisconsin	Sadoff and Rudoy Industry	2,400	--	Steam, ferrous	1982	Advanced planning
Columbus, Ohio	City of Columbus	1,200	--	Electricity, ferrous	1981	Processing operational; generating plant in planning
Lakeland, Florida	City of Lakeland; Orlando Utilities Comm.	300	--	Electricity, ferrous	1981	Under construction

Table 1. Continued.

Location	Owner	Capacity, TPD Design	Capacity, TPD Operating	Products	Start-up Date	Status
Newark, New Jersey	Combustian Engineering Assoc.; Occidental Resources Recovery Assoc.	2,000	--	RDF, ferrous, aluminum, glass	1981	Advanced planning
Norfolk, Virginia (SE Vir. Plan. Auth.)	Southeastern Public Service Authority	2,000	--	RDF, electricity	1983	Advanced planning
Detroit, Michigan	City of Detroit	3,000	--	RDF, steam	1983	Advanced planning
Peabody, Massachusetts	Combustian Engineering Assoc. Inc.	1,800	--	RDF, ferrous	no	Advanced planning
Tulsa, Oklahoma	Tulsa Energy Resources Recovery Authority	1,000	--	RDF, ferrous	1982	Advanced planning

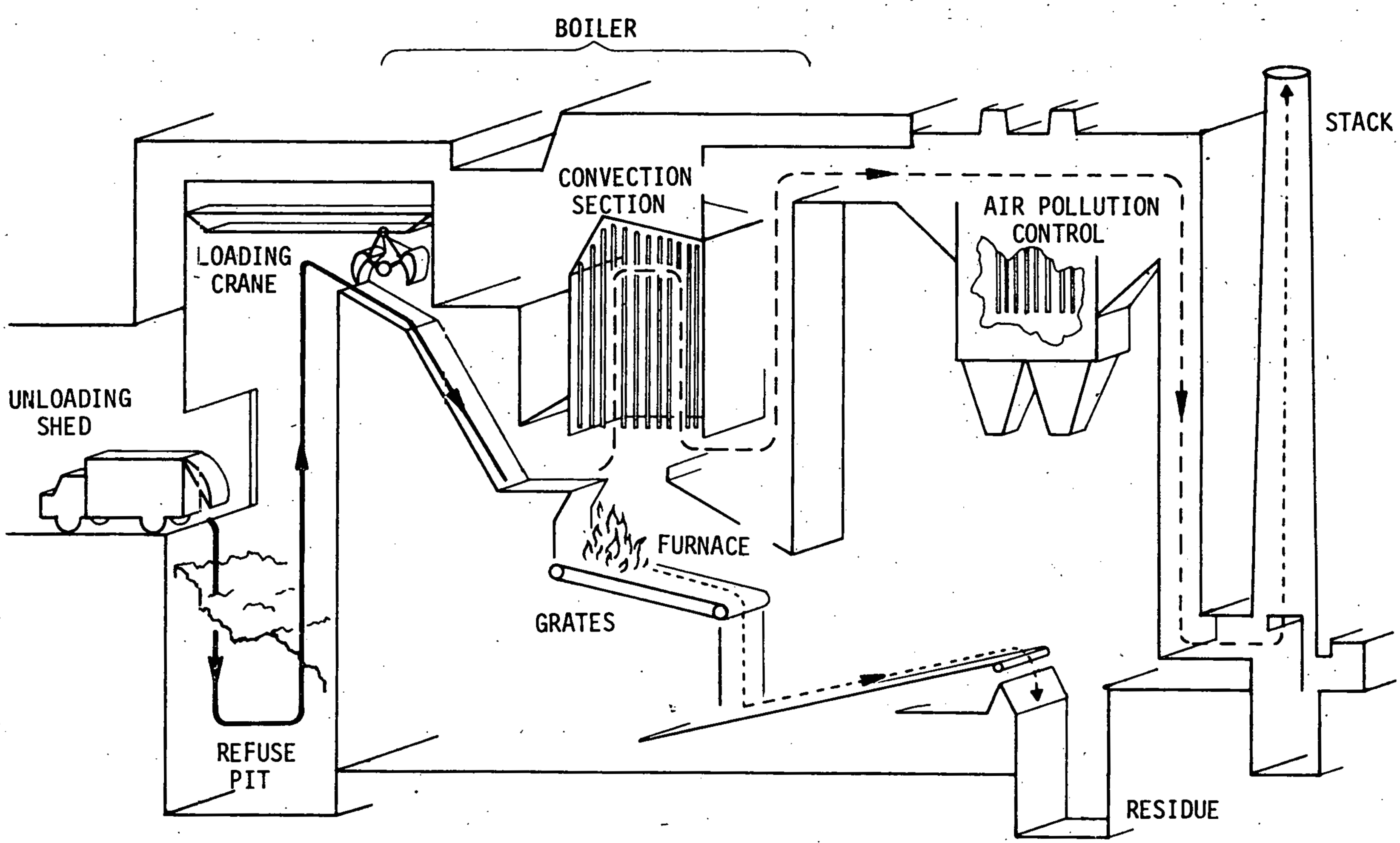

Fig. 2. Schematic diagram of a typical mass-burning solid waste processing/energy recovery plant (From Levy, S.J., Rigo, H.G., U.S. EPA Report No. SW-157.2, 1976).

Table 2. Mass-burning energy conversion facilities in the U.S. as of Nov. 1979 (11).

Location	Owner	Capacity, TPD		Products	Start-up Date	Status
		Design	Operating			
Braintree, Massachusetts	City of Braintree	384	250	Steam	1971	Operational
City of Chicago	City of Chicago (Northwest)	1,600	1,200	Steam	1971	Operational
Harrisburg, Pennsylvania	City of Harrisburg	720 + 14 sludge	500	Steam	1972 (1979)	Operational
Nashville, Tennessee	Nashville Thermal Transfer Corp.	720	400	Steam	1974	Operational
Norfolk, Virginia	U.S. Naval Station	360	140	Steam	1967	Operational
Saugus, Massachusetts	RESCO	1,500	1,000	Steam, ferrous	1976	Operational
Oceanside, New York	Township of Hempstead, N.Y.	750	750	Steam, electricity	1974, (1976)	Operational
Portsmouth, Virginia	Norfolk Naval Shipyard	160	30	Steam	1976	Operational
Akron, Ohio	City of Akron	1,000		Steam, ferrous	1980	Shakedown early 1980
Hampton, Virginia	NASA, USAF	200		Steam	1980	Expected start-up late 1980
Glen Cove, New York	City of Glen Cove	225 + 25 sludge		Electricity	1981	Under construction 1980
Wilmington, Delaware	Delaware Solid Waste Authority; Ratheon Service Co.	1,000 + 50 sludge		Steam	1982	Under construction 1980
Dubuque, Iowa	Dubuque Metropolitan Area Solid Waste Agency	250		Steam, ferrous	1981	Under construction
Gallatin, Tennessee	Gallatin, Hendersonville, Summer County Authority	150		Steam, electricity	1981	Advanced planning
North Andover, Massachusetts	Universal Oil Products, Inc.	3,000		Electricity	ND	Advanced planning
Beverly, Massachusetts	Industrial Development Financing Authority	591		Steam, electricity	ND	Advanced planning
Pinalles County, Florida	Pinellas County	2,000		Electricity, ferrous, nonferrous	1982	Advanced planning
Westchester County, N.Y.	Contractor and Municipal Authority	1,500		Steam	1983	Advanced planning

Pyrolysis involves the thermal-chemical decomposition of waste under controlled pressure, temperature and residence time by indirect application of heat. Ideally, the only gas flow leaving a pyrolysis reactor is that resulting directly from the decomposition of the waste from the solid to the gaseous phase (and of course those gases introduced when charging wastes such as through an air lock feeder). The type and consistency of the product (gas, liquid or char) produced from a heterogenous waste such as MSW is dependent on exposing all of the waste to the desired design temperature, pressure and residence time. Accomplishing pyrolysis in an essentially sealed reaction vessel through indirect heating is relatively simple compared to attempting to control combustion of a heterogenous waste in systems using large quantities of excess air such as those designed for combustion of coal.

