October 1992 • NREL/TP-431-4988D

Data Summary of Municipal Solid Waste Management Alternatives

Volume IV: Appendix B—RDF Technologies

SRI International
Menlo Park, California

National Renewable Energy Laboratory
A Division of Midwest Research Institute
Operated for the U.S. Department of Energy
Under Contract No. DE-AC02-83CH10093

Printed in the United States of America
Available from:
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Price: Microfiche A01
Printed Copy A07

Codes are used for pricing all publications. The code is determined by the number of pages in the publication. Information pertaining to the pricing codes can be found in the current issue of the following publications which are generally available in most libraries: *Energy Research Abstracts (ERA)*; *Government Reports Announcements* and Index (*GRA* and I); *Scientific and Technical Abstract Reports (STAR)*; and publication NTIS-PR-360 available from NTIS at the above address.

NREL/TP-431-4988D • UC Category 249 • DE92016433

Data Summary of Municipal Solid Waste Management Alternatives

Volume IV: Appendix B—RDF Technologies

SRI International
Menlo Park, California

NREL Technical Monitors: Bimleshwar Gupta
Philip Shepherd

National Renewable Energy Laboratory
(formerly the Solar Energy Research Institute)
1617 Cole Boulevard
Golden, Colorado 80401-3393
A Division of Midwest Research Institute
Operated for the U.S. Department of Energy
under Contract No. DE-AC02-83CH10093

Prepared under subcontract no: RF-1-1103

October 1992

Report Organization

This report, *Data Summary of Municipal Solid Waste Management Alternatives*, comprises 12 separately bound volumes. Volume I contains the report text. Volume II contains supporting exhibits. Volumes III through X are appendices, each addressing a specific MSW management technology. Volumes XI and XII contain project bibliographies. The document control page at the back of this volume contains contacts for obtaining copies of the other volumes.

Volume	Contents	Document Number
I	Report Text	TP-431-4988A
II	Exhibits	TP-431-4988B
III	Appendix A Mass Burn Technologies	TP-431-4988C
IV	Appendix B RDF Technologies	TP-431-4988D
V	Appendix C Fluidized-Bed Combustion	TP-431-4988E
VI	Appendix D Pyrolysis and Gasification of MSW	TP-431-4988F
VII	Appendix E Material Recovery/Material Recycling Technologies	TP-431-4988G
VIII	Appendix F Landfills	TP-431-4988H
IX	Appendix G Composting	TP-431-4988I
X	Appendix H Anaerobic Digestion of MSW	TP-431-4988J
XI	Alphabetically Indexed Bibliography	TP-431-4988K
XII	Numerically Indexed Bibliography	TP-431-4988L

TABLE OF CONTENTS

TABLE OF CONTENTS (cont)

LIST OF TABLES

LIST OF TABLES (cont)

LIST OF ILLUSTRATIONS

B.1 INTRODUCTION/OVERVIEW

Refuse-Derived Fuel, termed RDF, has come to mean any fuel product derived from the processing of municipal solid wastes (MSW). In addition to the recovery of a solid fuel, the term RDF also can be applied to liquid and gaseous fuels which are generated from processed waste materials through chemical or biological conversion. Further, strictly speaking, raw MSW is a form of RDF (21, 272, 861).

RDF can be produced to a range of specifications, classified on the basis of particle size, density, and production process. The American Society for Testing and Materials (ASTM) through its E-38.01 Energy Subcommittee on Resource Recovery (currently part of D34.13) established classifications defining the different types of RDF. These characterizations are provided in Table B-1.

TABLE B-1.
ASTM CHARACTERIZATION OF RDF (67)

Type of RDF	Description
RDF-1	Municipal solid waste used as a fuel in as-discarded form
RDF-2	MSW processed to coarse particle size, with or without ferrous metal separation, such that 95% by weight passes through a 6-inch square mesh screen
RDF-3	Shredded fuel derived from MSW and processed for the removal of metal, glass, and other entrained inorganics. The particle size of this material is such that 95% by weight passes through a 2-inch square mesh screen. Also called "fluff" RDF.
RDF-4	The combustible fraction processed into powdered form, 95% by weight passing through a 10-mesh (0.035-inch square) screen.
RDF-5	The combustible fraction densified into the form of pellets, slugs, cubettes, briquettes, or some similar form.
RDF-6	The combustible fraction processed into a liquid fuel (no standards have been developed).
RDF-7	The combustible fraction processed into a gaseous fuel (no standards have been developed).

The main difference between mass bum and RDF technologies is that, in the latter case of RDF, the refuse is processed prior to burning. The technologies associated with the use of unprocessed MSW as a fuel, classified as RDF-1 by the ASTM, are discussed in Appendix A. Mass Bum Technologies.

RDF-2, often termed coarse RDF, is MSW which has been shredded to a coarse particle size to make it more homogeneous. Ferrous metals may be removed, but this separation is not necessary within this definition. This type of RDF is suitable for firing on semi-suspension combustors with continuous stokers designed for either coal or refuse firing, or both. Examples of such systems are: Akron, Ohio; Columbus, Ohio; and Rochester, Massachusetts (SEMASS).

RDF-3, fluff RDF, is shredded finer in size than RDF-2. It is always air-classified and often screened for glass and grit removal. RDF-3 can be co-fired with pulverized coal in suspension-fired boilers where stationary drop or dump grates are sometimes installed above the wet furnace bottom of the boiler to enhance burnout of materials such as wood, leather, and rubber. Removal of large objects, especially metals, glass, and other non-combustible materials would enable the RDF to be combusted without major modifications to a standard, existing pulverized coal boiler ash discharge system. Examples of such systems are Ames, Iowa; Madison, Wisconsin; and Lakeland, Florida. RDF-3 can also be combusted in dedicated semi-suspension fired, spreader stoker boilers (as with RDF-2), as in Saco, Maine; Orrington, Maine; Hartford, Connecticut; Anoka County (Elk River), Minnesota; and Ramsey-Washington County (Newport), Minnesota.

RDF-4 is a powdered RDF. Under the tradename, "EcoFuel," RDF-4 was produced at a rate of 600 TPD in a full-scale plant in Bridgeport, Connecticut and co-fired in suspension with oil at substitution levels of up to 50 percent in boilers at United Illuminating Company. The Bridgeport RDF production plant was operational for one year, from September 1979 to September 1980. There are no records of suspension firing EcoFuel without the addition of pulverized coal or oil, and there is no report that RDF-4 has ever been fired in a semi-suspension combustion system. The process, though demonstrated at high capacities for short periods of time, was beset with explosions and technical difficulties and was never proven as a commercial, economically viable system. Since RDF-4 is no longer produced commercially, it will not be discussed further in this document.

RDF-5 is known as densified or d-RDF. It is produced by first producing RDF-3 and then compressing it into pellets, cubes, or briquettes. There has been some commercial interest in producing d-RDF in order to reduce the degree of modification or retrofit needed to combust RDF in existing coal-fired boilers. However, this technology has not received the level of commercial implementation in the U.S. that has been achieved by RDF-2 and RDF-3.

RDF-6 is the result of the chemical conversion of RDF-3 through pyrolysis into a liquid fuel. This technology is detailed in Appendix D. RDF-7 is produced by processing waste or RDF into a gaseous fuel. This can be acomplished by means of anaerobic digestion, as was demonstrated by the DOE-sponsored Pompano Beach, Florida Project or by pyrolysis (gasification in the absence of oxygen), as was demonstrated by the EPA-funded Baltimore Project which used the Monsanto proprietary technology (Landgard). These technologies are discussed in Appendices H and D, respectively. Significant progress has been made recently in fluid bed gasification of coal and biomass fuels which could make gasification of RDF a commercial reality in the future. However, at the present time, although successfully demonstrated at pilot scale, RDF-7 production has not been commercially proven at large scale in the United States.

Figure B-1 illustrates the typical unit operations for producing RDF types 1 through 5 (805). The mechanical processing of municipal solid waste (MSW) prior to combustion serves to reduce particle size, remove non-combustibles, and render the fuel more uniform, or "homogenized" (484). Processing also facilitates removal of slag-forming inert materials and certain metals and other elements that pose potential environmental impacts via air emission or ash disposal (67). In addition to fuel enhancement, the processing of MSW and removal of certain materials prior to burning has the added benefit of allowing materials recovery, viewed as an advantage of RDF technologies (24).

Table B-2 provides a comparison of unprocessed raw refuse with one type of RDF recommended for burning in suspension-fired boilers. Comparisons of RDF produced for three suspension-fired systems at full-scale operations are provided in Table B-3. As can be seen, RDF is a superior fuel to raw refuse. However, since mechanical separation is not 100% effective, the RDF fuel enhancement is accompanied by a loss of combustibles during processing. Some RDF systems produce a high quality fuel but have a reduced fuel yield while other systems produce a lower quality fuel but have a higher fuel yield.

RDF technologies may be defined by the type of RDF and by the type of combustion system that can utilize that particular type of RDF fuel. The level of fuel processing, type of equipment, and subsystem configuration of an RDF system depends on the requirements of the fuel user. Use of a dedicated boiler that can be tailored to the nature of the RDF likely will minimize the extent of RDF processing required. Conversely, co-firing RDF in an existing industrial boiler or suspension-fired utility boiler usually will require more extensive processing to produce a finer, more uniform RDF (484).

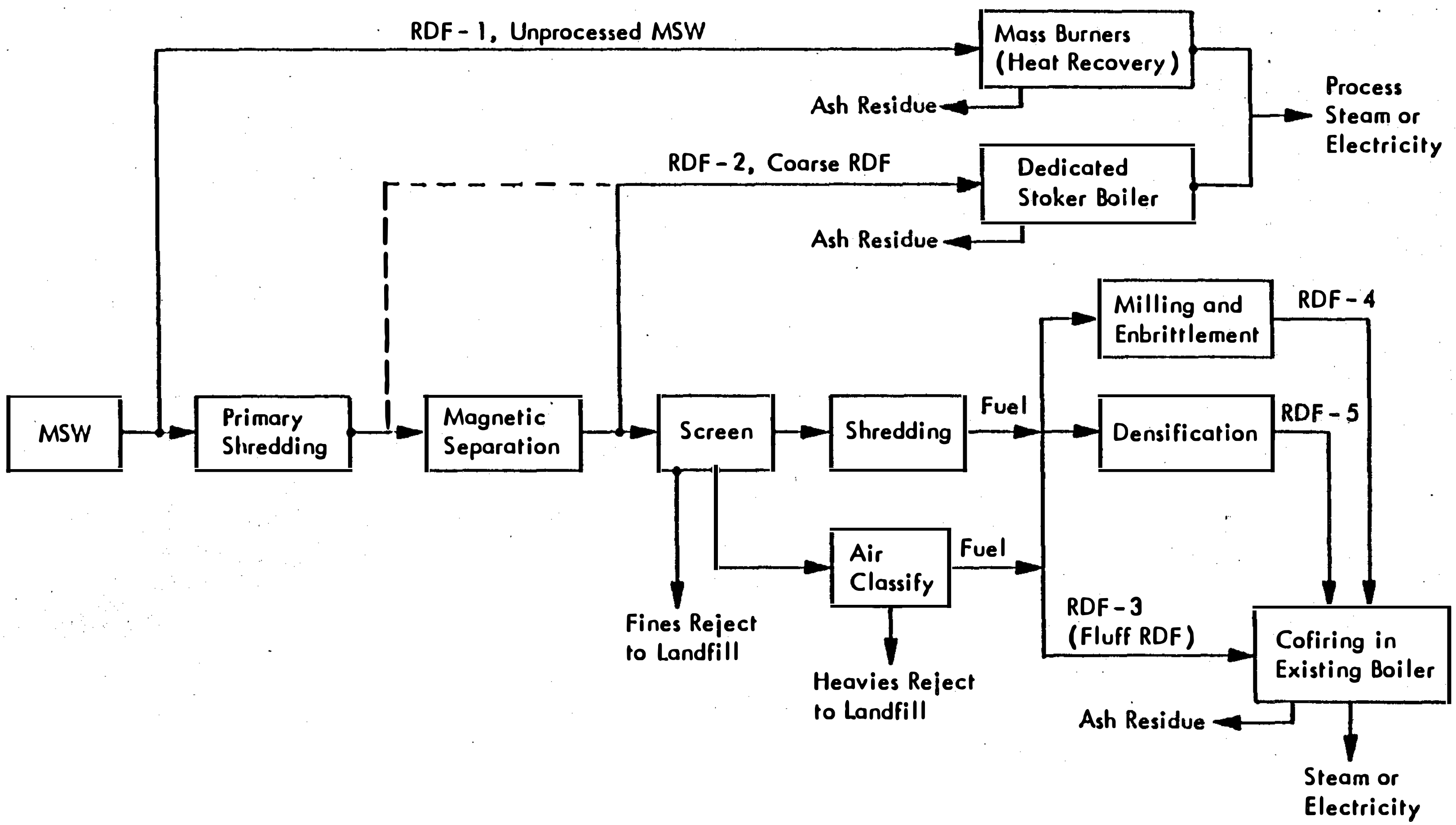


Figure B-1. Preparation of Various ASTM Classes of RDF (805)

TABLE B-2. COMPARISON OF RAW REFUSE (MSW) VS RDF CHARACTERISTICS (255, 805)

As Received Property	MSW	RDF
Maximum particle size	10 in. or greater	2.5 in.
Heating Value	4500 Btu/lb	5900 Btu/lb
Moisture	30% by weight	24%
Ash	25% by weight	12%
Sulfur, %	0.42	0.27
Nitrogen, %	0.71	0.57
Carbon, %	36	41

TABLE B-3. RDF PROPERTIES -- OPERATIONAL FACILITIES (805)

As Received Property	Ames, IA 1982	Baltimore, MD 1980	Milwaukee, WI 1979
Heating Value, Btu/lb	6356	6296	4800
Moisture, % by Wgt	22.5	28.0	31.3
Ash, % by Wgt	8.5	12.2	15.5
Ash, lb/MMBtu	13.4	19.4	32.3

B.1.1 Background

Prior to the evolution of modem-day RDF technology and the pursuit of recycling in the early 1970s, America's primary alternative to landfilling was incineration. In most cases, incineration was carried out without heat recovery. In addition, there was little or no consideration for air pollution control or ash disposal requirements. Many municipal incinerators were shut down because of unacceptable levels of emissions and the high costs associated with providing satisfactory controls or retrofits to reduce emission levels. One solution to the high costs was the recovery and sale of energy to reduce the cost of disposal (67).

The shift in demand from the early mass-burning technologies to RDF followed the evolution of coal combustion technology. Early coal-fired combustion systems burned coal on overfeed, mass-burning stokers. As coal combustion evolved, the technology began to shift toward the newer generation spreader stoker semi-suspension systems which provided higher efficiency and lower cost per unit of energy production. Coal burning technology then evolved into building "front-end processing" systems to "grind" the coal into a fine dust or powder which was then pneumatically blown into the furnace where it burned in suspension much like oil, providing more efficiency at higher capacities. Today, no new mass-fired coal units are being manufactured. In smaller commercial and industrial installations where coal is more cost effective than oil or gas, spreader stokers are still being installed for coal. Many utilities continue to operate spreader stoker boilers which were built many years ago, but almost all new utility boilers are pulverized coal boilers.

In the early 1970s, the spreader stoker and pulverized coal boiler market that could utilize RDF as a fuel became attractive. To produce a fuel which would be compatible with the coal boilers required RDF particle size control and materials recovery. In addition to energy recovery, the potential recovery of materials from MSW was a major factor in the development of the concept of processing wastes (67).