Pyrolysis processes differ in reactor designs, operating temperatures and reactor temperature gradients, residence times, recovered fuel characteristics and carrier gas source and composition (if any). Most full-scale pyrolysis systems that have been demonstrated to date have been starved-air combustion units in which part of the waste is burned in one section of the reactor to produce heat to decompose the remaining organic material (Figure 3, Table 3). Only the PYRO-SOL process has adhered to the use of indirect heating and exposure of all the input feedstock to a fixed residence time and temperature (33). Some such as the Baltimore facility, have on-site secondary combustion chambers with energy recovery in the form of steam or steam generated electricity only. Process residues range from inert slag to carbon-rich chars.

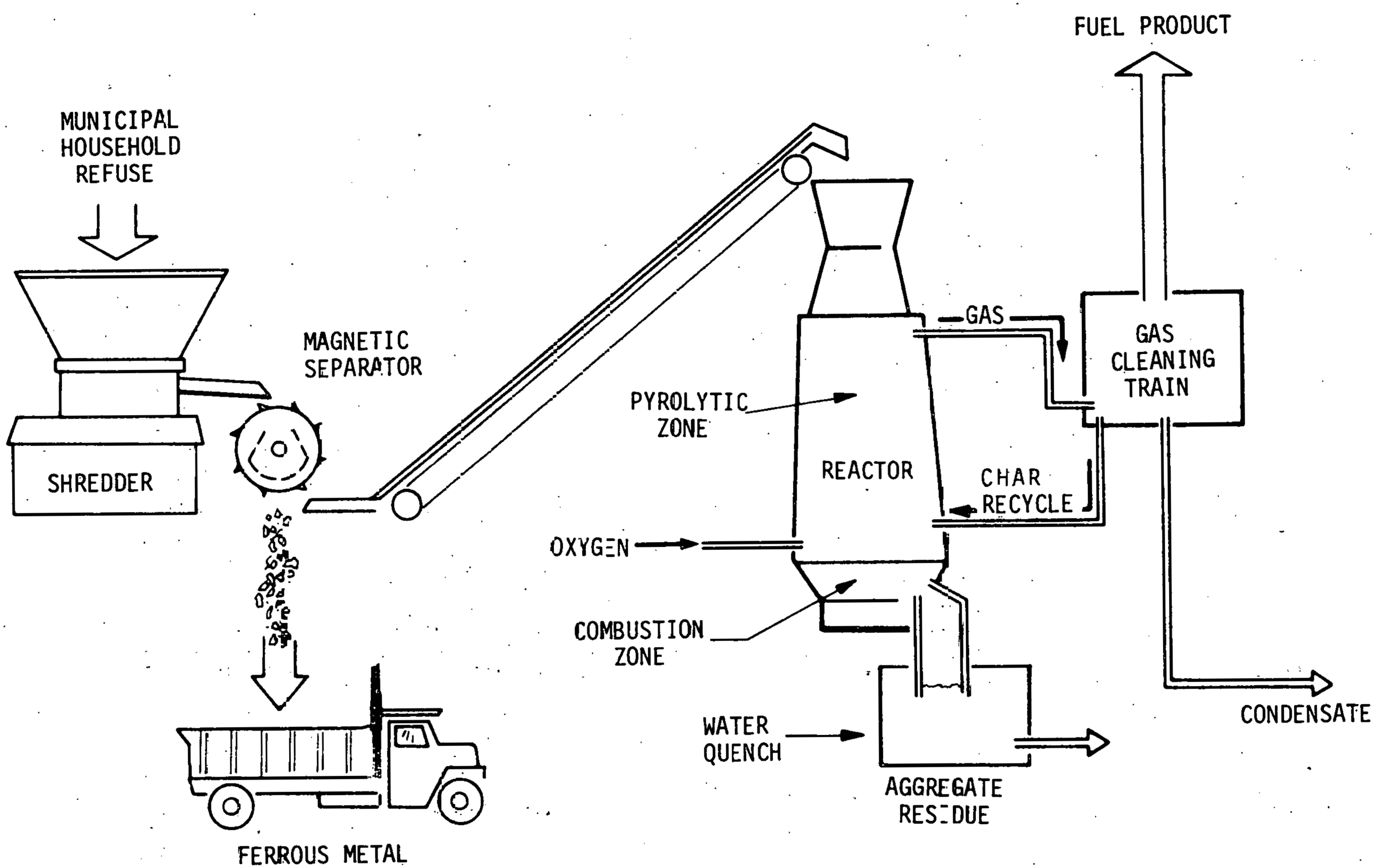

Fig. 3. Schematic diagram of a pyrolysis plant (Union Carbide's PUROX^{TM}). (From Report on Status of Technology in the recovery of Resources from Solid Wastes, County Sanitation Districts of Los Angeles, CA, January, 1979)

Table 3. Large-scale pyrolysis systems in the U.S. as of Nov. 1979 (11).

Location	Key participants	Process	Design capacity	Products	Start-up date	Status
Baltimore, Maryland	Monsanto Environ-Chem Systems, Inc; City of Baltimore; EPA	Landgard™ Process: shredding, water quenching, magnetic separation	1,000	Steam, ferrous, glassy aggregate	1975	Monsanto Environ-Chem Systems, Inc has withdrawn from the project; revised by City of Baltimore, operational 1980
El Cajon, California	Occidental Petroleum Corp; San Diego Co; EPA	Flash Pyrolysis™ process: shredding air classification, magnetic, and other mechanical separation, froth flotation	200	Pyrolytic oil, ferrous aluminum, glass cullet	--	Plant is currently not operating pending possible modification to correct problems in pyrolysis unit
Erie County, New York	Carborundum Torrax, Inc; Erie County; EPA	Slagging pyrolysis system	75	Pyrolysis gas/steam	1974	Demonstration plant closed. Three systems sold in Europe
S. Charleston, W. Virginia	Linde Division, Union Carbide Corp.	Purox™ oxygen converter, shredding	200	Pyrolysis gas	1975	Operational until 1979
Redwood City, California	Pyro-Sol, Inc	Indirect heat; cooling process	50-75/module	Gas, high-carbon char	no	In development stage

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SECTION II

IDENTIFICATION OF RESEARCH NEEDS CONCERNING THE AIR POLLUTION ASPECTS OF WASTE-TO-ENERGY PROCESSES

In 1974 EPA's Municipal Environmental Research Laboratory (MERL) required, as part of the City of St. Louis - Union Electric co-combustion demonstration project, a study of air pollution control efficiencies and emissions as well as a limited look at bacterial and viral emissions from front-end processing (1). Since then, EPA's Industrial Environmental Research Laboratory (IERL) has included air pollution emission studies as part of almost all waste-to-energy demonstration projects in which it has taken part. Of these, the investigation of the Ames Solid Waste Recovery System in Ames, Iowa is especially noteworthy because of its comprehensive nature. The Department of Energy, EPA and others have cooperated over a three year period to study emissions while co-firing RDF and coal in both stoker- and suspension-fired coal utility boilers at Ames. This investigation included an evaluation of the effects of various boiler modifications and RDF characteristic changes on air pollution control equipment operating performance as well as on emissions (17, 19).

IERL also has taken broader looks at air pollution control at waste-to-energy conversion facilities in three other studies. Their "Engineering and Economic Analysis of Waste-to-Energy Systems" published in May of 1978, included an evaluation of the air pollution control aspects of some eight waste-to-energy installations (35). EPA also has contracted with Midwest Research Institute of Kansas City to conduct an "Environmental Assessment of Waste-to-Energy Processes" (13). Third, PEDCO Environmental of Cincinatti, Ohio has published "Air Pollution Emissions and Control Technology for Waste-As-Fuel Processes" in October 1979 (10) as the initial effort in an EPA/IERL contract to develop, test, and evaluate pilot-scale air pollution control devices for use on various waste-to-energy processes. Their report details the status of knowledge about air emissions from waste-to-energy processes and control equipment capabilities as of 1979 but did not identify research needs.

These and other reports have concluded that not enough reliable data are available to adequately assess the air pollution impacts of mass incineration for other than particulates. If this is true it follows that it would be difficult to provide any kind of comprehensive comparisons of the air pollution impacts of the various waste-to-energy processes. But in spite of this conclusion, there are some indications in the literature and from current research projects that there may indeed be significant differences in these impacts and in air pollution control equipment capabilities to meet air quality standards. For example, Greenberg, Zoller and Gordon from the University of Maryland (15) concluded after studying composition and size of particles released in refuse incineration in 1978 that "If all urban refuse were burned in incinerators, the level of some toxic elements in urban air would probably be intolerable." These include Cd, Sn, Ag, Pb and possibly vapor-phase mercury. Granted, this does not account for cooler exhaust streams from mass-burning energy recovery which likely causes some condensation with subsequent removal in particulate collection devices. However, the PEDCO (10) report references studies which show that a large portion of metals are adsorbed onto the large surface areas of the smaller particle fractions (less than 2 micrometers) which leads to the probability that large amounts of metals (75% or greater of Pb, Zn, Cd, Cu and others) escape collection by air pollution control devices. It is this size range that is most likely to be inhaled deep into the lungs, thus making their removal more important.

There are only limited available data on the differences in trace metal emissions between firing coal only and coal plus RDF. The PEDCO report (10) concludes (pg. 135) that control of lead on fine particles from co-firing may be necessary. This conclusion is based on their comparison of conservatively estimated ground level concentrations with work-place threshold limit values established by OSHA as being safe for continuous 40 hours a week exposure. EPA has not yet formally addressed heavy metals emissions from coal firing, and any required control would likely apply both to mass incineration and to co-firing of municipal solid wastes.

Indirect-heated pyrolysis (such as used in the PYRO-SOL process) appears to be unique among waste-to-energy systems in its potential for control of the type and consistency of the products leaving the reaction vessel with similar implications for quality of energy production and for environmental control. DOE's Resource Recovery Research, Development and Demonstration plan (pgs. 194-196) draws similar conclusions (28). The processes developed by Union Carbide (PUROX™) Monsanto (LANDGARD), ANDCO Inc. (ANDCO-TORRAX) or Occidental Research Corp. (Flash Pyrolysis) all introduce either air or pure oxygen into the pyrolysis chamber for combustion of part of the waste to provide sufficient heat to pyrolyze the remainder. This causes the pyrolytic gases to be diluted with combustion products and nitrogen. The resulting product gas stream is larger in volume, more contaminated with solids and high molecular weight organic materials, less consistent in quality and lower in BTU content than that produced by indirectly heated pyrolysis (References 6, 25, 29 & 34 provide good examples of the types of pilot scale pyrolysis processes that have been developed for disposing of wastes).

Currently there is practically no trace element emission information available for any of the pyrolysis processes. Union Carbide, though not currently operating its PUROX™ plant, claims low trace element emission upon combustion of their produce gas, but substantial trace elements remain in their wastewater sludges (24). Andco-Torrax claims a 40% reduction of flue gas flow over waterwall incineration. But with potentially incomplete pyrolysis and without gas cleaning prior to the secondary combustion chamber, metals emission may be a problem. PYRO-SOL, the only operational indirect-heated pyrolysis system has shown very low particulate emissions from combustion of product gas in a boiler without control equipment. Metals and complex organic emissions also are expected to be very low because of long residence time at pyrolysis design temperatures and low temperature product gas recovery which also provides extensive gas cleaning (32).

Western Europe turned heavily to mass incineration in the 1970's and currently disposes of the wastes of some 100 million people in this way much of it employs energy recovery (22). But since then many of these countries are showing concern for emissions from these incinerators. West Germany for example, will require chloride control on any new incinerators (8). Many of the RDF emission studies have shown significant increases in chloride emission over coal alone (9, 17, 19).

Recent attempts by EPA to lower incinerator particulate emission standards from 0.08 to 0.03 gr/SCF has brought a flurry of comments on supposed difficulties for current ESP control technology to maintain a 0.03 gr/SCF standard over the years (2). This could be another indication that more municipalities and MSW disposal firms are considering mass incineration-energy recovery as refuse transportation costs increase.

REVIEW BY FACILITY OF SIGNIFICANT OPERATING EXPERIENCE AND RESEARCH FINDINGS

A brief description of the significant operating experiences and research findings as reported in the above referenced reports and as learned from discussions with designers or operating personnel are included here for currently operating waste-to-energy facilities. This review is presented by facility type: co-combustion, mass incineration, then pyrolysis.

Co-combustion Facilities

Ames Solid Waste Recovery System - Ames, Iowa

The Ames Solid Waste Recovery System (19) consists of one resource recovery RDF production line currently processing 100 to 150 tons per day (TPD) of MSW via 2-stage shredding, ferrous metal removal, and air classification. The RDF is stored in a 500 ton capacity Atlas storage bin and is fired in any of three boilers, two of which are small spreader stokers (7.5 or 12.5 MW) and the other a larger (35 MW) suspension fired unit.

Boiler operation evaluation while co-firing RDF. Evaluation of the Ames boiler operation resulted in the following conclusions:

Existing stoker-fired boilers:

1. Boiler grate heat release design rate (BTU's/hr/ft^2 of grate) and geometry of flue gas routing may affect particulate loadings at the entrance to the air pollution control unit (20).
2. Introducing overfire air from the front of the boiler seems to have the effect of increasing residence time of combustibles thereby promoting more complete burning and consequent decrease in particulate loadings.