The U.S. Bureau of Mines (USBM) was a pioneer in the processing of MSW, conducting extensive research to recover metals and minerals as well as to produce RDF. The USBM tested both MSW and incinerator ash obtained from many localities throughout the nation to determine the composition and methods of separation into major constituents (865, 883).

Employing techniques from the mining industry for materials separation, the USBM's first pilot plant was intended to recover ferrous metals (two grades), aluminum (two grades), glass (two grades), and a fine ash from incinerator residue. Equipment included rotary trommels, magnetic separators, rod mills, froth flotation cells, screens, hammermills, and dewatering screws and clarifiers. Experience gained showed that the value and marketability of incinerated metals and glass were reduced due to contamination during combustion. Materials were believed to be more valuable if they were removed prior to the incineration process. Further, such RDF processing, if successful, could recover paper and plastic as well as glass, aluminum, and ferrous metals for recycling. This led to the USBM's second pilot plant aimed at the recovery of materials and energy from raw, unprocessed MSW. A flowsheet of the raw refuse processing plant in the mid-1970s is shown in Figure B-2 (883).

In 1972, the National Center for Resource Recovery (NCRR), an organization formed by the packaging and beverage industries, began conducting fundamental and applied research on resource recovery through its pilot plant testing facility in Washington, DC. The NCRR focused on glass and aluminum recovery and also conducted research on waste processing unit operations such as air classification, conveying, and screening. Also during the early 1970s, several private companies conducted original research on their own proprietary systems to recover RDF and materials from MSW. Such firms included: American Can, Occidental Petroleum (formerly Garrett Research and Development Company), Raytheon Company, National Teledyne Corporation, Monsanto, Parsons-Whittemore, and Hercules also conducted original research on their own proprietary systems to recover RDF and materials from MSW.

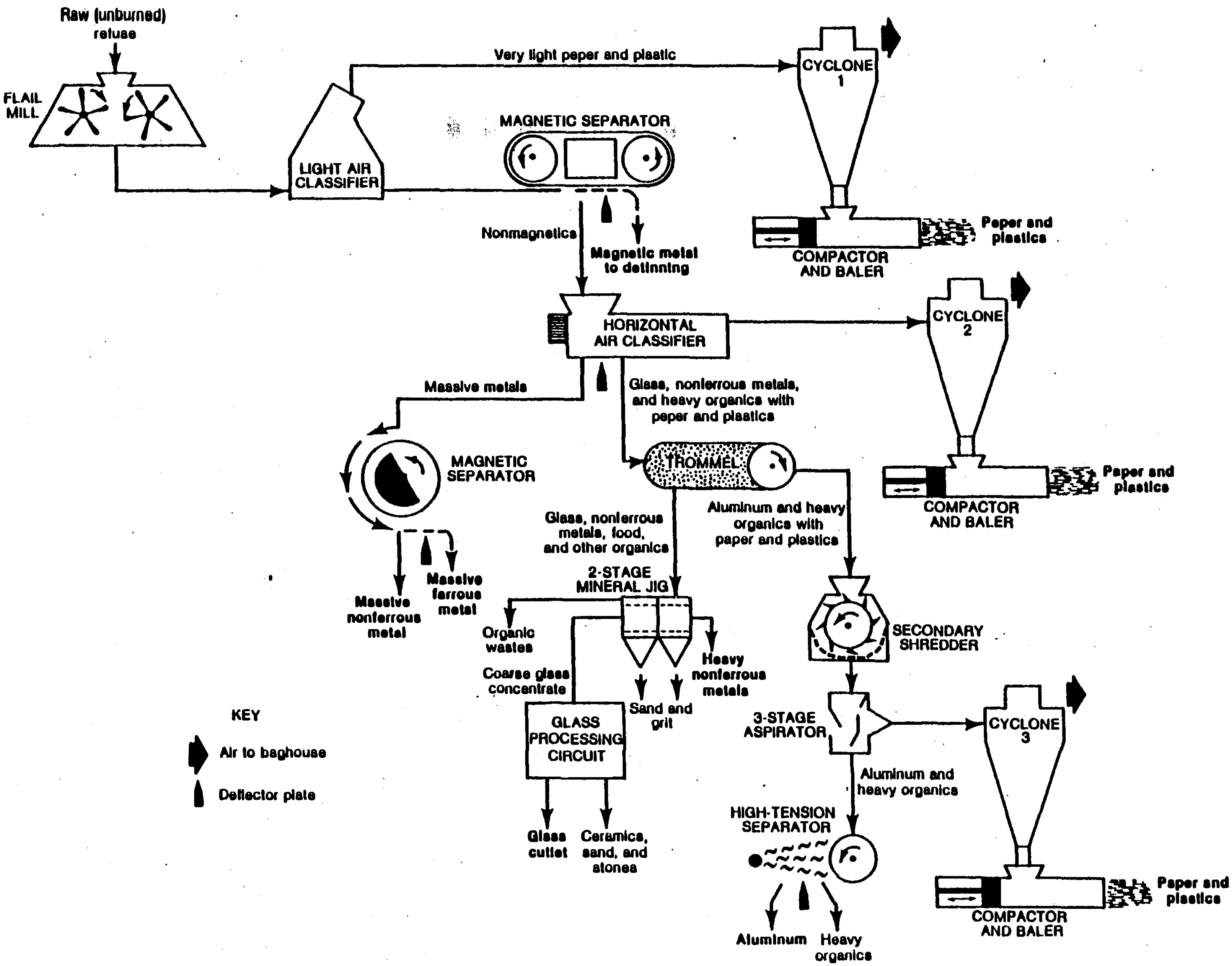


Figure B-2. USBM Raw Refuse Processing Flowsheet (883)

B.1.1.1 RDF Demonstration Programs

Concurrent with the pilot plant programs conducted by the USBM and others, the U.S. EPA initiated several large-scale demonstration programs, starting in 1972 that were aimed at: 1) recovery of metals and minerals from incinerator residue (Lowell, Massachusetts); 2) recovery of paper from refuse (Franklin, Ohio); 3) energy recovery from refuse by co-combustion with coal in utility boilers (St. Louis, Missouri); 4) pyrolysis of refuse into oil (San Diego, California); 5) pyrolysis of refuse into gas (Baltimore, Maryland); and 6) digestion of refuse into humus combined with the co-firing of RDF with oil (Wilmington, Delaware). These demonstration programs were critical steps to the commercial implementation of many full-scale RDF projects. Further, they showed not only what could be done on a practical scale, but also showed that some technologies were not technically and/or financially practical. Those programs involving the production of RDF-2 and -3 are described below.

After the energy crisis in 1973, the newly-created Department of Energy took up the charge for development of demonstrations of synthetic fuel recovery, co-generation, and long-range development of energy efficient technologies. In the RDF arena, the DOE funded testing to demonstrate production and use of RDF in cement kilns, the production of RDF and its chemical conversion into methane through anaerobic digestion, and numerous efforts in the production of d-RDF and recovery of energy.

B.1.1.1.1 St. Louis, Missouri Demonstration Plant (RDF-3). In the early 1970s, it was thought that refuse (MSW) could be fired directly into existing utility boilers as a substitute for pulverized coal after only shredding and magnetic separation. The St. Louis project was funded by the EPA to demonstrate this technology. The RDF produced was transported to Union Electric's Meramec station and blown into their pulverized coal boilers through a simple pipe. A diagram of the facilities for receiving, storing, and burning the RDF is shown in Figure B-3. Problems experienced in storage, pneumatic conveying, and ash handling were presumed to result from metals, oversize materials and glass contained in the waste. Air classifiers were added to improve the storage, metering, and combustion characteristics of the fuel. Union Electric initiated a larger scale project, almost 10 times in size, as a private venture. However, due to certain regulatory restrictions, the project was canceled even after much of the equipment had been procured.

The St. Louis plant was closed in 1975. However, several utilities, private companies, and communities followed Union Electric's lead and initiated similar large scale projects. Among these were Ames, Iowa; Chicago, Illinois; Milwaukee, Wisconsin; Madison, Wisconsin; and Monroe County, New York. The

Ames and Madison plants have been operational for more than 10 years. Monroe County operated for 3 years before being closed for economic reasons. Chicago and Milwaukee closed after about 1 year of operation. These projects typically fired 5% to 20% RDF by heating value.

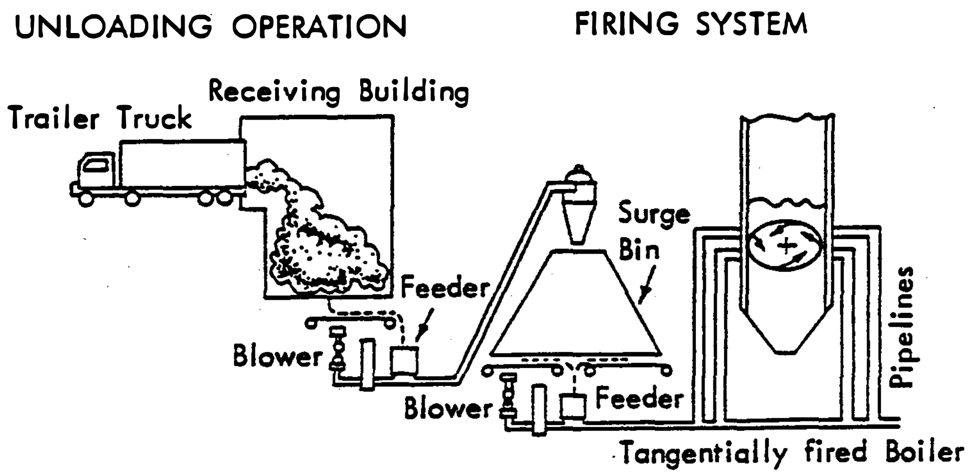


Figure B-3. Schematic Diagram of Union Electric Facilities to Receive, Store, and Burn RDF (884)

B.1.1.1.2 Franklin, Ohio Demonstration Project (RDF-3). This $3.2 million, 150 TPD project demonstrated the Hydrasposal/Fiberclaim system developed by Black Clawson, a division of Parsons & Whittemore. Refuse was placed in a hydropulper and mixed with water. Paper and cardboard contained in the waste were segregated into a long fiber product, dewatered, and ultimately used in making roofing felt. The shorter fibers were combusted in a fluid bed combustion unit along with sewage sludge. Metals (ferrous and nonferrous) were recovered and glass was sorted into clear, amber, and green colors and sold. This project, which closed in 1978, laid the foundation for much larger projects developed by Parsons & Whittemore for Hempstead, New York and Dade County, Florida. The Hempstead plant started up in 1978 and was permanently shut down in 1980 (387). A schematic diagram of the as-built Dade County project in 1982, showing wet and dry systems, is provided in Figure B-4. This facility was operational at a capacity of 3,000 TPD. A substantial retrofit was recently conducted by Montenay, the current operator. The hydropulping system was removed and replaced with a more conventional dry RDF processing system. The glass and non-ferrous metal recovery systems are not presently functioning.

B.1.1.1.3 Delaware Reclamation Project (RDF-3). The Delaware Reclamation Project (DRP) is the only one of the original EPA demonstration projects which is still operational. When originally proposed by Hercules, the project was to demonstrate a number of technologies including the production of RDF and co-firing RDF-3 into Delmarva Power and Light's Edgemore Power station; the recovery of ferrous metals, aluminum, and glass from the heavy fraction remaining after RDF removal; and the recycling of the heavier combustible material by conversion of this material into humus through co-composting with municipal sewage sludge.

The plant was built by Raytheon Service Company under contract to the Delaware Solid Waste Authority. Currently operational, it has a capacity of 1000 TPD of MSW and 350 TPD of sewage sludge. It produces RDF-3; mixed color glass, by froth flotation; mixed nonferrous metals, by a passive and active eddy-current separator; ferrous metals, by simple two-stage magnetic separation; and humus, by an aerobic digestion process from RDF and dewatered sewage sludge. A flow diagram of the system is shown in Figure B-5.

The RDF that is produced by shredding and air classification in a large rotary drum air classifier, was never fired in Delmarva's Edgemore Station because the utility would not commit to purchase the RDF for a long enough period to justify the capital investment for associated RDF storage, metering and feeding systems at their facility. Initially, the RDF was landfilled (which was assumed at the time of financing). Later, five Vicon mass-fired modular combustors were installed to burn the RDF along with unprocessed MSW. This combustion system, the Energy Generating Facility, was operational for about 3 years selling steam to ICI Americas and electricity to Delmarva Power and Light. It has been closed for economic reasons.

B.1.1.1.4 d-RDF Programs (RDF-5). Since the 1970s, there has been an interest in replacing the conventional fuel used in smaller institutional boilers (e.g., universities, hospitals) and industrial boilers with RDF. Thirteen test programs on the combustion of d-RDF were reported (875) for the period 1972 to 1981 (Table B-4). These tests ranged from 40 tons to approximately 8,000 tons of pellets combusted in various boilers, cement kilns, and retort furnaces. In mid-1985, eight d-RDF production facilities were reported (873); most of which were pilot or demonstration facilities. Also, a 700-ton d-RDF production run was conducted in 1983 at the Monroe County (New York) Resource Recovery Facility (874). Pellets produced were burned in various boilers in the Rochester, New York area. Warren Spring Laboratory has reported considerable experience with d-RDF production and combustion in the United Kingdom (876, 877, 878). However, although demonstrated successfully, d-RDF technology has achieved little commercial significance in the United States to date.

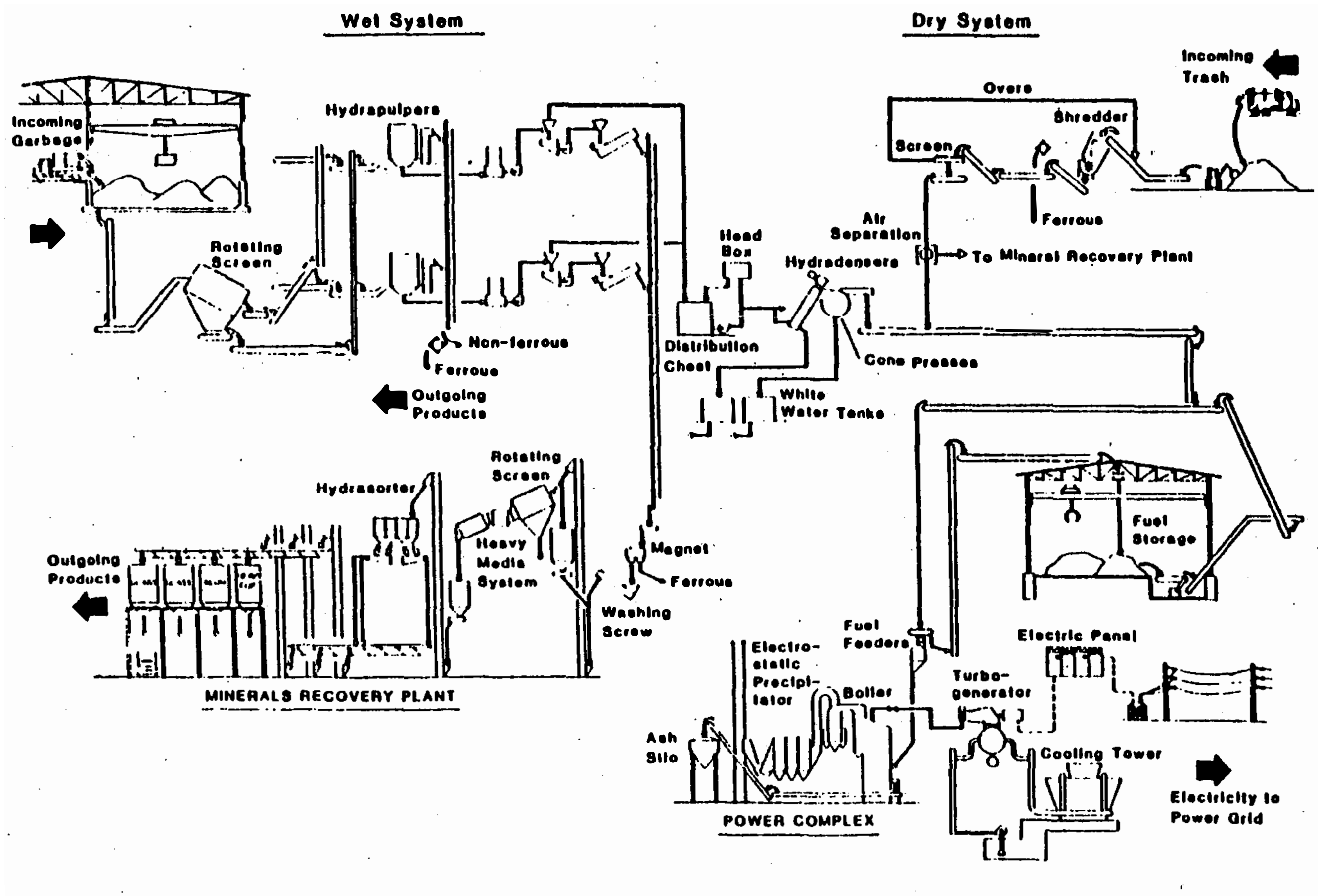


Figure B-4. Dade County, Florida Project Schematic Diagram (67)

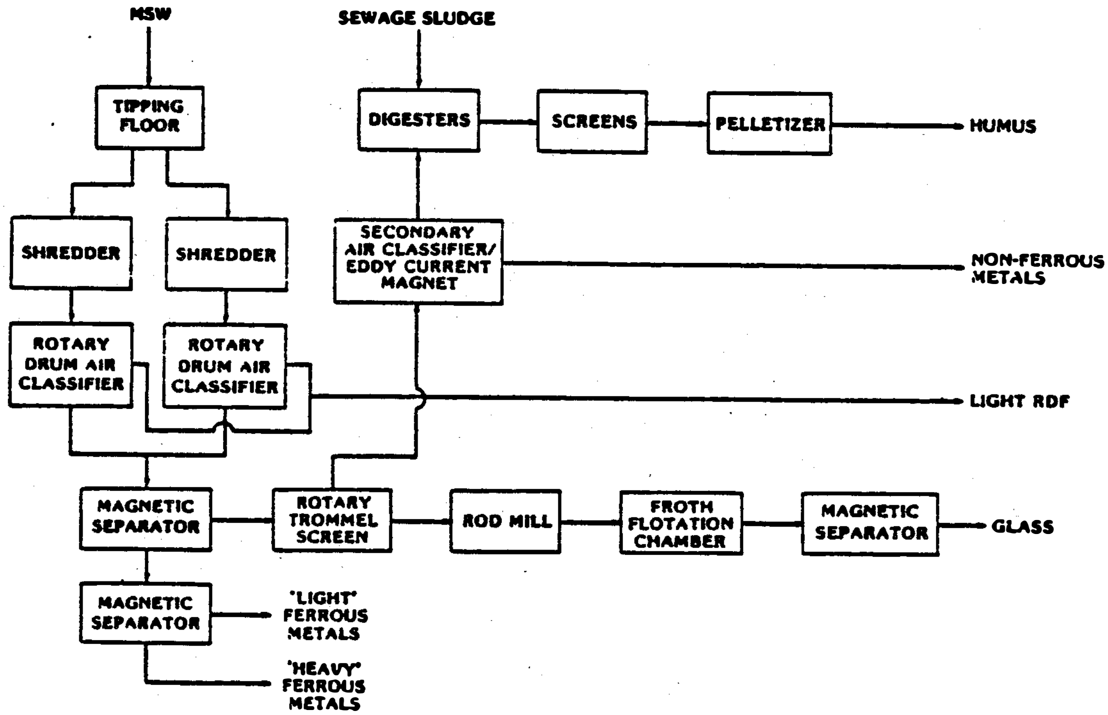


Figure B-5. Flow Diagram of the Delaware Reclamation Plant (484)

B.1.1.2 Early Commercial RDF Systems

A total of 23 RDF-type facilities were built or financed in the United States and Canada prior to 1982 (21). Table B-5 indicates those 11 RDF plants that produced RDF-3 which was then transported to a separately owned and operated boiler where it was fired in suspension with conventional fossil fuel -- normally, pulverized coal. The energy facility in each case was not responsible for preparation of the RDF and had an alternative fuel available that could sustain its operation without the use of RDF. In most cases, the RDF-3 was co-fired with pulverized coal in suspension-fired boilers. In the case of the closed Bridgeport, Connecticut plant, RDF-4 was co-fired with fuel oil in a cyclone boiler. As noted on Table B-5, seven of the eleven plants were closed as of 1987. Of those shown to be in operation as of 1987, all have actual operating throughputs below design; i.e., Ames - 174 TPD, Cockeysville - 600 TPD, Lakeland - 275 TPD, and Madison - 250 TPD (387).

TABLE B-4. d-RDF TEST BURN SUMMARY (885 as cited in 875)

Location/User	Date	Boiler Description	d-RDF Quantity & Description	d-RDF Producer	Comments
Ft. Wayne, Ind. Ft. Wayne Mun. Power Co.	1972	Underfeed-multiple retort	40 tons 1½" x 1½" x 2 cubettes	National Recycling Corp.	3:1 by volume; 6850-8350 Btu/lb.
Appleton, Wis. Consolidated Paper	May 1976, Oct. 1976	52,000 lb/hr modified for gas; tested with gravity feed, manual ash removal	40 tons 3/4" pellets	Grumman	Market development test
Green Bay, Wis. Ft. Howard Paper	Nov. 1976	275,000 lb/hr Babcock & Wilcox spreader stoker	40 tons 3/4" pellets	Grumman	1:3 & 1:2 blends; market development test
Palmerstown, Pa. Hercules Cement	April 1975	Cement kiln	Reground 200 tons 1-1/8" & 5/8" pellets	Vista	7 day test—problems in regrind with existing pulverizers
Sunbury, Pa. Pennsylvania Power & Light	May 1975	Suspension-fired utility boiler	Reground 80 tons 5/8" pellets	Heikki Elo	2 day test
Dayton, Ohio Wright-Patterson Air Force Base	July 1975	80,000 lb/hr traveling grate-spreader stoker	40 tons 3/8" pellets	Black Clawson	34 hrs. 1:1; 6 hrs. 1:2
Champagne, Ill. Chanute Air Force Base	Sept.-Oct. 1975	35,000 lb/hr traveling chain grate-gravity overfeed	150 tons 1-1/8" pellets	Vista	1:1 and 0:1; 4 boxcars; material degraded in transit and long storage
Hagerstown, Md. Maryland Correc-tional Institute	March, May 1977	60,000 lb/hr Erie City spreader stoker	280 tons ½" pellets	NCRR	58 hrs. 1:1, 53 hrs. 1:2, 29 hrs. 0:1
Hagerstown, Md. Maryland Correc-tional Institute	Fall 1978	As above	250 tons ½" & 1" pellets	Teledyne National	3 test burns over approx. 2 months
Spring Grove, Pa. P.H. Glatfelter Co.	Fall 1978	Small bark boiler	100 tons ½" & 1" pellets & some fluff	Teledyne National	Market development test
Washington, D.C. Gen. Services Admin. Va. Heating Plant (Pentagon)	March 1979	70,000 lb/hr underfed multiple retort	125 tons ½" pellets from office wastes	NCRR	30 hrs. 4:1; 30 hrs. 2:3; 90 hrs. 3:2; 6600 Btu/lb.
Erie, Pa. General Electric	March-April 1979	125,000 lb/hr spreader stoker	2000 tons ½" pellets	NCRR 700 tons; Teledyne National 1300 tons	Testing conducted by Systems Technology Corp.
Dayton, Ohio Wright-Patterson Air Force Base	May 1979-Oct. 1981	80,000 lb/hr spreader stoker—traveling grate	approx. 8000 tons ½" pellets	Teledyne National	Contract for $27 ton F.O.B. plant

TABLE B-5. RDF TYPE PREPROCESSING FACILITIES IN NORTH AMERICA, BUILT PRIOR TO 1982 (21)

Facility Location	Design Capacity (tons/day)	Year Started	1987 Status
Ames, Iowa	200	1975	Operating
Cockeysville, Maryland	1200	1978	Operating
Bridgeport, Connecticut	1800	1979	Shut Down
Chicago, Illinois (SW)	1000	1978	Shut Down
Lakeland, Florida	300	1982	Operating
Lane County, Oregon	500	1979	Shut Down
Los Gatos, California	200	1976	Shut Down
Madison, Wisconsin	400	1979	Operating
Milwaukee, Wisconsin	1000	1977	Shut Down
Rochester, New York/ Monroe County	2000	1980	Shut Down
Tacoma, Washington	750	1978	Shut Down

Among the remaining 12 pre-1982 RDF projects, listed in Table B-6, only one was closed -- Hempstead, New York. Reportedly, emission of dioxins was partly responsible for closure. Odors, labor issues, and operational problems were also key factors (348, 484). The 11 operating projects produce RDF-2 or RDF-3. In all but two cases (Albany, New York and Wilmington, Delaware), the operations of the power plant and the RDF fuel preparation plant are under the control of the same entity. A better success record is evident in those plants listed in Table B-6 where the same entity controls both the boiler operation and the RDF preparation system. Also, these plants employ dedicated boilers especially designed to burn waste fuel thus affording greater technical potential for success compared to boilers that are not specially designed to burn RDF as a secondary fuel.

TABLE B-6. DEDICATED PREPARED FUEL TYPE PREPROCESSING FACILITIES IN NORTH AMERICA, BUILT PRIOR TO 1982 (21)

Facility Location	Design Capacity (tons/day)	Year Started	1987 Status
Akron, Ohio	1000	1979	Operating
Albany, New York	750	1981	Operating
Columbus, Ohio	2000	1983	Operating
Duluth, Minnesota	400	1980	Operating
Hamilton, Ontario	500	1974	Operating
Haverhill/Lawrence, Massachusetts	1300	1984	Operating
Niagara Falls, New York	2000	1981	Operating
Miami, Florida	3000	1982	Operating
Hempstead, New York	2000	1980	Shut Down
Rochester, New York/Kodak	120	1974	Operating
Toronto, Ontario	220	1978	Operating
Wilmington, Delaware	1000	1982	Operating

B.1.2 Current RDF Systems

The 1991 Resource Recovery Yearbook prepared by Government Advisory Associates (GAA), Inc. (387) provides information on a total of 294 waste-to-energy facilities -- 55 are in conceptual planning, 202 are in advanced planning (62) or existing (140), and 37 are permanently shut down. The RDF facilities included in the advanced planning/existing category are tabulated in Table B-7 by status and process. The following paragraphs summarize the overall status of RDF projects in each of the three categories.

TABLE B-7. RDF FACILITIES -- ADVANCED PLANNED/EXISTING (387)

FACILITY	CITY	ST	DESIGN CAPACITY (TPD)	OWNER	OPERATOR	START UP DATE
Advanced Planned RDF, Shredded Facilities						
Chester Resource Recovery Project	Chester	PA	2250	City of Chester	A.B.B. Resource Recovery Systems (C.E.)	/
Petersburg	Petersburg	VA	700	United Bio-Fuel Industries, Inc.	United Bio-Fuel Industries, Inc.	/
San Marcos (Northern San Diego County)	San Marcos	CA	2100	North County Res. Recovery Associates	North County Res. Recovery Associates	/
Tulalip Indian Tribe	Marysville	WA	2200	Tulalip Indian Tribe (or public auth.)	A.B.B. Resource Recovery Systems (C.E.)	/
Advanced Planned RDF, Fluidized-Bed Combustion Facilities						
Robbins Resource Recovery Facility	Robbins (Village of)	IL	1200	Reading Energy Company	Bechtel Corporation	/
Truckee Meadows Res. Recovery Facility	Reno	NV	1000	Truckee Meadows Limited Partnership	Truckee Meadows Limited Partnership	/
In Construction RDF, Pelletized Facilities						
Broward County (Reuter)	Pembroke Pines	FL	660	Reuter Recycling of Florida, Inc.	Reuter Recycling of Florida, Inc.	/
Jefferson County	Lee	WV	550	Jefferson County	Waste Service Technologies	/
In Shakedown RDF, Pelletized Facilities						
Fairbanks (Waste Tech.)	Fairbanks	AK	200	WasteTech	WasteTech	/
Robertson	Robertson	TN	150	Robertson County	Robertson County	10/90
Operational RDF, Shredded Facilities						
ANSWERS Plant	Albany	NY	800	City of Albany	EAC Operations-Albany, Inc.	02/81
Akron Recycle Energy Systems (RES)	Akron	OH	1000	City of Akron	wTe Corporation/City of Akron	06/79
Albany Steam Plant	Albany	NY	600			04/81
Anoka County/Elk River R.R. Project	Elk River	MN	1500	No. States Power/United Power Associates	Northern States Power Company	08/89
City & County of Honolulu	Honolulu	HI	2160	City of Honolulu/Ford Motor Credit Corp.	A.B.B. Resource Recovery Systems (C.E.)	05/90
Columbus S.W. Reduction Facility	Columbus	OH	2000	City of Columbus	City of Columbus	06/83
Dade Co. S.W. Resource Recovery Project	Miami	FL	3000	Dade County	Montenay Power Corporation	01/82
Delaware Reclamation Project	Newcastle	DE	1000	Delaware Solid Waste Authority	Raytheon Service Company	03/84
Greater Detroit Res. Recovery Facility	Detroit	MI	4000	Greater Detroit Res. Recovery Authority	A.B.B. Resource Recovery Systems (C.E.)	07/89
Humboldt	Humboldt	TN	100	City of Humboldt	City of Humboldt	10/89
Lawrence & Haverhill (RDF)	Lawrence & Haverhill	MA	900	Ogden Martin Systems of Haverhill, Inc.	Ogden Martin Systems of Haverhill, Inc.	03/85
Maine Energy Recovery Company (MERC)	Biddeford	ME	607	Maine Energy Recovery Company	KTI Operations, Inc.	12/87
Niagara Falls	Niagara Falls	NY	2000	Occidental Chemical Corporation	Occidental Chemical Corporation	12/80
Palm Beach County (North)	Riviera Beach	FL	2000	Solid Waste Authority of Palm Beach Co.	Babcock & Wilcox/National Ecology	11/89
Penobscot Energy Recovery Company (PERC)	Orrington	ME	750	Penobscot Energy Recovery Company	ESOCO Orrington, Inc. (Energy National)	06/88
Ramsey & Washington Counties	Newport	MN	1000	Northern States Power Company	Northern States Power Company	07/87
SEMASS	Rochester	MA	1800	SEMASS Partnership	Bechtel Civil, Inc.	10/88
Southeast Tidewater Energy Project	Portsmouth	VA	2000	Southeastern Public Service Authority	Southeastern Public Service Authority	01/88
Tacoma (RDF Plant)	Tacoma	WA	500	City of Tacoma	City of Tacoma	07/79