3. Elimination of the fines re-injection (recycling of a portion of the fly ash from some collection point back to the boiler) may very well reduce particulate loadings at the expense of a slight decrease in boiler efficiency.
4. Appropriate coal screening reduces the amount of coal fines and seems to result in decreased particulate emissions. This action will make it easier to meet particulate standards when co-firing RDF and coal.
5. Some combination of the above changes in boiler operation may make it possible to use existing smaller stoker-fired boilers without modification or with more efficient mechanical collectors (such as cyclones and baghouses) which cannot be used currently because they will not meet particulate standards for firing coal or coal plus RDF; and their size will not justify installation of expensive ESP's. This is exactly the case for Ames Units 5 & 6 where new mechanical collectors and reduction of RDF fines has made it possible to meet particuate standards. Similar changes may make it economically feasible to burn RDF in locations where stokers already exist but which cannot justify additional capital investments as required for mass-burning or large suspension-fired boilers.

Existing suspension fired boilers: It was found in the Ames co-firing tests that the location of the RDF injection-firing ports relative to the coal ports influenced both the stack emission and the amount of unburned RDF dropping into the bottom ash hopper (19). Moving the RDF injection ports to a location below coal injection and retrofiting a dump grate into the bottom of the boiler have solved the problem of unburned wastes and minimized the impact of RDF firing on stack emissions. Boiler heat release rate design criteria also may affect particulate emissions when burning RDF, but such a correlation has not yet been verified (20).

Changes in RDF processing: Reducing fines in RDF by as much as 50% significantly decreases slagging problems because of the increased ash softening temperature. Ash content also is reduced by as much as 50% (19). This lower ash content also will reduce particulate loadings into the APC equipment. This conclusion applies to stoker-fired as well as suspension-fired units.

Emission tests evaluation: Emission tests on the spreader-stoker boilers at Ames while co-firing RDF with coal (Tables 4 & 5) show significant increases in chlorides and trace elements lead, copper and zinc in the fine particulates above the levels normally found when firing coal alone (17). These tests were run in 1976 and 1977. In September of 1979 additional particulate tests for compliance purposes were run on one boiler (No. 6) after the installation of new, higher efficiency mechanical dust collectors while burning low-ash Colorado coal and RDF processed to remove fines and to lower the ash content. The tests were conducted at average 70% of rated boiler load and 40% RDF by heat content. The associated particulate emissions averaged 0.412 lb/MBTU. This shows a substantial improvement over the 1976-77 tests during which 2 to 4.4 lb/MBTU particles were measured (17). Even though these tests should not be compared strictly with the 76-77 data because of coal and operating condition differences, it is obvious that the experiences and equipment modifications at Ames have significantly reduced particulate emissions.

These decreases in particulate emissions probably will not significantly change gaseous chloride emissions but may change the trace metal emission rate from that reported in the 1976-77 tests since many metals are adsorbed to

Table 4. Selected emissions from Boiler Unit 5 at Ames, Iowa when co-firing coal and RDF (17).

Parameter (units)		80% load 1976 Iowa coal with			80% load 1977 Iowa/Wyoming coal with			60% load 1976 Iowa coal with			100% load 1976 Iowa coal with		
		0% RDF	20% RDF	50% RDF	0% RDF	20% RDF	50% RDF	0% RDF	20% RDF	50% RDF	0% RDF	20% RDF	50% RDF[a]
Particulates (controlled)	(g/MJ)	0.7	0.4	0.3	0.8	0.9	1.0	0.9	1.1	1.3	1.3	0.4	0.4
Particulates (uncontrolled)	(g/MJ)	3.6	4.1	3.4	3.2	3.8	4.2	3.2	4.4	3.5	4.1	2.2	3.1
Oxides of sulfur, SO_x	(g/MJ)	2.3	1.9	1.5	1.0	0.7	0.9	1.3	2.3	0.8	2.4	2.0	1.7
Oxides of nitrogen, NO_x	(mg/MJ)	80.0	76.0	64.0	77.0	67.0	69.0	99.0	104.0	78.0	81.0	76.0	50.0
Chlorides	(mg/MJ)	13.0	68.0	97.0	6.5	87.0	139.0	22.0	58.0	100.0	7.0	62.0	101.0
Formaldehyde	(mg/MJ)	0.2	0.2	4.3	11.7	3.7	3.4	2.7	3.1	6.2	3.3	2.0	0.2
Hydrocarbons	(mg/MJ)	0.22	0.17	0.19	0.08	0.09	0.07	0.15	0.19	0.31	0.09	0.15	0.17

[a]Only two runs at this load and % RDF were accomplished.

Table 5. Selected emissions from Boiler Unit 6 at Ames, Iowa when co-firing coal and RDF (17).

Parameter (units)		80% load 1976 Iowa/Wyoming coal with			80% load 1977 Iowa/Wyoming coal with		60% load 1977 Iowa/Wyoming coal with		
		0% RDF	20% RDF	50% RDF	0% RDF[a]	50% RDF	0% RDF	20% RDF	50% RDF
Particulates (controlled)	(g/MJ)	0.5	0.7	0.9	0.8	1.9	0.7	1.8	1.7
Particulates (uncontrolled)	(g/MJ)	2.5	3.5	4.4	1.8	3.9	2.0	3.7	4.3
Oxides of sulfur, SO_x	(g/MJ)	0.8	0.3	0.4	0.9	0.6	1.4	0.8	0.5
Oxides of nitrogen, NO_x	(mg/MJ)	133.0	131.0	106.0	91.0	88.0	106.0	52.0	96.0
Chlorides	(mg/MJ)	6.3	44.0	88.0	9.4	110.0	4.2	96.0	127.0
Formaldehyde	(mg/MJ)	5.8	0.6	1.6	16.0	20.0	22.0	28.0	23.0
Hydrocarbons	(mg/MJ)	--	--	--	0.07	0.13	0.08	0.07	0.07

[a]Only two runs at this load and % RDF were accomplished.

particulates that pass through the APC device.

Stack emissions data obtained from the suspension fired boiler at Ames (Unit 7) while burning RDF are summarized in Table 6 (19). Additional compliance tests run in September 1978 after changing the RDF firing port location from above the coal nozzles to below them indicate further improvement in particulate emissions beyond that experienced by dump grate installation. Chloride emissions increased with increasing percent RDF in a manner similar to that found in the stoker-fired Units 5 and 6 (Table 6). Additional tests run at 16 to 18% RDF content (by BTU) and 100% load showed a decrease in particulates from 0.57 lb/MBTU before moving the RDF injection port to 0.31 lb/MBTU after lowering the injection port (32).

Madison Gas and Electric - Madison, Wisconsin

The City of Madison, Wisconsin processes MSW to produce RDF for firing by Madison Gas and Electric in a 50 MW suspension-fired pulverized coal boiler. The air pollution control device at this plant is an existing electrostatic precipitator that was conservatively designed for use with low-sulfur western coal. Although as of this writing comprehensive emission tests have not been performed, preliminary observations indicate that ESP performance is excellent when burning RDF. This entire operation has proven so successful that Madison Gas and Electric is finalizing plans to similarly modify a second 50 MW suspension fired unit for firing RDF sometime during 1980 (5). It is logical that the ESP here would be more likely to perform well when burning RDF (assuming good solid waste burnout) because low sulfur coal has fly ash resistivity characteristics closer to RDF fly ash than does high sulfur coal. Therefore, any ESP designed to perform well with low sulfur fly ash would be expected to perform well with RDF fly ash. There is also belief among some researchers that expected heat

Table 6. Selected emissions from Boiler Unit 7 at Ames, Iowa, when co-firing coal and RDF (19).