N/A = Not Available

TABLE B-7. RDF FACILITIES -- ADVANCED PLANNED/EXISTING (cont)

FACILITY	CITY	ST	DESIGN CAPACITY (TPD)	OWNER	OPERATOR	START UP DATE
Operational RDF, Pelletized Facilities						
Hennepin County (Reuter)	Eden Prairie	MN	800	Reuter Recycling, Inc.	Reuter Recycling, Inc.	03/87
Iowa Falls	Iowa Falls	IA	100	Waste Resource Recycling Company	Waste Resource Recycling Company	10/88
Muncie	Muncie	IN	150	Muncie Paper Products	Muncie Paper Products	09/90
Thief River Falls	Thief River Falls	MN	100	Pennington County	Future Fuels, Inc.	11/85
Yankton	Yankton	SD	100	Arnes Recycling, Inc.	Arnes Recycling, Inc.	12/89
Operational RDF, Fluidized-Bed Combustion Facilities						
La Crosse County (French Island)	La Crosse	WI	400	Northern States Power Company	Northern States Power Company	07/88
Operational RDF-Coal, Burned Together Facilities						
Ames	Ames	IA	200	City of Ames	City of Ames	09/75
Madison	Madison	WI	400	City of Madison	City of Madison	01/79
Mid-Connecticut	Hartford	CT	2000	Connecticut Resource Recovery Authority	Metropolitan District Commission	10/88
RDF Plant/CD McIntosh Power Plant Unit 3	Lakeland	FL	300	City of Lakeland/Orlando Utility Comm.	City of Lakeland	07/83
Tacoma (Steam Plant)	Tacoma	WA	300			03/90
Operational RDF, Co-disposal With Sludge Facilities						
Duluth	Duluth	MN	400	Western Lake Superior Sanitary District	Western Lake Superior Sanitary District	03/81
Operational - No Fuel Customer RDF-Coal, Burned Together Facilities						
Baltimore County	Cockeysville	MD	1200	Baltimore County/Maryland Envir. Service	Maryland Environmental Service	01/76
Temporarily Shutdown RDF, Shredded Facilities						
WRI-Dade, Inc. (wTe Corporation)	Dade County	FL	600	WRI Dade, Inc. (wTe Corporation)	WRI Dade, Inc. (wTe Corporation)	04/89

N/A = Not Available

B.1.2.1 Conceptually Planned Facilities

The recent unsettled regulatory and economic climate has slowed the growth of the waste-to-energy industry. Overall, there has been a substantial reduction of 60% in conceptually planned installations, from 139 facilities in 1988 to 55 facilities in 1990 (387). Conceptually planned RDF facilities displayed a lesser reduction of 42% during this same time period, however, and as a result, they commanded a higher percentage of the waste-to-energy market in 1990 (20%) than they did in 1988 (13.8%) or 1986 (10.4%). The data show a constant increase in the number of conceptually planned RDF facilities. Of the total overall planned market, 8.3% will produce RDF to sell to off-site customers.

B.1.2.2 Advanced Planned/Existing Projects

RDF projects represent 21.4% of the 202 existing and advanced planned projects (compared to mass burn field-erected units with a market share of 51.5%, and modular combustion with 26.7%). This represents an increase from the 17.8% share that RDF facilities commanded of the 1988 existing and advanced planned projects. RDF technologies represent 25% of the 140 existing operating projects, but only 12.9% of the 62 advanced planned projects. Of the latter, the average capacity of RDF plants is 1,333 TPD compared to 1,151 TPD for mass burn plants.

B.1.2.3 Permanently Shut Down Projects

RDF plants account for 35% of the 37 permanently shut down projects. However, they also account for nearly 78% of the $1 billion (in 1990 dollars) that was expended on all shut down facilities. Small, relatively inexpensive modular facilities made up the highest percentage of shut down facilities (38%) skewing the cost percentage toward the fewer, although relatively more expensive RDF plants. Mass burning plants accounted for 11 percent of the closures. Of the shut-down installations, 32 percent, or most of the RDF plants, shipped RDF off-site for combustion.

B.2 TECHNOLOGY DESCRIPTION

The key to success of an energy recovery system is controlling the combustion process so that the heat produced can be transferred from the hot combustion gases to some other medium -- usually water contained in a boiler. Regardless of whether mass burning or RDF technology is employed, certain conditions must be met in order to avoid damage to the boiler (484):

- The temperature of combustion gases entering the boiler's main heat transfer section should not exceed 1600°F in order to avoid high temperature corrosion.

- The temperature of the combustion gases leaving the boiler must be maintained above 300°F to prevent the corrosion that results from the condensation of acids present in the gas stream.

- The volatile gases released during combustion must be well mixed with the air and completely burned before the gas stream enters the boiler section, because corrosion can occur if the boiler environment alternates between oxidizing and reducing conditions.

Controlling the gas temperatures and conditions is particularly difficult in municipal solid waste combustion systems because of the inherent variability of the fuel (484). Cooling the combustion gases entering the boiler can be accomplished in two ways: 1) adding excess air, or 2) removing heat through radiation to the furnace waterwalls (which also enhances thermal efficiency). The temperature leaving the furnace can be controlled partly by regulating the energy output of the boiler, or, if inadequate load demand exists, by blowing off steam. Complete combustion is controlled by ensuring that adequate time, temperature, and turbulence exists in the combustion zone.

Based on these ideal fuel burning considerations, technologies which prepare the fuel prior to combustion had apparent theoretical advantages over combustion of unprocessed waste fuels. RDF potentially offered smaller furnace size, lower excess air requirements, and thus higher combustion efficiency. RDF could also provide faster response times to load changes and lower ash content due to materials recovery (67). Disadvantages would be the space and cost associated with the fuel preparation system.

B.2.1 RDF Production - Process Operations

RDF is produced from MSW by a series of processes aimed at increasing fuel quality. There are basically two generic types of successful RDF systems with substantial commercial experience in the United States today: 1) production of coarse RDF (RDF-2) and firing in semi-suspension dedicated spreader stoker boilers, and 2) production of fluff RDF (RDF-3) for either suspension cofiring with pulverized coal or firing in semi-suspension boilers. The unit operations involved in the production of these fuels are discussed in the following paragraphs.

B.2.1.1 Size Reduction

Size reduction of MSW and fuel liberation in the production of RDF is critical to combustion efficiency. The size of the fuel particles directly affects their ability to devolatilize. The smaller the pieces, the more rapidly their volatile components will evolve and burn. Further, large pieces of RDF tend to insulate their interior, so more time is required for the volatile material to become sufficiently hot to vaporize. Large particles can plug the feed system and cause slow ignition of the fuel which can result in increased carbon loss and loss of flame stability. More of the large particles will burn on the grate than in suspension (104).

In general, size reduction of the MSW: 1) reduces large size pieces to prevent blockage of downstream processing steps; 2) produces smaller fuel particles which burn more quickly; 3) produces more uniform composition of the fuel to reduce the variability of heat release in the boiler; 4) liberates individual particles trapped inside containers for subsequent removal and recovery; and 5) densifies process rejects, thereby conserving landfill disposal volume (56).

There are four major types of shredders for MSW size reduction: 1) horizontal shaft hammermills, 2) vertical shaft hammermills, 3) flail mills, and 4) rotary shear shredders. Several other types of size reduction devices have been used in RDF production, including cannon shredders, ball mills, hydropulpers and screw compactors (57, 67, 271, 484), but these have not been applied to suspension cofiring of RDF-3 with pulverized coal at commercial levels for long periods of time.

Hammermill shredders are the preferred size reduction device especially for single stage operations or as the primary device (57, 59, 67, 271, 484). These hammermills and pulverizers produce the greatest degree of control over the particle size of the finished product because the refuse cannot escape the shredder until it is ground down fine enough to pass through a grate, which resembles a large screen. Among the suppliers of this equipment are: Williams Patent Crusher, Hammermills Inc. Division of Pettibone, American Pulverizer, Newell, Hazemag, Gruendler, and Jeffrey Division of Dresser Industries.

Hammermills have the greatest experience in MSW processing but are susceptible to explosions and have high maintenance and operations costs. Explosions and risk of fire result from the high impact grinding of a heterogeneous material where sparks can occur and from overheating due to grinding the feedstock (57). In the early days of RDF production, explosions were a major cause of downtime and project failures. Explosions are not nearly the problem that they used to be in processing RDF due to the development of sophisticated designs to accommodate, not prevent, them. Explosion suppression devices, manufactured primarily by Fenwall Inc., were and are still used frequently to reduce the damage and incipient fires from explosions. In some cases, the Fenwall system can prevent explosions. However, recent trends have been to vent the explosions and control and direct their energy and force rather than trying to eliminate them through suppression. Explosive vapor detection devices both on the tipping floor and downstream of the shredder, induced downdraft, sufficient ventilation, and personnel training and safety procedures are other precautions that can be taken to avoid explosions, as suggested by Nolett (196), based on many years of high volume shredding in Albany, New York.

Vertical shaft shredders and pulverizers do not normally provide the degree of control over "top size" that is provided when the shredder has a grate to control particle size. The reason is that vertical shaft shredders have a large "annulus" through which long stringy materials can pass. Particle size is controlled to some degree by the length of the hammer arm and clearance between the hammer and the breaker plates on the sides of the machine. Heil is the principal supplier of this equipment, sometimes called the Heil Tollemache unit (licensed by Heil from Tollemache in England).

Flail mills were first applied to refuse by the U.S. Bureau of Mines. A Longhorne double flail was used in the Bureau's pilot plant. Since that time, a front feed flail mill has been employed on a number of RDF projects (e.g., Madison, Wisconsin and Ogden, Utah). Asea Brown Boveri (ABB) and National Ecology, Inc. (NEI) developed similar units which are used in their Hartford, Connecticut and Palm Beach, Florida facilities, respectively. The Williams "Scramblers" which were also made available to flail MSW, were installed by KTI Operations, Inc. and Northern States Power in their projects, but have since been removed and replaced with conventional hammermills due to inadequate control over top size. Although the flail mill, which is somewhat like a hammermill without a grate, is believed to reduce the potential for explosions, explosions have been known to occur in these machines.

Rotary shear shredders have also been applied to processing refuse as well as oversized bulky wastes (870). Although the shear shredder may be of value in producing RDF-3 for cofiring with pulverized coal, it has not been used for this purpose to date.

The rotary shear shredder installation in Elmira (Chemung County), New York, which uses proprietary Cedarapids equipment, has been operating for more than 5 years at capacities near 50 tons per hour (871). Another installation of the same design was installed in Charleston, South Carolina and reached instantaneous daily inputs exceeding 100 tons per hour and averaged over 60 tons per hour for several months (872). Saturn Shredders also furnished rotary shear shredders to Charleston which were portable and operated successfully on the face of the landfill. Triple S Dynamics and Shredding Systems are also suppliers of this equipment. The Williams rotary shear shredders in Dade County, Florida and in Saco, Maine (Maine Energy Recovery Company) were installed, tested, and later removed and replaced with conventional hammermills.

Rotary shear shredders have the advantages of never having produced an explosion from processing refuse, and requiring relatively little power consumption. However, the rotary shear shredder does produce a product which can contain oversized materials which are quite large at least in one dimension. It is important when considering rotary shear shredders to note that this type of shredder does not pulverize glass; thus, the glass will not be significantly reduced in size from its size in the raw MSW. Accordingly, following rotary shear shredding, a screen or trommel will not operate as efficiently in glass removal as an air classifier. The air classifier must be able to accommodate large size objects. The glass would fall out as a heavy fraction. Screening may still be useful in removing dirt and grit from the waste.

B.2.1.2 Materials Separation

B.2.1.2.1 Air Classification. Air classification is critical in the suspension firing of RDF with pulverized coal primarily because it separates materials that can be pneumatically conveyed from those that can not. This processing step may also increase the heating content of the fuel or reduce ash content in the RDF but these are secondary objectives compared to preparing the RDF for pneumatic transport into the suspension fired boiler.

The most significant types of air classifiers that have processed shredded MSW are: the vertical column furnished by Rader Pneumatics; the conventional rotary drum air classifier furnished by Cedarapids; the vibroelutriator furnished by Triple S Dynamics; and the air knife, usually custom designed by each engineer. A zig-zag air classifier, also custom designed, was used in early RDF-3/coal cofiring projects.

According to EPRI's 1988 report (805), "a recent trend has been to perform separation for combustible recovery using an air knife and/or disc or other screens rather than an air classifier. Air knives and air classifiers both work on aerodynamic principals, but the air knife typically does not remove as much heavy material from the shredded MSW material flow stream as the air classifier" (805).

Air classifiers are susceptible to jamming, and their performance can be inconsistent when dealing with fluctuations in feed rate and feed composition (57). Moreover, air classifiers are less effective in separating glass, sand, and grit that cause abrasion and slagging problems downstream (271).

Although air classification has traditionally been carried out following primary shredding, it may be desirable to carry out air classification ahead of primary shredding in order to reduce the potential for explosions in the primary shredder (195, 196). Under the auspices of the New York State Energy Research and Development Authority (NYSERDA), an 18-month test program (1984-1986) was conducted in Albany, New York on a rotary drum air classifier (RDAC*tm*) developed by All American Engineering Company (AENCO). The RDAC*tm* was used to air classify both shredded and unshredded MSW to determine the benefits of air classification to combustion. It has not been used to prepare RDF for suspension firing with pulverized coal, however, a similar device was installed in Rochester, New York to produce RDF-3 for firing at Rochester Gas & Electric. Tests were conducted on spreader stoker boilers. Test results revealed a higher RDF yield than with other known equipment, high processing rates with low power consumption, and greater steam production from the RDF produced than with RDF produced by shredding and magnetic separation only. Also, boiler feed and furnace slagging problems were minimized.

B.2.1.2.2 <u>Screening</u>. Screening is usually performed in the preparation of RDF-3 to reduce ash content by screening out broken glass and dirt. Rotary screens or trommels and disc screens are the two primary types of screens for RDF production. Vibrating screens are applicable in RDF processing only for fine size feed material due to the tendency of a flat screen to "blind" with wire and oblong objects. A vibrating screen was used in Rochester, New York to remove glass and grit from the light fraction after primary shredding and air classification. The air classifier only picked up very fine glass -- the rest dropping out into the heavy fraction.

Trommels have proven effective in upgrading the combustible fraction of MSW on a reliable, commercial basis (91). Experience indicates that trommels require only limited maintenance and are adaptable to many site-specific feedstock characteristics (57, 91). Often, more than one stage of trommel screen is used, or alternatively, the trommel contains two sections with different size holes. Among the manufacturers of trommels, the largest are Heil and Triple S Dynamics.

The largest manufacturers of disc screens for RDF applications are Heil Engineering, Rader Pneumatics, and Williams Patent Crusher. National Recovery Technologies (NRT) has also developed a rotary screening device which is of a unique design for removing fine size ash and grit from RDF. It involves lifters which are like "cups" which catch the fines and drop them on a discharge conveyor for removal from the drum.

B.2.1.3 Materials Recovery

B.2.1.3.1 Magnetic Separation. Magnetic separation is critical for removal of ferrous metals from the RDF which can damage downstream processing equipment and create maintenance problems in the RDF storage systems, boilers, and ash discharge systems of the power plant. Most magnetic separators do not produce a salable ferrous metal product without substantial added processing to remove trash and contamination. Prior to shipment, ferrous can be shredded and baled, nuggetized, or processed through a rolls crusher to densify the product for shipment and meet end-user specifications (67, 271, 484).

There are numerous types of magnetic separators which have been used in preparing RDF, including drum, in-line belt, cross belt, head pulley, and combinations thereof. Magnets are of the permanent (both ferro-magnetic and rare-earth) magnet type and the electromagnet type. Wet High Intensity Magnetic Separators (WHIMS) and high intensity magnetic separators [HIMS] are used in glass recovery, but not in the production of RDF. Differential magnetic separators are special applications and designs of the conventional types of magnets. The three largest suppliers are Stearns Magnetics, Dings Magnetics, and Eriez Magnetics.

The goals and design of a magnetic separator to properly remove a high percentage of ferrous metal from the MSW or heavy fraction of RDF, or light fraction of RDF, is quite different than the design of a magnetic separator which produces a clean ferrous metal product which can be sold. Materials handling considerations to properly handle wire, strapping, heavy massive ferrous items, and long bars (e.g., reinforcing rod) makes magnetic system design critical to the operation of an RDF plant. Although magnetic system design seems simple, and is in principle, plants continue to make major design errors in the proper application and design of their magnetic separation systems causing substantial retrofit problems. Magnetic separation is particularly important for production of RDF-3 where the particle size of the RDF is quite small, less than 1-1/2 inch. Residual ferrous metal in the RDF can still cause problems. For example, if the RDF contains 1/10th of a percent ferrous metal (99.9% ferrous free) and the RDF cofiring rate is 200 TPD, then the amount of ferrous metals going through the air locks, into the boilers and out of the ash discharge systems is 400 pounds per day. Since this ferrous metal is in the form of wire, bedsprings, etc., which tend to jam and stick in elbows, air holes, etc. this can create serious maintenance problems.

B.2.1.3.2 Nonferrous Metal and Glass Recovery. In each of the above unit operations, the objective was to remove contamination such as metals, glass and grit from the RDF to improve fuel quality. Another objective was to prepare the RDF-3 for pneumatic transport. Some processing operations installed non-ferrous metal separation and glass recovery systems to not only remove these materials from the RDF, but also to recover glass and non-ferrous metals (mostly aluminum) in a grade or purity that could be sold.

Nonferrous metals are usually removed from RDF by air classification and report to the heavy fraction. Recovery at high purity or grade is usually accomplished by eddy current separation. Non-ferrous metal separation after air classification and magnetic separation and screening can be cost effective, but only at high processing capacities. (Wilmington, Delaware is an example, and the same technology was installed in Rochester, New York, but not properly implemented.) Examples of eddy current aluminum separation systems and applications are the NRT (Pulsort^{tm}) system at Dade County, Florida and the Eriez rare earth magnet system installed at West Palm Beach, Florida to replace handpicking of aluminum. Non-ferrous metal separation systems were also installed in Ames and Milwaukee, but in both cases the systems never performed properly or were too small to be economical and thus were later removed.

Glass is removed by screening after shredding in conventional horizontal, vertical, or flail type shredders. Glass can be recovered by optical sorting (when it is large in size) or by froth flotation when it is sand sized, but in both cases, the cost of recovery is not likely to be offset from the revenues of the finished products. Milwaukee included an aggregate recovery system, but due to materials handling problems it was never really made operable before the entire plant closed.

B.2.1.4 Material Handling

In contrast to mass bum systems, RDF operations require more sophisticated material handling systems due to the higher degree of processing, the requirement for continuous feed throughout fuel preparation, the need to prevent explosions during processing, and possibly the shipment of fuel to a remote site for combustion (484). Material handling subsystems Include MSW storage and retrieval, RDF storage and retrieval, conveyors, and, as required, transportation.

MSW receiving, storage, and retrieval operations can employ a pit and crane operation (similar to a mass-bum operation), an infeed conveyor system fed by front-end loader from the tipping floor, or an infeed conveyor system fed by hydraulic rams. Typically, grapple cranes are provided for removal of nonprocessibles from the infeed conveyors.

Processed RDF typically is stored and retrieved prior to combustion in a variety of ways including pit and crane systems, conical bins with drag buckets, live-center bins, and bins with screw unloaders. If the fuel is to be transported, it can be be blown or conveyed into transfer trailers or shipping bins (67, 484).

A variety of conveyors are used for RDF production and handling applications. These are described in Table B-8.

TABLE B-8. RDF PRODUCTION CONVEYORS (484)

Conveyor Type	Description and Characteristics	Applications
Flexible Belt	Continuous band of flexible materials (laminated layers of fabric and rubber) friction driven by a pulley and supported by idlers and rollers.	Horizontal or inclined conveying where impact is limited.
Steel Pan or Apron	Overlapping steel plates with raised sides, that are chain-driven and impact resistant.	Raw MSW feeding; shredder exit.
Drag	Two chains, connected with bars at intervals, dragged over a stationary surface.	Raw MSW feeding; ash handling.
Vibrating	Conveyor plates that repeatedly vibtate upward and in the desired direction of movement, evening out material flow rate.	Air classifier feeding; raw MSW feeding.
Pneumatic	Pipes or ducts through which material is moved by air under positive or negative pressure.	Transportation from production to storage and storage to boilers.

B.2.2 RDF Combustion Systems

As with coal, where the type of fuel preparation is selectively matched to the type of fuel feed system, grate, furnace, and ash discharge system, the type of RDF which is produced by the RDF preparation system is also matched to a combustion system. RDF can be fired: 1) in suspension or cyclone boilers (as are used for pulverized coal), 2) partially in suspension and partly on a grate as in spreader stoker systems, or 3) only on the grate as in mass-fired systems. The optimum method of feeding and transporting the refuse through the combustion device, the configuration of the combustion device itself, and the details of design for the system and its ancillary equipment depends on the nature of the fuel and the size or heat generation rate, as well as on whether the RDF will be burned in combination with other fossil fuels.

The types of stokers or grates for coal are defined as: 1) underfeed, 2) overfeed, and 3) spreader designs (862). Underfeed stokers or grates have not been used in the United States for the burning of refuse-derived fuels. Overfeed and spreader designs are discussed below. Suspension firing in pulverized coal boilers must also be considered even though a stoker is normally not used in coal applications while a "stationary dump grate" is used for RDF. Overfeed stokers or grates for coal are classified as: chain, traveling, and water cooled, vibrating grates. In coal firing applications, the depth of the fuel bed which is conveyed into the furnace is regulated by a vertically adjustable feed gate across the width of the unit.

In the case of overfeed mass burning of refuse, a ram feeder or highly inclined reciprocating grate is used (863), as shown in Figure B-6. The fuel carried onto the grate and through the furnace passes over several regulated air zones where air is forced up through the grate to assist oxidation in the combustion process. The grate often tumbles the fuel using rocking, reciprocating, or rotary action to enhance agitation and increase the efficiency of contact between oxygen and fuel. Ash is continuously discharged from the end of the grate and is cooled by air or water. The grate moves from the front of the furnace to the back. The inventory of fuel in the furnace is large at all times; thus, energy input control through fuel firing control is of limited value.

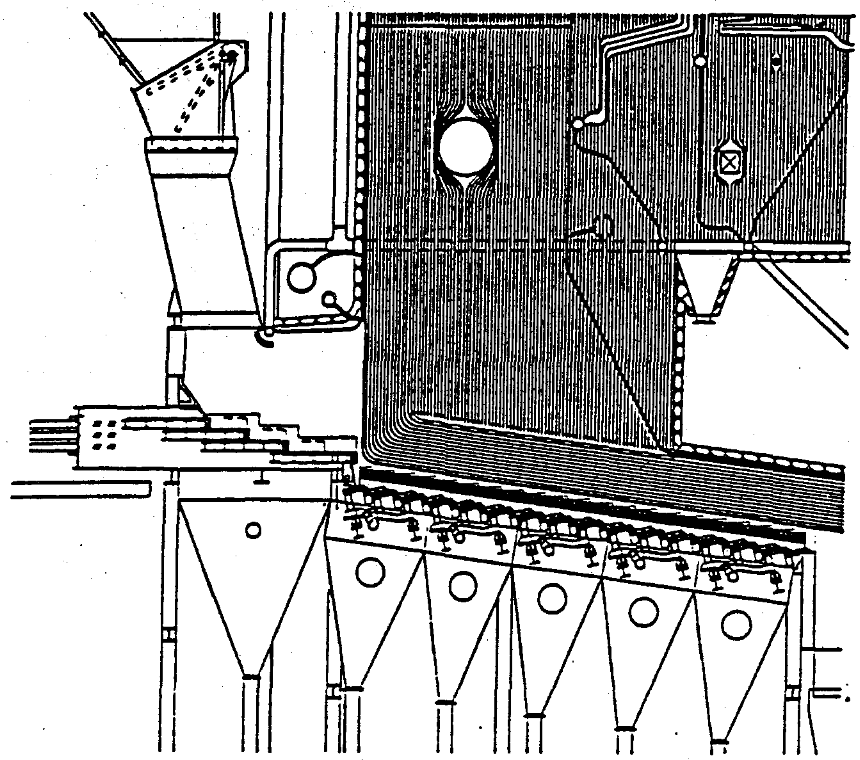


Figure B-6. Overfeed Stoker In Mass-Burning Furnace (863)

Introduction of the continuous-ash-discharge traveling grate of the air-metering design in the late 1930s brought widespread popularity to the spreader stoker. Although continuous cleaning grates of reciprocating and vibrating designs have also been developed since that time, the continuous ash discharge traveling grate is preferred for large boilers because of its higher burning rates which correspond to about 525 sq ft of grate surface area and a steam capacity somewhat over 400,000 lb steam/hr. The furnace width required for stokers above this size usually results in increased boiler costs as compared to pulverized coal or cyclone-furnace fired units with narrower and higher furnaces (864).

Figures B-7 and B-8 are schematic diagrams of spreader stokers. The fuel is spread into the furnace and over the grates from feeders located across the front of the unit. In the event some of the coal or other solid fuel is broken, or fine in size, it will burn partly in suspension as it is being thrown onto and across the grate. Larger heavy particles are spread across the grate surface to release an equal amount of energy from each square foot of the grate surface (862). Air is metered under the grate. Over-the-grate additional air is added to assist in combustion of unoxidized fuel.

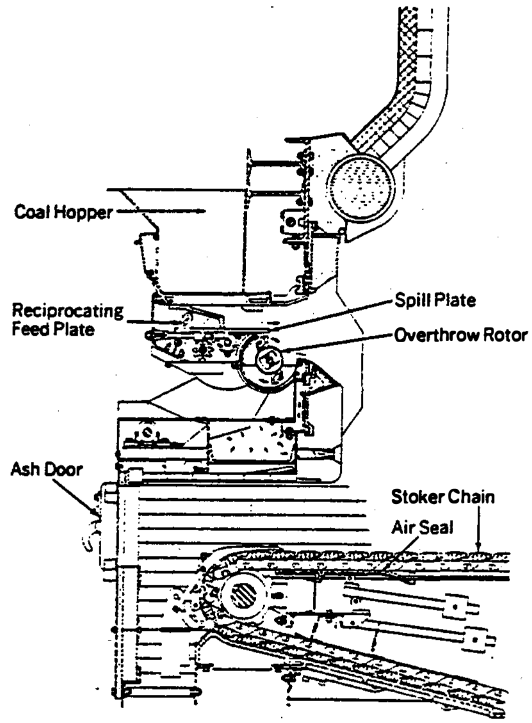


Figure B-7. Reciprocating-Feeder for Spreader Stokers (864)

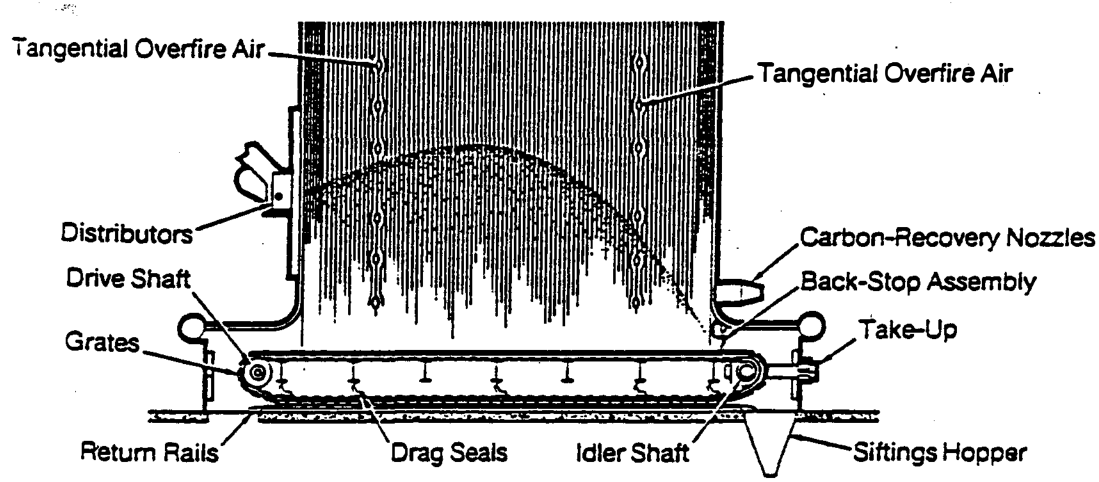


Figure B-8. Spreader Stoker with Continuous Ash Discharge Grate (863)

Since the fuel is burned both in suspension and in a thin fuel bed on a spreader stoker, the inventory of energy in a furnace is small compared to the mass burning spreader stoker. If the fuel supply is interrupted, the fire will be completely out in a matter of minutes (862). This can be a disadvantage if a fuel feed system plugs and may require the introduction of auxiliary fuel. However, it also allows the energy source level to be changed rapidly, and thus this type of fuel feed and combustion system is able to follow rapid changes in steam demand. This method of firing provides extreme sensitivity to load fluctuations as ignition is almost instantaneous on increase of firing rate and the thin fuel bed can be burned out rapidly when desired. (864).

A schematic of an RDF-fired spreader stoker furnished by Combustion Engineering/Asea Brown Boveri (CE/ABB) is shown in Figure B-9. A unique feature of this design for refuse is that the undergrate air is split to each grate half and then into five compartments along the length for a total of ten individual zones. Each compartment has its own damper control to regulate the amount of air to that zone (863). A combination feeder for both coal and refuse is shown in Figure B-10. One of the advantages of spreader stoker RDF combustion systems is the capability to fire either coal or refuse. Experience in Columbus, Ohio has indicated that co-firing both fuels simultaneously is limited because the combined fuels have a low ash fusion temperature which deteriorates boiler and stoker performance, and thus capacity (868). Thus, the boiler operates best when one or the other fuel is fired, but not both co-fired simultaneously.

Suspension firing is most appropriate when high capacity coal firing is desired. This type of unit is more cost effective than spreader stoker designs above 400,000 lb/hr steam outputs. Suspension firing of pulverized coal does not normally require a grate. The bottom of the furnace is usually filled with water which forms a seal between the furnace and the outside atmosphere. The water is also used as a medium to remove ash from the furnace bottom ("bottom ash sluicing").

However, when firing refuse-derived fuels in suspension, some of the fuel is large or dense and will not burn completely during the short time, only a few seconds, it is held in suspension. Thus, a "dump grate" (Figure B-11) is usually desirable when a pulverized coal boiler is utilized to burn refuse-derived fuel to allow combustion to be completed prior to discharge or sluicing of the water when ash is removed.