Parameter		Prior to Installation of Dump Grates 1976, 1977				After Installation of Drump Grates 1978					
		60% Load	80% Load	100% Load		80% Load			100% Load		
		0% RDF	0% RDF	0% RDF	10% RDF	0% RDF	10% RDF	20% RDF	0% RDF	10% RDF	20% RDF
Particulates (controlled)	$lb/10^6$ BTU[a]	0.23	0.35	0.60	0.53	0.21	0.37	0.37	0.42	0.44	0.53
Particulates (uncontrolled)	$lb/10^6$ BTU	9.05	7.49	8.26	8.35	6.54	7.63	8.21	7.93	7.28	7.47
Oxides of Sulfur SO_x	$lb/10^6$ BTU	2.61	2.88	3.70	2.88	3.42	2.84	2.33	3.30	2.33	1.93
Oxides of Nitrogen NO_x	$lb/10^6$ BTU	0.32	0.26	0.35	0.27	0.39	0.33	0.33	0.31	0.26	0.26
Chlorides	$lb/10^9$ BTU	5.14	13.6	28.14	7.65	10.7	50.9	93.7	7.65	58.4	28.6
Formaldehyde	$lb/10^9$ BTU	4.56	20.9	5.49	60.0	8.37	12.0	0.77	0.19	1.44	0.42
Methane	$lb/10^9$ BTU	0.00	0.00	0.00	0.00	5.30	6.07	3.77	3.35	4.58	2.47

release rates (BTU transfer per square foot) used in boiler design may be critical to good RDF burnout and that the Madison unit is an example of a boiler design well-suited to burning RDF (20).

Milwaukee, American Can, Wisconsin Electrical RDF Co-combustion

The City of Milwaukee, the Americology Division of the American Can. Co. and Wisconsin Electric Power are cooperating in an effort to produce RDF for use by Wisconsin Electric in supplementing suspension firing of coal in their Oak Creek plant units 7 and 8 (310 MW each). These are among the largest boilers ever used to fire RDF. Some boiler slagging and low ESP efficiency problems have been experienced during 2 years of extensive testing and evaluation by Wisconsin Electric (Table 7). There is some indication that the experience gained at Ames in experimenting with 1) RDF firing port locations on their suspension fired boiler and 2) RDF fines content could possibly solve some of the problems at Milwaukee. From on air emissions standpoint, ESP's on both boilers would not meet particulate emission standards of 0.15 lb/MBTU when burning RDF. Also emission rates seem to increase with accumulative RDF fired. ESP performance returned to normal overnight after co-firing of RDF was stopped (36).

Chicago Supplementary Fuel Processing Plant and Commonwealth Edison Co-Combustion

The City of Chicago and Commonwealth Edison are cooperating in a joint venture to convert MSW to RDF for co-combustion in utility boilers at the Commonwealth Edison Crawford plant adjacent to the processing facility. The City of Chicago has built what is one of the larger capacity RDF (1000 TPD) production plants currently in existence (35). The process includes primary shredding, air classification into heavy and light fractions with resource recovery or land-filling of the heavy fraction, and secondary shredding of the light fraction. The

Table 7. Unit conditions and particulate emissions at Wisconsin Electric Power Plant when burning RDF (36).

Test No.	Test Date	Steam Load (klb/hr)	RDF Feed (ton/hr)	Particulate Emissions (lb/MBTU)	Unusual Conditions
1	5/18/79	-	-	-	Invalid-improper sampling technique.
2	5/18/79	1677	0	0.159	
3	5/21/79	-	-	-	Invalid-improper sampling technique.
4	5/21/79	1802	0	0.172	
5	5/22/79	1775	0	0.242	
6	5/22/79	1719	0	0.228	
7	5/23/79	1690	0	0.342	Precipitator double powered; power supplies limited by arcing[a]
8	5/23/79	1882	0	0.137	" " " "
9	5/24/79	1726	0	0.058	Precipitator double powered.
10	5/24/79	1841	0	0.047	" " "
11	5/25/79	1758	0	0.050	" " "
12	5/25/79	1666	0	0.036	" " "
13	5/31/79	1557	30	0.066	" " "
14	5/31/79	1542	30	0.068	" " "
15	6/5/79	1658	30	0.186	
16	6/5/79	1602	30	0.196	
17	6/7/79	1596	21	0.390	
18	6/8/79	1594	20	1.442	Excessive pulverizer fineness.
19	6/8/79	1566	10	1.282	" " "
20	6/18/79	1591	20	0.736	
21	6/18/79	1547	20	0.658	
22	6/19/79	1554	10	0.566	
23	6/19/79	1514	10	0.448	
24	8/7/79	1533	0	0.960	Test interrupted due to system requirements.
25	8/22/79	1522	0	0.378	
26	8/22/79	1613	0	0.374	
27	8/23/79	1209	0	0.094	
28	8/24/79	1146	0	0.278	

[a]Arcing was in the temporary double power connections, external to the precipitator.

resultant RDF is transfered pneumatically to storage at the power plant for eventual co-combustion. Because the processing and co-combustion systems were designed in the early 70's, this facility did not benefit from improvements in processing and co-combustion designs developed in the last few years. The facility is currently (June 1980) shut down for equipment modifications and very little information is yet available about power plant particulate emissions when co-firing RDF. Again, it may be that experience gained at Ames in improving burnout and decreasing ash content of RDF will lead to significant improvements in air pollution control.

Densified RDF Co-combustion

With the exception of the ECO-FUEL II process marketed by Combustion Equipment Associates (CEA) there has been only minor effort put into investigating processes for densifying RDF and turning it into a powdered, pelletized or briquetted fuel for co-firing without modification to existing coal or oil-fired boilers or fuel-handling equipment.

Dust in the ECO-FUEL II production process is controlled with conventional baghouse technology added after the facility was first constructed. Some sulfur is added to the fuel in the chemical imbrittlement stage of the process to make the fuel brittle so that heated ball mills can be used to accomplish final size reduction (ball mills tumble small heated steel balls through the waste). The sulfur content specification of the fuel is 0.6 lb/million BTU heat input (7). Currently, ECO-FUEL II from CEA's ECO FUEL processing plant at Bridgeport, Connecticut is being co-fired with oil in a boiler located at United Illuminating Co. State particulate standards are being met, but meeting the Connecticut sulfur standard of 0.55 lb S/MBTU heat input is still in question. CEA claims an overall process energy efficiency equivalent to coarse size reduction only and the use of ECO-FUEL II is expected to require little or no boiler modification. EPA has contracted with Systems Technology Corporation (SYSTECH) of Xenia, Ohio to evaluate boiler performance and emissions while burning 285 tons of densified RDF briquettes (1/2" diam. x 3/4" long) in two small stoker-fired boilers (60,000 lb/HR and 75,000 lb/HR steam) at Hagerstown, MD. The report evaluating the tests of these boilers is in draft form (9) as of August 1980. The preliminary results from the Hagerstown tests did not indicate any significant boiler operating problems while burning briquette/coal blends although low steam demands prevented testing at full boiler loads. Briquettes were successfully fired at 100% of the boiler fuel during this evaluation but resulted in the clogging of bottom ash handling equipment.

Emissions tests showed 1) no significant increase in particulate emissions above coal alone (Table 8), 2) an increase in chloride emissions (Table 8), and 3) an increase in some metals and a decrease in others (Table 9). These results only indicate trends because they were observed during very low boiler load conditions and when using only low-efficiency cyclones for fly ash collection.