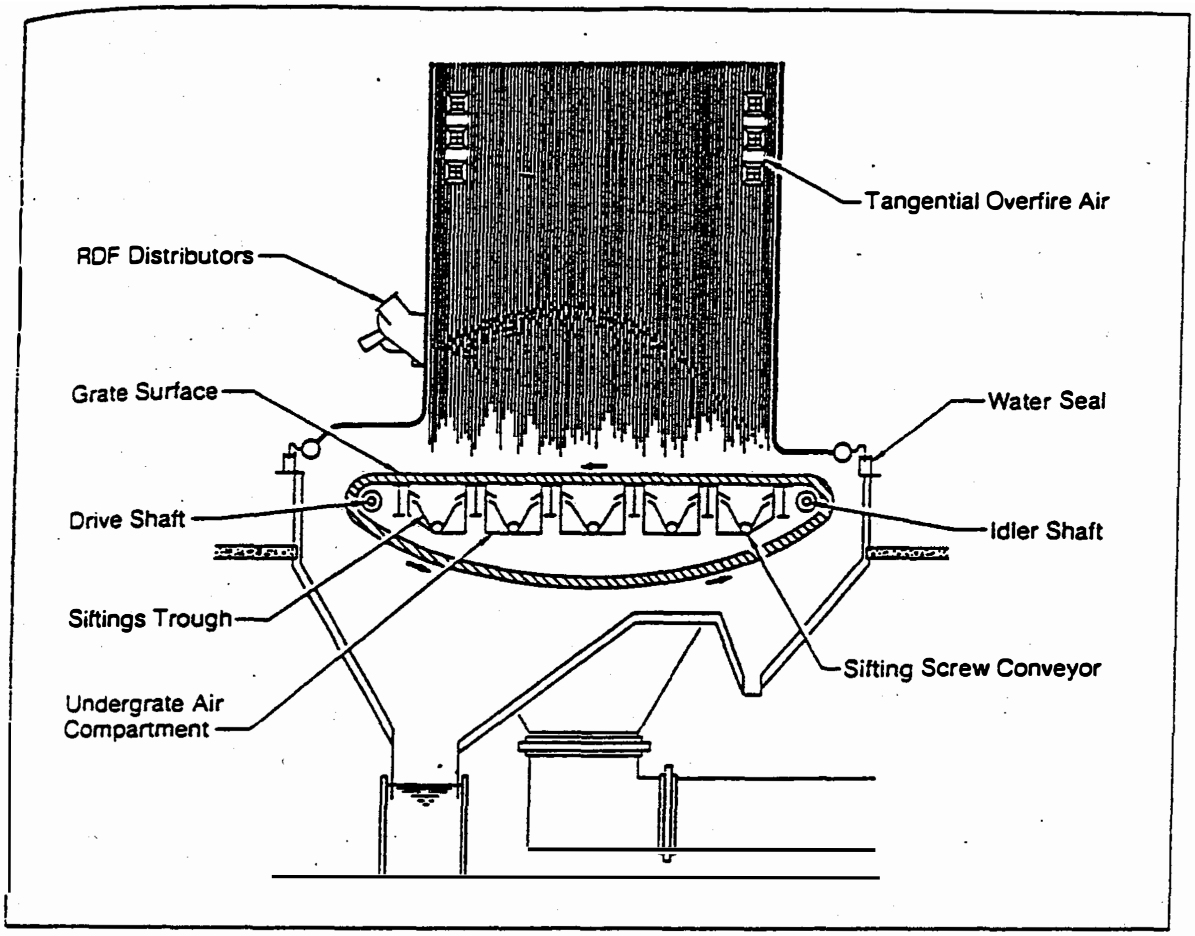


Figure B-9. RDF-Fired Spreader Stoker (863)

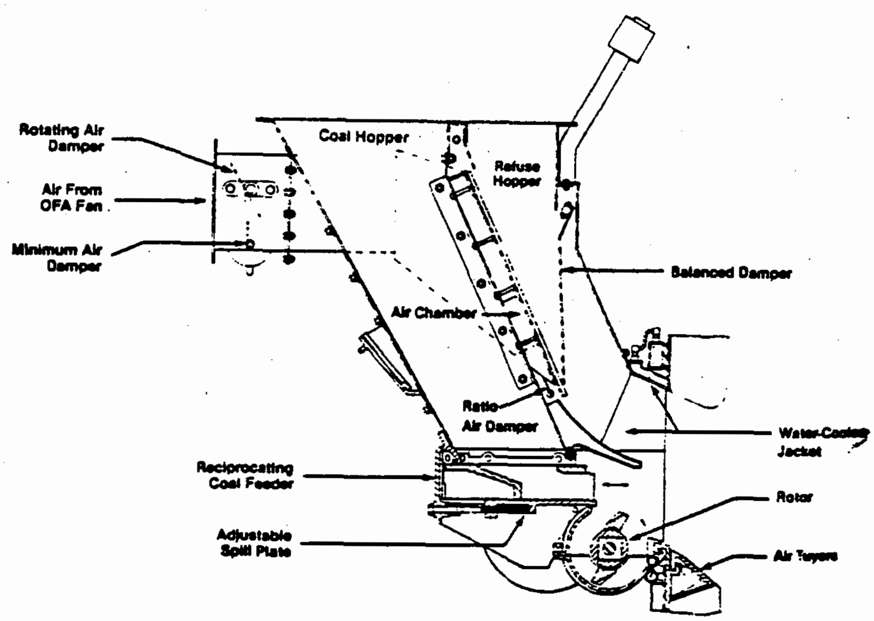


Figure B-10. Combination Coal and Refuse Feeder (862)

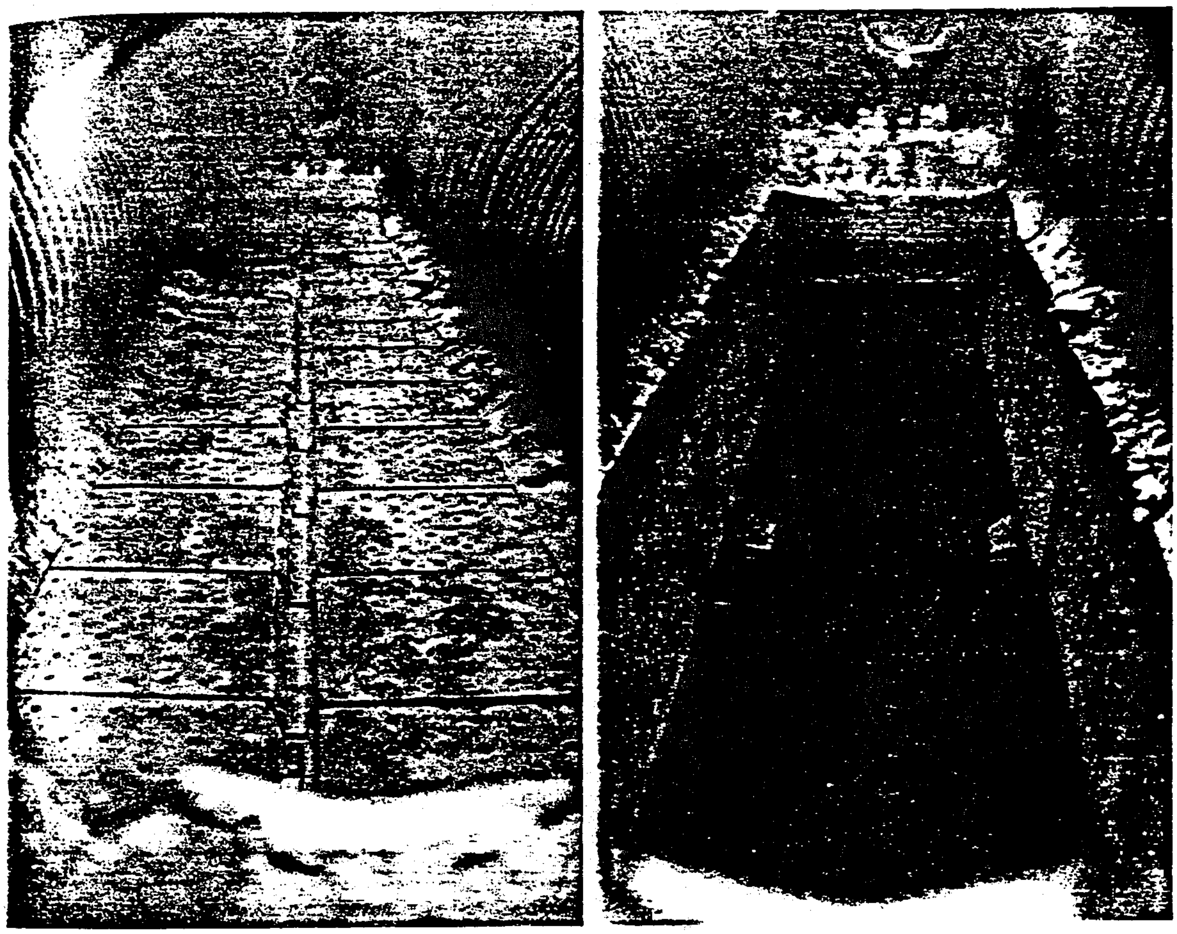


Figure B-11. Dump Grates at Furnace Bottom
(left, closed; right, open) (863)

B.2.3 RDF Production and Suspension Cofiring with Pulverized Coal

The U.S. DOE and EPRI cosponsored the development of guidelines for RDF cofiring to provide a basis for future suspension co-firing with pulverized coal projects (805, 806, 807). These guidelines, published in 1988, address procedures for evaluating proposed RDF cofiring projects, RDF specifications and preparation, impact of RDF cofiring on power plant performance and operation, design criteria for RDF handling and other equipment, environmental control systems, capital and O&M cost estimates, economic analysis, and the breakeven RDF value to the utility.

Assuming that all 150 million tons of refuse generated in the U.S. were processed in RDF plants and fired in suspension with pulverized coal, and assuming the entire heat content of the refuse was recovered at 4500 Btu/lb of MSW, then, the amount of heat available would represent only 10% of the nation's annual electric utility consumption (805). Thus, cofiring of RDF at a 10% level (which has shown to be technically possible) could consume the heat from all of the nation's municipal solid waste.

B.2.3.1 Projects and System Vendors

Between 1972 and 1988, nine U.S. utilities cofired almost 1 million tons of refuse-derived fuel with coal or oil (624). Table B-9 provides a listing of those utilities. The units in which RDF was fired, the start date, and current status is provided as well as the heat input from RDF as a total percentage of fuel burned. Heat input as a percentage of total fuel requirements often exceeded 20% even though the average was closer to 10%. The cofiring experience represents an order of magnitude range of unit size from 35 MW to 364 MW.

The nine facilities that prepared RDF for cofiring are listed, by location, in Table B-10 along with the associated public and/or investor owned utilities, and system vendors. Figure B-12 provides a comparison of the RDF production unit operations of these facilities. Presently, only four of the utilities are currently cofiring RDF with coal: Ames, Iowa (operating since September, 1975); Madison, Wisconsin (operating since January 1979); Lakeland, Florida (operating since July 1983); and Baltimore, Maryland (operating intermittently since January 1976). The remaining five utilities listed have discontinued operations for a variety of reasons, mostly economic (624). Table B-11 provides additional information on the cofiring projects in terms of capacity, power output, emission controls, and ash residue. (The St. Louis project is not listed; it operated from 1972 to 1975 as a demonstration project.)

TABLE B-9. ELECTRIC UTILITY RDF COFIRING EXPERIENCE (624)

Location	Power Plant	Unit No.	Capa- city (MW)	Unit Boiler Mfr.[a]	Firing Method	Cofiring Fuel	Dump Grate	RDF Heat Input[b] (%) Max.	RDF Heat Input[b] (%) Avg.	RDF Mass Feed Rate[b] (tons/h) Max.	RDF Mass Feed Rate[b] (tons/h) Avg.	RDF Cofired through 1988 (tons)	Co-firing Start Date	Commercial Start Date	Cofiring Duration (years)	Status
Ames, IA	Ames	7	35	C-E	Suspension	Coal	Yes	22		13.0[c]	6	398,644	1975	April 1978[d]	11.4	Operating
Ames, IA	Ames	8	65	B&W	Suspension	Coal	Yes						1981			
Baltimore, MD	Crane	2	200	B&W	Cyclone	Coal	No	20	10	7.9	5.6	170,923	1980	February 1984	5.6	Operating
Bridgeport, CT	Bridgeport Harbor	1	80	B&W	Cyclone	Oil	No	51				7,900	1979	November 1979	0.2	Shut down 1981
Chicago, IL	Crawford	7	240	C-E	Suspension	Coal	No	10				20,000	1978	October 1978	1.3	Shut down 1979
Chicago, IL	Crawford	8	358	C-E	Suspension	Coal	No									
Lakeland, FL	McIntosh	3	364	B&W	Suspension	Coal	Yes	10				88,185	1983	February 1983	6.6	Operating
Madison, WI	Blount	8&9	50 ea.	B&W	Suspension	Coal	Yes	26	11	13.0	5.4	101,051	1975	January 1979	10.7	Operating
Milwaukee, WI	Oak Creek	7&8	310 ea.	C-E	Suspension	Coal	No	20	15	30	25	100,000	1977	March 1977	3.5	Shut down 1980
Rochester, NY	Russell[e]	1	42	C-E	Suspension	Coal	Yes									
Rochester, NY	Russell	2	63	C-E	Suspension	Coal	No	15	10			47,900	1981	September 1981	3±	Shut down 1984
Rochester, NY	Russell	3	63	C-E	Suspension	Coal	Yes									
Rochester, NY	Russell	4	75	C-E	Suspension	Coal	Yes									
St. Louis, MO	Meramec	1&2	125 ea.	C-E	Suspension	Coal	No	27	10		9.1	48,972	1972	April 1972	3.7	Shut down 1975
											Total	984,000				

[a] C-E, Combustion Engineering; B&W, Babcock and Wilcox.

[b] Heat input and mass feed rate from either yearly averages or specific tests. Best available measured values are shown but actual current usage may differ. Madison 5.4 tons/hour is 1981 average and St. Louis 9.1 tons/hour is from plant records.

[c] Maximum during Unit 8 3-hour boiler test in 1982 was 14.7 tons/hour.

[d] Trial operation in 1975 and 1976--commercial since 1978 grate installation.

[e] Induced draft fans limit cofiring to about 90% of capacity.

TABLE B-10. RDF PRODUCTION FACILITIES FOR COFIRING WITH COAL

LOCATION	OWNER	ELECTRIC UTILITY	VENDOR
Ames, IA	City of Ames	Ames Municipal Electric Co.	Gibbs and Hill
Baltimore, MD	Baltimore County	Baltimore Gas and Electric Co.	National Ecology Inc (NEI)
Bridgeport, CT	Connecticut Resource Recovery Authority	United Illuminating	Combustion Equipment Associates (CEA)
Chicago, IL	City of Chicago	Commonwealth Edison	Parsons
Lakeland, FL	City of Lakeland	Lakeland Dept of Elec. & Water Utilities	Homer & Shifron
Madison, WI	City of Madison	Madison Gas and Electric	City of Madison
Milwaukee, WI	City of Milwaukee	Wisconsin Electric Power Co.	American Can Co.
Rochester, NY	Monroe County	Rochester Gas and Electric Co.	Raytheon Service Co.
St. Louis, MO	City of St. Louis	Union Electric Co.	Homer & Shifron

Ames, Iowa was the nation's first RDF project built at commercial scale and it has been operational since 1975 -- over 15 years. After firing in both semi-suspension boilers with spreader stokers, and the higher efficiency pulverized coal boilers, given the overall objective of generating power at the lowest cost, Ames Electric expanded its project by installing a new pulverized coal boiler which cofired RDF at low levels of substitution. Thus, it could be assumed that under certain circumstances, suspension firing of RDF in a pulverized coal boiler is more efficient than semi-suspension firing in spreader stokers when the goal is to reduce the overall cost of electric production rather than maximize reduction of refuse volume through burning.

Most of the vendors listed in Table B-10 continue to provide RDF engineering and system design services with the exception of Combustion Equipment Associates and American Can Company. Additional entrants who are actively providing services include: Asea Brown Boveri (formerly Combustion Engineering); Babcock & Wilcox (B&W) and a subsidiary NEC (formerly National Ecology); KTI Operations; National Recovery Technologies; Northern States Power; Waste Energy Recovery Systems, and wTe Corporation. Numerous power plant engineering companies also offer services to conduct design and construction of a project.

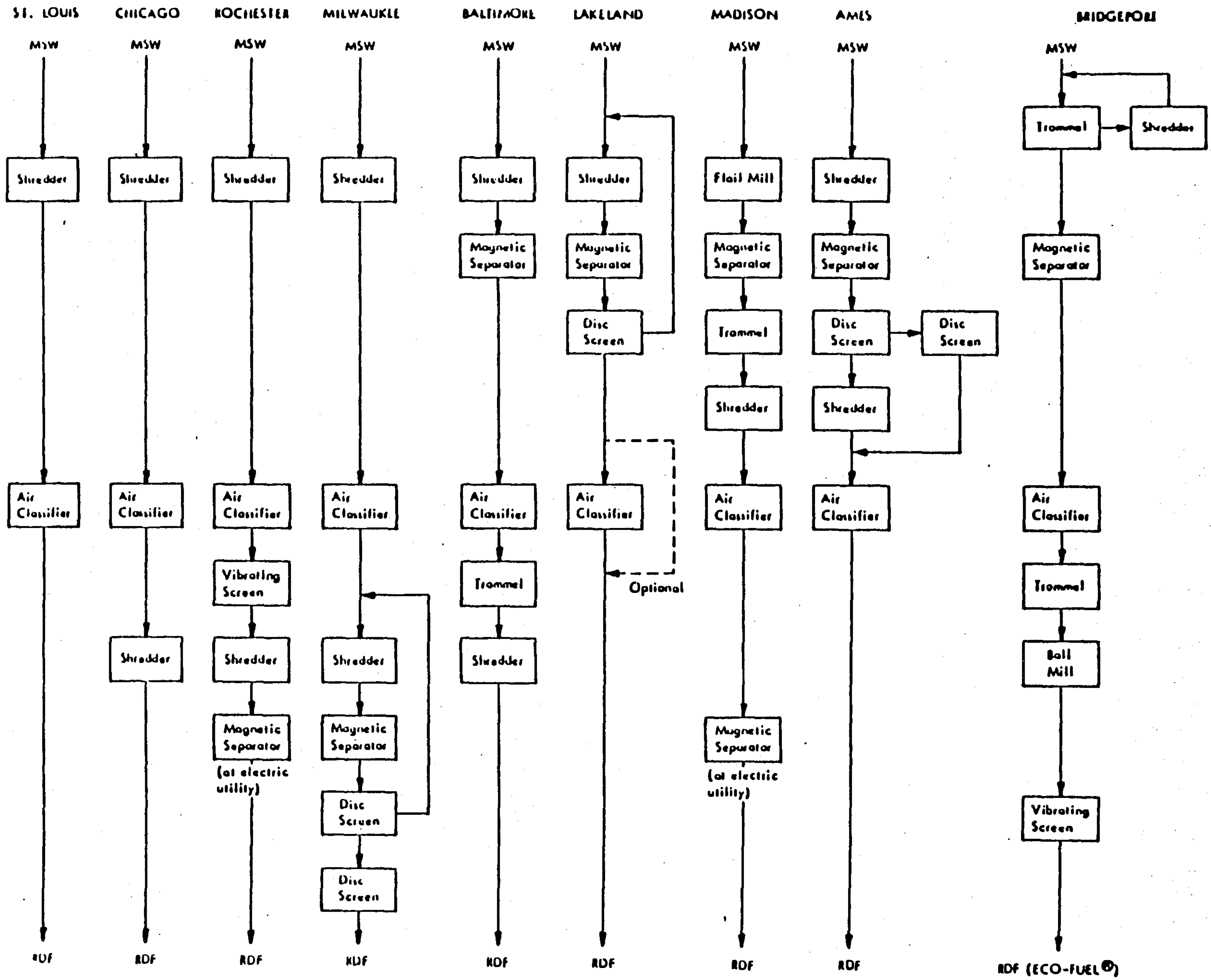


Figure B-12. RDF Production Plant Flow Diagrams (477)

TABLE B-11. RDF COFIRING PROJECTS -- MAJOR FEATURES (387)

FACILITY	DESIGN CAPACITY (TPD)	ACTUAL CAPACITY (TPD)	RATIO ACT/DES CAPACITY	NUMBER OF BOILERS	GROSS PWR OUTPUT (MW)	NET PWR OUTPUT (MW)	RATIO GROSS/NET PWR OUTPUT	GROSS KWH PER TON PROCESSED	POUNDS PER HOUR STEAM	BTUs PER POUND
Ames	200	174	0.87	2	100	95	1.05	N/A	360000	6200
Baltimore County	1200	600	0.50	2	200	188	1.06	N/A	1362000	6800
Bridgeport (CEA)	2400	900	0.38	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Madison	400	250	0.63	2	100	N/A	N/A	N/A	860000	5759
Milwaukee	1600	1000	0.63	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Monroe County	2000	500	0.25	4	N/A	N/A	N/A	N/A	N/A	N/A
Lakeland/CD McIntosh Unit 3	300	275	0.92	1	364	335	1.09	N/A	2300000	4500
Chicago	1000	500	0.50	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NUMERICAL AVERAGE OF NON-ZERO VALUES	1138	525	0.58	2	191	206	1.07	0	1220500	5815
STANDARD DEVIATION	766	282	0.21	1	108	99	0.01	0	716897	844

FACILITY	APC DEVICES USED	ASH RESIDUE (TPD)	RATIO ASH TO ACT TPD	PERCENT ASH RESIDUE	ASH DISPOSAL	DISPOSAL SITE OWNER	TIP FEE $/TON
Ames	ESPs	N/A	N/A	N/A	Sanitary Landfill	Public	10
Baltimore County	ESPs	N/A	N/A	N/A	Sanitary Landfill	Public	50
Bridgeport (CEA)	ESPs	N/A	N/A	N/A	Sanitary Landfill	Private	20
Madison	ESPs	90	0.36	36.0	Sanitary Landfill	Public	20
Milwaukee	ESPs	N/A	N/A	N/A	Sanitary Landfill	Private	14
Monroe County	ESPs	N/A	N/A	N/A	Sanitary Landfill	Private	5
Lakeland/CD McIntosh Unit 3	ESPs, Wet Scrubbers	28	0.10	10.2	Dedicated Ashfill	Public	16
Chicago		N/A	N/A	N/A	Sanitary Landfill	Public	N/A
NUMERICAL AVERAGE OF NON-ZERO VALUES		59	0.23	23.1			
STANDARD DEVIATION		31	0.13	12.9			

N/A = Not Available

B.2.3.2 Technical Discussion

Typically, the utilities employing suspension cofiring of RDF have furnished 10 to 15% of their overall unit fuel requirements through the use of fluff RDF. As of 1988, however, problems from the uneconomical production of RDF and, in some cases, the use of boilers not well suited to RDF cofiring prompted five of the nine utilities listed in Table B-10 to discontinue RDF cofiring operations (624, 805).

A typical arrangement for an RDF cofiring system in an electric utility boiler is shown in Figure B-13. The figure shows the RDF receiving station, storage bin, reclaim, flow metering, and fuel feed (furnace injection system). The RDF combustion air flow arrangement and ash disposal system are also shown.

The most important factors to be considered in evaluating an RDF cofiring project include: 1) plant location relative to the RDF source; 2) unit age, size, average capacity factor, and load duration curve; 3) the unit's ability to consume the available RDF stream without severe boiler slagging and fouling, ash handling, electrostatic precipitator, or unit derating problems; and 4) the costs and difficulty associated with installing RDF receiving, handling, and cofiring equipment. Thus, to maximize the overall project economics, units for RDF cofiring should be selected which have at least 15 years of remaining useful life, operate at a high capacity factor, are of sufficient size to consume the available RDF stream, and do not exhibit boiler slagging and fouling, electrostatic precipitator, or unit derating problems while burning coal or oil (624).

The RDF cofiring capacity of a given boiler depends on the unit capacity, capacity factor, and fraction of heat input from the RDF. Figure B-14 shows typical RDF feed rates for different coal types in boilers of either 50 or 200 MW. An important part of the planning process is to assess the system and unit load compatibility of the candidate units versus the required RDF firing rate (805).

In general, RDF can be cofired only when the unit is operating above 45 to 50% of its rated capacity. Thus, a base load unit can cofire RDF only a portion of the time it is operating. If sufficient RDF is available, RDF cofiring can reduce coal consumption by 5 to 10% (805). The maximum RDF cofiring rate recommended by steam generator manufacturers is typically 20% of the total fuel heat input. This limit was selected to ensure that hydrochloric acid (HCl) concentration in the flue gas resulting from RDF combustion is low enough to avoid increased corrosion or tube metal wastage in the boiler (805). It should be noted however, that Eastman Kodak has been firing 100% commercial/industrial RDF in suspension at its Rochester facility for many years; methods to overcome corrosion are reported in the literature (523).

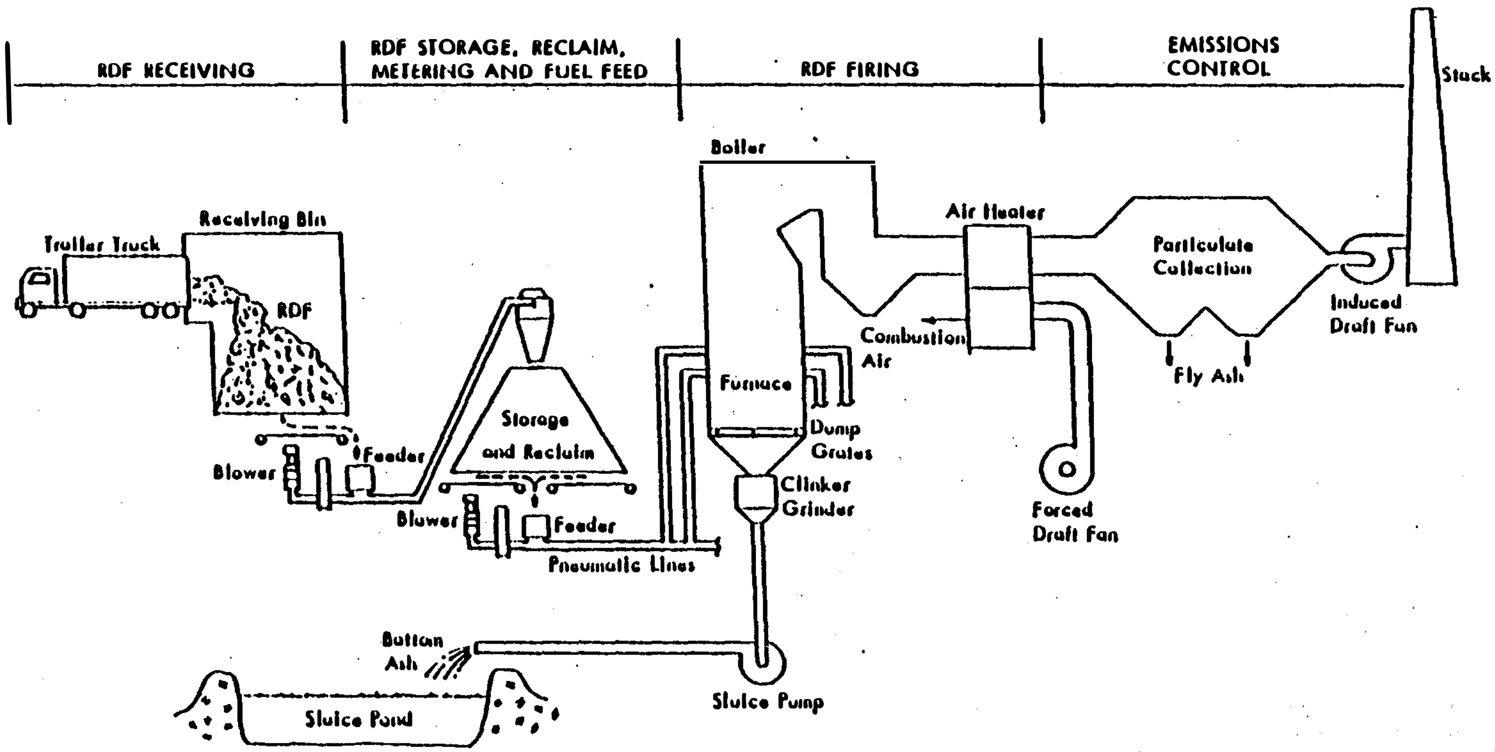


Figure B-13. Scope of Electric Utility RDF Cofiring System (805)