The data analysis is not yet completed for the second larger boiler tested by SYSTECH at Erie, Pennsylvania using densified RDF briquettes in a 150,000 lb/HR spreader-stoker steam boiler at which particulate emissions are controlled by an ESP. Also, in 1978 Detroit Edison evaluated the grinding and handling properties of a single, several hundred ton, batch of briquettes produced from ECO-FUEL II but an apparent mistake in briquette producion caused serious briquette deterioration, dust problems and equipment clogging and prevented continuous firing. This precluded any meaningful evaluation of boiler performance or emissions (31).

Table 8. Corrected field test results for four coal:dRDF blends. Stoker-fired boiler at Hagerstown, Maryland. (Emission data were normalized to the March referenced coal)(9).

Blend (Coal:RDF)	Date	Fraction of Rated Load	Boiler	ASH-GR/SCF	Chlorides ppm	Total Hydro carbons, ppm
1:0 (coal only)	3/19	.51	1	.311	72	
	3/19	.51	1	.458	84	
	3/21	.40	2	.267		21.9
	3/21	.40	2	.325	75	
	3/22	.40	1	.226	55	12.7
	3/28	.38	1	.197	38	13.7
	3/31	.27	1	.286	35	
	3/31	.27	1	.234	36	29.6
	4/1	.35	1	.281	44	34.1
	5/3	.25	2	.124	50	
	5/4	.20	2	.142	38	
	5/4	.22	2			
	5/5	.31	2	.087		
	5/5	.51	2	.084	38	
	5/16	.21	2	.247	50	17.3
	5/16	.36	2	.125	52	
	5/17	.17	2	.188		
	5/17	.17	2			
	1/20	.53	1	.238	11	13.1
	1/20	.53	1	.314	13	9.6
	1/21	.47	1	.154	6	13.7
	1/24	.53	1	.235	12	2.0
	1/25	.50	1			1.7
	12/10		1	.165	39	
	12/10		1	.173	46	
1:1	3/23	.43	1	.137	280	8.1
	3/23	.43	1	.189	289	18.0
	3/24	.44	1	.194	239	13.1
	5/12	.34	2	.161	234	
	5/12	.28	2	.170	206	
	5/13	.39	2	.107	175	18.8
	5/13	.30	2			
	12/8	.45	1	.196	202	8.1
	12/13	.45	1	.503	315	
	12/13	.45	1	.255	131	
	12/14	.43	1	.223	42	
	12/14	.43	1	.202	222	
1:2	3/29	.36	1	.201	407	19.3
	3/29	.36	1	.174	300	15.5
	3/30	.26	1	.178	280	33.5
	5/10	.36	2	.175	216	
	5/10	.30	2	.198	259	
	5/11	.36	2	.154	265	18.3
	5/11	.34	2			
0:1 (dRDF only)	5/14	.27	2	.268	654	55.7
	5/14	.26	2	.274	610	

Table 9. Average heavy metal emissions in stack particulates from blend firing tests of coal and densified RDF in stoker-fired boilers at Hagestown, Maryland (9).

MONTH	Coal: RDF Blend	No. of samples analyzed	Pb	Cd	As	Hg	Cr	Ni	Mn	Zn	Cu	Sn	Sb	Ag	Vn
			Threshold limit level, $\mu g/m^3$												
			200	20	500	100	100	1000	--	5000	--	--	500	10	
MARCH															
	1:0	7	228	≤4.43	173	≤7.85	35.1	32.6	47.7	592	≤51.7	≤1.46	<87.2	<8.72	<87.2
	1:1	3	3975	79.4	45.9	19.6	33.5	32.1	64.6	6012	96.1	3.36	<52.2	12.0	<52.2
	1:2	3	7660	233	44.9	12.3	47.6	41.0	101	8569	82.5	4.99	≤87.3	17.1	59.6
MAY															
	1:0	7	230	4.33	184	≤5.57	50.7	49.5	30.4	596	50.1	≤1.45	<65.6	<6.56	<65.6
	1:1	3	4237	72.4	153	15.7	35.4	35.9	62.6	5664	82.4	2.70	<48.5	<6.51	<48.5
	1:2	3	8217	220	126	11.4	55.4	50.9	115	8317	134	3.47	59.1	19.4	<59.1
	0:1	2	9953	267	49.4	94.7	79.7	29.4	275	8033	203	6.07	<107	29.7	<107

CEA claims (18) that the best approach to controlling hazardous metals emissions from solid waste-to-energy processes is to remove as many of the metals as practical in the front-end resource recovery process and then to produce a fuel with consistent burning characteristics that will eliminate hot spots and minimize incomplete combustion. In spite of efforts to remove all metals, lead emissions are still expected and may come from printing ink on the paper in MSW (32). A mass balanced of metals in ECO-FUEL II combustion has not yet been performed. CEA also expects that blending a consistent powdered RDF with coal or oil will improve burnout of the coal or oil (lowers the carbon content) and therefore will improve fly ash resistivity for electrostatic collection purposes.

RDF Processing In-Plant Air Quality Control

Essentially all RDF processing facilities that include any kind of shredding also include some type of in-plant dust collection system which generally is extended throughout the processing line. These systems collect dust from shredding operations, exhaust from air classification and pneumatic conveying as well as at other interim processing points. Baghouses generally are used as control devices because of their reliability and efficiency in meeting particulate emission standards. Bacterial and viral emissions from baghouse exhausts external to the building are not thought to be a problem (3) although only limited tests to verify this have been performed. Also, fines from these collectors may contain significant bacterial contamination but this has not been investigated. Current practice is often to burn them with the RDF.

Hempstead Resource Recovery Corp., Hempstead, New York

This private corporation built and operates a resource recovery system which is designed to take up to 2000 TPD MSW and produce RDF, through a wet-pulping process, which is then fired alone in an air-swept spout spreader stoker boiler.

Dust control equipment is used to control air quality within the front-end processing building. ESP air pollution control is used on the boiler stack and has been tested at 0.032 gr/std ft^3 (26) which is about 30% of the New York State particulate standard. Emissions data other than particulates were not available at the time of this writing but EPA has conducted other tests which will be published in the near future.

Mass-Incineration

RESCO (Refuse Energy System Co.) Saugus, Massachusetts

The system at Saugus consists of two 750 TPD Von Roll waterwall incinerators of European design that have been operated for 3-1/2 years at approximately their design capacity. Recent overhaul and grate replacement in the incinerators will raise total capacity to as much as 2000 TPD total MSW processed. Emission tests on the ESP's used for particulate control after a recent routine overhaul averaged 0.027 gr/std ft^3 as compared to a 0.05 gr/std ft^3 standard established by the State of Massachusetts (23). Incinerator residue is put through magnetic separation and is then sold as aggregate for use in road construction.

Nashville - Thermal Transfer Corp.

Thermal Transfer Corp. of Nashville operates two reciprocating grate waterwall incinerators rated at 360 TPD each. Original air pollution control equipment consisted of multicones and wet scrubbers. Emissions from these units did not meet air pollution standards of 0.08 gr/std ft^3 and these control devices were replaced with ESP's, one on each boiler unit (35). In addition to improved particulate collection efficiency, the increased draft also improved solid waste burnout. Since installation of the two ESP's, this waterwall incineration facility has operated very successfully with minimum manpower requirements, has met state standards for particulate emissions, and has had few operating problems after initial shakedown.

Pyrolysis Waste-to-Energy Systems

PUROX™ System

The PUROX™ pyrolysis system was developed by the Union Carbide Corp. and was successfully operated at a 200 TPD level for processing a combination of MSW and sewage sludge at South Charleston, West Virginia (24). The feedstock, consisting of shredded MSW with metals removed or a combination of processed MSW and partially dewatered sewage sludge, is injected near the top of a vertical reactor which has a counter-flow of hot gases (See Figure 3). The feedstock is dried in the upper section of the reactor, then descends further into a pyrolysis zone where breakdown of the cellulose produces gases, liquids and char. Pure oxygen is introduced at the bottom of the reactor to support the pyrolysis reaction. Pyrolysis products include 1) molten inorganic slag which is quenched and 2) gases which rise through the descending refuse column. The gases leave the reactor at the top to be cleaned of oils, liquids, moisture and particulates in a wet-scrubbing/ESP system. Afterwards, it can be used or sold as a medium-value BTU gas. Energy conversion is equivalent to mass incineration but net efficiency (including front-end processing) is only about 50% (35).

The gas cleaning system reduces the gas temperature to about 100°F which likely condenses most vaporized metals. This condensation, in combination with front-end metals removal, reduces trace metal emissions resulting from final project gas combustion to very low levels (25). Co-disposal of sewage sludge in the PUROX™ system results in a wastewater sludge having substantially reduced metals content when compared to conventional domestic wastewater sludge. The reason for this according to Union Carbide's mass balance information is that the majority of the metals in the feedstock are tied up in the inorganic inert silica slag taken off the bottom of the reactor.

Based on particulate loads in the product gas, Union Carbide estimates that particulate emissions from gas combustion after ESP control will be on the order of 0.001 to 0.003 gr/SCF at 12% CO_2 with trace metals emissions at correspondingly low levels in the stack (24). The PUROX™ System has baghouse dust control on the front-end typical of other shredding, classification and resource recovery systems.

ANDCO-TORRAX Pyrolysis System

The ANDCO-TORRAX system uses unprocessed MSW as feedstock in a vertical pyrolysis reactor similar in operational characteristics to the PUROX™ system except that preheated air rather than pure oxygen is used to support the reaction. Consequently, the heating value of the pyrolysis gas is too low to justify cleaning and resale. Instead, it is burned immediately in a secondary combustion chamber using minimum excess air. A portion (10%) of the exhaust gases are used to meet pyrolysis reactor preheat needs through use of regenerative heating towers and the remainder is used to produce steam in a heat recovery boiler (35). Conversion and net efficiencies are similar to those experienced for the PUROX™ process. The use of a secondary combustion chamber instead of a product gas cleaning system eliminates any significant wastewater stream, but the lack of front-end metals recovery and low temperature product gas cleaning before final gas combustion means increased potential for trace metals emissions in the air pollution stream relative to the PUROX™ system. However, compared to conventional mass incineration installations of similar size, ANDCO-TORRAX claims (ton for ton of MSW) approximately 40% less exhaust gas volume (30). Therefore, it is expected to produce at least 40% lower emissions per ton of refuse disposed than mass incineration with equivalent air pollution control equipment. This does not take into account any differences in tie-up of metals in inert slag versus incinerator residue. Like PUROX™, the TORRAX system also produces an inert slag which is usable as concrete aggregate or is suitable for landfilling.

The ANDCO-TORRAX system has been sold and constructed in Western Europe (4 installations), Japan (1 installation), and the U.S. (1 for MSW disposal and for simulating disposal of nuclear wastes at Orlando, FL) (4).

Occidental Research Corporation Flash Pyrolysis

The flash pyrolysis system developed by Occidental Research Corp. has been tested briefly in a demonstration plant constructed at El Cajon, California with funds coming primarily from Occidental but with some support from EPA and San Diego County. This 200 TPD process (35) consists of pyrolysis of the shredded light organic fraction of MSW in a fast moving (1400°F) gas and particle stream recycled from the char burner. This gas cools in the reactor to an average pyrolysis temperature of 950°F before entering a cyclone for removal of char to the char burners for recycling. Residence time in the reactor is about 5 sec. The gas continues to an oil quenching, decanting system for recovery of product oil and the remaining product gas is compressed and used as 1) an oxygen free transport gas, 2) as fuel for preheating combustion air in the char burner, and 3) as fuel in the afterburner. Again, low-product-gas temperature before combustion in the afterburner and front-end metals removal indicates low potential for trace metals emission after baghouse control. Conversion efficiencies are lower than other pyrolysis systems mentioned here partially because there is heating value left in the char. The recovered product oil can be mixed with No. 6 fuel oil and burned. The system was demonstrated at the El Cajon facility although extended continuous operation did not ensue. As a result, extensive air emissions testing did not take place.

PYRO-SOL Indirect-Heated Pyrolysis

The PYRO-SOL process is an indirect heated pyrolysis system currently used in a 50 TPD scale plant to dispose of an RDF obtained from an auto salvage operation. It also has been tested using MSW and wood chips as feedstock (33). The system consists of primary shredding and then feeding through an air lock into a sealed horizontal pyrolysis reactor or "tunnel". A vibrating bed moves the feedstock from one end of the 60-ft length to the other at an average temperature of 1750°F with a slightly lower temperature at the air lock end than at the char collection end. The system is heated indirectly through tubes spaced over the vibrating bed (throughout the tunnel length). Product gas and waste heat also are recovered throughout the reactor. The product gas leaves the reactor at approximately 1100°F, is cleaned and quenched in a cyclone and wet scrubber and the cooled gas (350 - 400 BTU/SCF) is stored for use in a gas boiler/steam generator combination. The Bay Area Air Pollution Control District has tested the boiler when burning PYRO-SOL production gas. Test results show particulate emissions of 0.023 gr/SCF which is well below the standard of 0.15 gr/SCF but this included noticeable rust from an infrequently used boiler (1). Because of this, these emission results are probably higher than would be the case in day to day boiler operating conditions.

A high energy content char is produced from the waste and is processed via magnetic separation and air classification and a small percentage of it is used to filter scrubber wastewater. It may also have market value or possibly could be burned on site to produce more energy for indirect heating (33).

REFERENCES

1. Air Pollution Control District, San Francisco, CA. "Summary of Stack Test Results on 6/20/79 Test of PYRO-SOL Process (July 1979).

2. Ajax, R. "U.S. Environmental Protection Agency, Personal communication (January 1980).

3. Ames Laboratory Quarterly Report, Pollutant Characterization and Safety Research Division, Ames Laboratory, Ames, Iowa (April-June 1979).

4. "Andco-Torrax Process For Slagging Pyrolysis of Solid Waste", Andco, Inc.,Buffalo, N.Y., company bulletin.

5. Barlow, K., Madison Gas and Electric; Madison, WI. Personal Communication (January 16, 1980).

6. Bowen, M.D., Smyly, E.D., Knight, J.A., Purdy, K.R. "A Vertical-Bed Pyrolysis System". Tech-Air Corp., Atlanta, GA. Proceedings of symposium sponsored by the Division of Environmental Chemistry at 175th Meeting of ACS, Anaheim, CA (March 13-17, 1978), ACS Symposium Series #76.

7. Combustion Engineering Associates, NY, NY. ECO-FUEL II Process, Unpublished company paper (undated).

8. Cornaby, B., Battelle- Columbus, personal communication (May 16, 1980).

9. Degler, G.H., "A Field Test Using Coal: dRDF Blends in Spreader-Stoker Fired Boilers", Final Report for EPA Project 68-03-2426, Systech, Zenia, Ohio.

10. Devitt, T.W., "Air Pollution Emissions and Control Technology for Waste-As-Fuel Processes," PEDCO Environmental, Inc., Cincinnati, Ohio (October 1979).

11. Environmental Protection Agency, "Resource Recovery and Waste Reduction Activities - A Nationwide Survey, SW-432a (November 1979).

12. Freeman, H., U.S. Environmental Protection Agency, Unpublished information presented at the EPA-Sponsored Waste-To-Energy Technology Update 1980, Cincinnati, Ohio (April 15-16, 1980).

13. Golanbiewski, M., "Environmental Assessment of Waste-to-Energy Processes: Braintree Municipal Incineration," Final Report for EPA contract 60-02-2166 (April 1979).

14. Gorman, P.G., "St. Louis Demonstration Final Report: Power Plant Equipment, Facilities and Environmental Evaluation". U.S. Environmental Protection Agency Report EPA-600/2-77-1556 (December 1977).

15. Greenberg, R.R., Zoller, W.H., Gordon, G.E. "Composition and Size Distribution of Particles Released in Refuse Incineration," Environmental Science and Technology, 12, 5, 566 (May 1978).

16. Griffeth, D.M., "The Recovery of Solid and Gaseous Resources from Industrial Wastes Using the PYRO-SOL Process," H.S. Haslam and Associates, (January 1979).

17. Hall, J.L. et al., "Evaluation of the Ames Solid Waste Recovery System: Parts I, II, III. U.S. Environmental Protection Agency Report EPA 600/7-79-222 (October 1979).

18. Hasselriis, F., Combustion Engineering Associates, Personal Communication (April 17, 1980).

19. Joensen, A.W, et al., "Evaluation of the Ames Solid Waste Recovery System: Refuse Processing Plant and Suspension-Fired Steam Generators." Draft Report for EPA Grant No. R803903-01-0 (Undated).

20. Joensen, A.W., Iowa State University, Personal Communication (January 17, 1979).

21. Lewis, D.F., "The Occurrences of Lead in Municipal Solid Waste," Proceedings of the Fifth Annual Research Symposium on Municipal Solid Waste: Resource Recovery," Orlando, FL, (March 26-29, 1979).

22. Martin, W.J., Weiand, H., "Practice of Heat Utilization from Refuse" Proceedings 8th National Wastes Processing Conference, American Society of Mechanical Engineers, Chicago (May 7-10, 1978).

23. McDonough, T., "Refuse Energy System Co., Saugus, MA. Personal Communication (January 9, 1980).

24. Moses, C.T., "Co-Disposal of Sludge and Refuse in a PUROX™ Converter," Solid Wastes and Residues-Conversion by Advanced Processes, Proceedings of symposium sponsored by the Division of Environmental Chemistry at 175th Meeting of ACS, Anaheim, CA, (March 13-17, 1978), ACS Symposium Series #76.

25. Mudge, L.K. and Rohrman, C.A., "Gasification of Solid Waste Fuels in a Fixed-Bed Gasifier," Proceedings of symposium sponsored by the Division of Environmental Chemistry at 175th Meeting of ACS, Anaheim, CA, (March 13-17, 1978), ACS Symposium Series #76.

26. New York State Department of Environmental Conservation, "Stack Gas Results on Hempstead Resource Recovery Facility (April 30 and May 1, 1979).

27. Nowak, F., "Development of the Kiener Pyrolysis System for Environmental Protection, Energy Recovery and Recycling," Proceedings, 8th National Waste Processing Conference, American Society of Mechanical Engineers, Chicago (May 7-10, 1978).

28. Scaramelli, A.B., "Resource Recovery Research Development and Demonstration Plan," Mitre Corp. Technical Report MTR-79W00173 (October 1979).

29. Shelton, R.C., "Stagewise Gasification in a Multiple-Hearth Furnace for Co-Disposal of RDF and Sludge," Proceedings of symposium sponsored by the Division of Environmental Chemistry at 175th Meeting of ACS, Anaheim, CA, (March 13-17, 1978), ACS Symposium Series #76.

30. Stanley, D.M., Andco Inc., Personal Communication (February 18, 1980).

31. Stevens, N., Detroit Edison, Personal Communication (January 18, 1980).

32. Titus, G., City of Ames, Iowa, Personal Communication (September 1979).

33. Welty, J., PYRO-SOL, Inc., Personal Communication (April 1980).

34. Williams, R.D., Gross, J.R., "Development of Pilot Plant Gasification Systems for the Conversion of Crop and Wood Residues to Thermal and Electrical Energy," Proceedings of symposium sponsored by the Division of Environmental Chemistry at 175th Meeting of ACS, Anaheim, CA, (March 13-17, 1978), ACS Symposium Series #76.

35. Wilson, E.M., "Engineering and Economic Evaluation of Waste-to-Energy Systems," Final Report EPA Project 68-02-2101. The Ralph M. Parsons Co. (May 1978).

36. Wisconsin Electric Power Co. "Resource Recovery Project Particulate Emissions Evaluation Program," Final Report (February 1980).

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APPENDIX A

STATUS OF AIR POLLUTION STANDARDS APPLICABLE TO WASTE-TO-ENERGY PROCESSES

1. New Source Performance Standards (NSPS)

   a. Co-combustion

New Source Performance Standards for particulate emissions from electric utility boilers larger than 250 mil BTU/hr heat input (approximately 10T/hr coal) recently have been revised downward by the U.S. Environmental Protection Agency from 0.1 to 0.03 lb/10^6 BTU (A1). The revised NSPS for industrial boilers are expected to be in a similar range. These standards are maximum and may be lowered significantly depending on regional and local off-set criteria. These standards also are expected to apply to boilers co-firing RDF with other fossil fuels.

   b. Mass-incineration

The U.S. EPA has proposed a new Federal NSPS of 0.03 gr/dSCF for incinerators greater than 50 tons per day. Current federal standards for mass incinerators is 0.08 grains per dry standard cubic foot (gr/dSCF) with many states having lower standards (Maryland = 0.03 gr/dSCF; Massachusetts = 0.05 gr/dSCF)(A2). New NSPS are likely to be set by best available control technology.

Gaseous phase Chloride (HCl) apparently is being considered in the NSPS review required by the Clean Air Act Amendments of 1977 because of the increased occurrence of polyvinyl chloride (PVC) in municipal solid wastes. Heavy metals, particularly lead (Pb) and cadmium (Cd), similarly are under review as possible NSPS's in the hazardous pollutant category. However, the fate of those proposals depend on the results of studies not yet completed by EPA.

c. Pyrolysis

There currently are no NSPS specific to pyrolysis processes. These processes are expected as a minimum to meet indirect heat boiler emission standards or process weight emission standards which vary according to heat input.

2. Ambient Air Standards

EPA is planning to propose an ambient air standard for respirable particulates in addition to the current ambient standard of 75 $\mu g/m^3$ annual geometric mean for total suspended particulates (A3). It is not known how this ultimately may affect NSPS for co-fired boilers, mass-incinerators or pyrolysis processes.

REFERENCES

A1. Title 40 CFR 60.42a

A2. Title 40 CFR 60.52

A3. Title 40 CFR 50.6

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