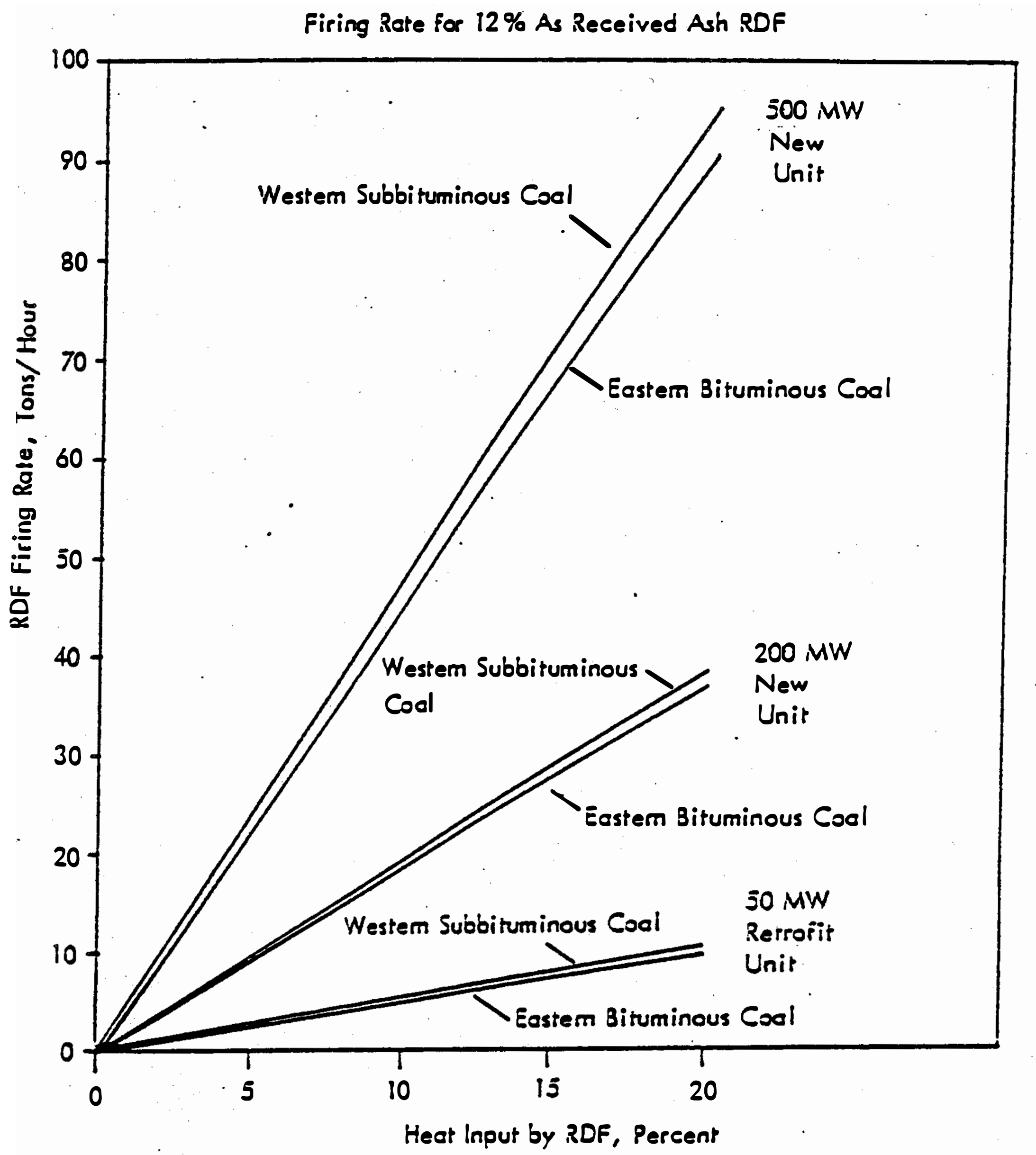


Figure B-14. Typical RDF Cofiring Rates ((805)

The unit load duration curve is particularly important because it determines the number of hours per year the unit operates above the minimum load required for RDF cofiring. Figure B-15 shows an example of a load duration curve in which the unit co-fires RDF with coal between 50 and 100% of full load. RDF is not fired above 100% full load, presumably due to ash or gas handling and cleaning limitations, nor below 50% due to flame instability problems. The shaded area in this example, which amounts to 56%, is the maximum capacity factor during RDF cofiring (806).

A number of operating problems were encountered by the utilities during their RDF cofiring operations as compared to coal only firing. These included: upper furnace wall slagging, electrostatic precipitator (ESP) collection efficiency decrease, boiler tubing corrosion, high bottom ash accumulation, reduced performance of ash sluice water treatment systems, pluggage of sluice water overflows by floating material, septic ash sluice water, and RDF materials handling and storage problems (624). Many of these problems were overcome through evolutionary improvements in RDF quality since the 1970s, and by design improvements such as installation of bottom ash dump grates above the ash hopper, and by avoiding "tight" design boilers with high heat release rates, that are prone to slagging (624).

McGowin (624) has reported that reductions in RDF ash content from 18 to 20% (mid-1970s) down to 10 to 12% (1989) have significantly reduced ash handling and furnace slagging problems, but ESP performance and RDF handling problems still exist. However, at Lakeland, an RDF yield of over 91% has been reported so that ash content is probably above 20%. Further, plant operations at Lakeland indicate that RDF production is now quite reliable. The problems are now with combustion burnout, the Atlas bin, and ash removal equipment (621). A recommended rule of thumb is that, "for problem boilers with pre-existing ash handling or slagging and fouling problems, RDF with one inch maximum particle size and 10% ash content is recommended (624).

Figure B-16 presents the proximate and ultimate analysis of RDF from the Madison, Wisconsin plant compared to a high volatile Illinois bituminous coal. The RDF has 3.4 times the moisture, 1.7 times the ash on a dry basis and 1.8 times the volatile matter as the coal. The fixed carbon of the RDF is only 23% of the coal, and the higher heating value of the RDF is 55% of the coal on a dry basis. RDF is lower in carbon, hydrogen, nitrogen, and sulfur and higher in chlorine and oxygen than the coal (67).

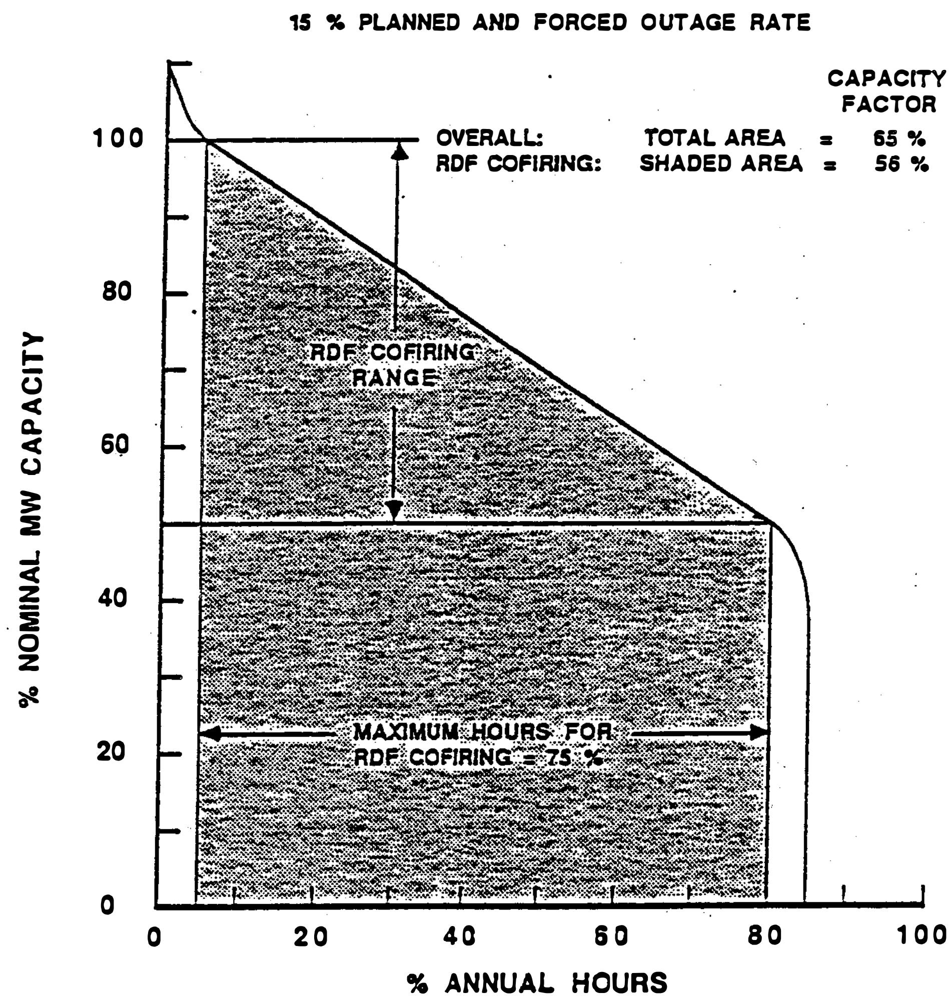


Figure B-15. Example Load Duration Curve for Base-Loaded Unit (806)

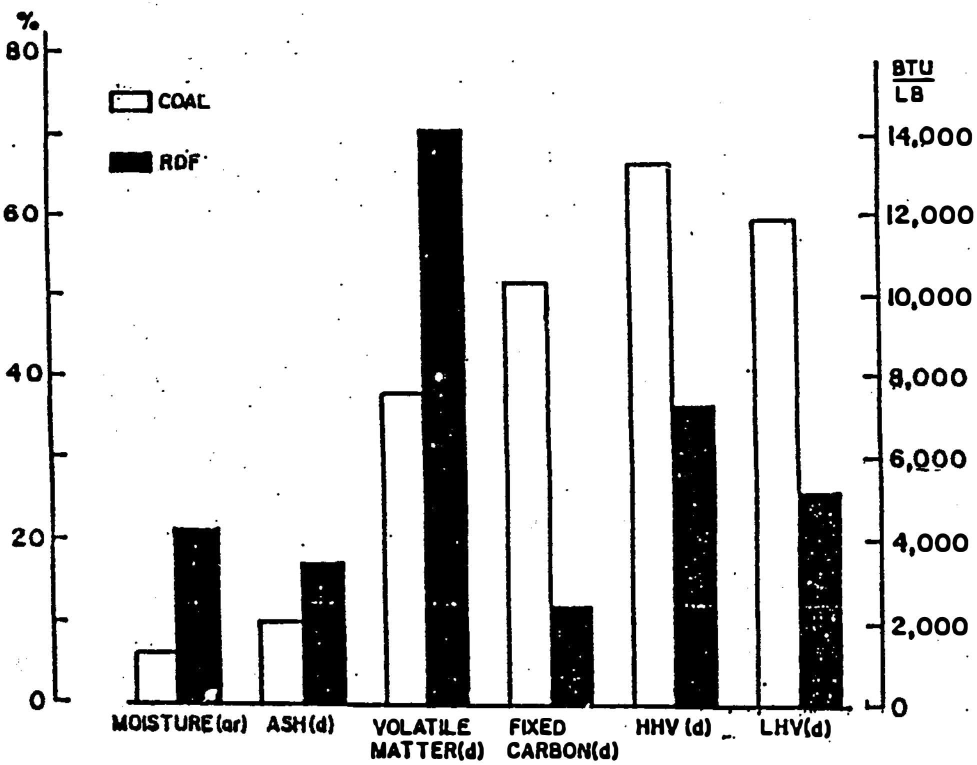


Figure B-16. Average Proximate and Heating Value Analysis of Coal and RDF (67)

Because RDF is a lower quality fuel than the coals and fuel oils typically burned in utility boilers, RDF cofiring can have a negative impact on power plant performance and operation. As a result of its higher ash content, RDF cofiring can increase slagging and fouling of the boiler and thus the amount of boiler ash which must be sluiced, treated, and disposed. In addition, slagging will reduce heat transfer and thus efficiency as well as increase operations and maintenance cost for the boiler. The higher moisture content, the need to pneumatically convey the RDF into the boiler normally with non-preheated air, and the larger amount of excess air required to burn the RDF can also reduce boiler operating efficiency. These factors also contribute to increased demand on the air emission control equipment and the induced draft fans (806). In the case of a new unit designed for coal and RDF, RDF cofiring at 15% heat input is estimated to reduce boiler efficiency by 1.5 to 2.5% as compared to firing 100% coal. In a retrofitted unit for RDF cofiring, the maximum efficiency loss caused by using unheated RDF combustion air can create an efficiency loss of 3.5% (624). The major issue is whether these disadvantages associated with RDF cofiring are offset by savings in cost over conventional fossil fuels.

B.2.4 RDF Production and Firing in Semi-Suspension, Spreader Stokers

Spreader-stoker technology has been utilized successfully on a variety of fuels for decades, and it is the most commonly used technology for RDF combustion today (274). As described previously, in a spreader stoker, the RDF is introduced above a traveling grate where it is burned partly in suspension. This type of combustion is thus sometimes referred to as semi-suspension firing. What does not burn in suspension drops on the traveling grate or stoker. Greater than one hour residence time can be required to achieve full burn-out and at least 40 to 60% excess air is required to optimize combustion characteristics (484). The capability to provide this long residence time enables fuel of varying sizes, composition and densities to fully burn out. As a result, the spreader stoker is well suited for even coarse RDF (RDF-2).

Some semi-suspension RDF combustion facilities were built new and utilize systems dedicated solely to the combustion of RDF. These include Akron, Ohio; Niagara Falls, New York; Palm Beach County, Florida; and Dade County (Miami), Florida. Some such as Columbus, Ohio and Hartford, Connecticut, were built new to burn either RDF, coal, or both simultaneously. Saco and Orrington, Maine (MERC and PERC) and Honolulu, Hawaii were built new and designed to co-fire RDF with other wood-waste or biomass fuels. Older, coal-fired installations which were retrofitted to burn RDF include Anoka/Elk River and Ramsey-Washington County, Minnesota. Many of the units are also capable of back-up fuel firing with either natural gas or oil.

Table B-12 provides a listing of the owners and operators for each of the RDF processing systems with spreader stoker type waste combustion systems. In some cases, the owner and/or operator of the RDF processing system is not the same as the owner and/or operator of the RDF combustion system. In many cases, the RDF combustor is located in close proximity to the RDF processing facility, and in other cases they are separated by a significant distance and the RDF must be transported by truck to the combustion site. These boilers are not all dedicated to RDF alone.

TABLE B-12. RDF PRODUCTION FACILITIES - SEMI-SUSPENSION FIRING

LOCATION	FACILITY	OWNER	OPERATOR
1. Akron OH	Akron Recycle Energy System [RES]	City of Akron	wTe Corporation
2. Albany NY	ANSWERS RDF Plant NYS-OGS Power Plant	City of Albany NYS Office of Gen. Services	EAC Operations NYS-OGS
3. Anoka MN	Anoka County RDF Plant Elk River Power Plant	Northern States Power United Power Associates	NSP UPA/NSP
4. Columbus OH	Columbus Coal-Refuse Fired Municipal Electric Plant	City of Columbus	City of Columbus
5. Detroit MI	Greater Detroit Resource Recovery Facility	Greater Detroit Resource Recovery Authority	Asea Brown Boveri [ABB]
6. Honolulu HI	City & County of Honolulu RRF	City of Honolulu Ford Motor Credit Corp.	Asea Brown Boveri [ABB]
7. Hartford CT	Mid-Connecticut Resource Recovery Facility [RDF] Power Plant	Conn. Resource Recovery Authority [CRRA] CRRA	Metro.Dist.Comm. ABB
8. Haverhill MA	Haverhill RDF Plant Lawrence Power Plant	Ogden Martin Systems of Haverhill, Inc.	Ogden Martin Ogden Martin
9. Miami FL	Dade County S.W. Resource Recovery Facility	Metro-Dade County	Montenay
10.Newport MN	Ramsey & Washington County Project [RDF] Power Plant	Northern States Power [NSP] Red Wing	NSP NSP
11.Niagara NY	Occidental Energy From Waste Facility	Occidental Chem. Corp.	Occidental Chem.
12.Orrington ME	Penobscott [PERC] Project	Penobscott Energy Recovery Corp. [PERC]	ESOCO
13.Portsmouth VA	Southeastern Tidewater Energy Project [RDF] Power Plant	Southeast Public Service Authority [SEPSA] Norfolk Navy Shipyard	SEPSA SEPSA
14.Rochester MA	SEMASS Project	SEMASS Partnership	Bechtel
15.Saco ME	Saco/Biddeford MERC Project	Maine Energy Recovery Corporation [MERC]	KTI
16.WestPalm FL	Solid Waste Auth. of Palm Beach	WPB-RRA	B&W/NEI

The major features of the commercial facilities which fire RDF in semi-suspension spreader stokers are provided in Table B-13, based upon data compiled by GAA in the 1991 Resource Recovery Yearbook (387). As can be seen, the average size of these installations is 1720 tons per day. All of these installations are in operation today. A further analysis of this data indicates that these facilities operate at an average of 92% of their design capacity and generate an average of 44 MW of electricity from which 37 MW is available for sale; the balance being parasitic load for internal needs. At least one of the facilities, Akron, Ohio, produces steam for district heating and cooling systems and thus only cogenerates a small amount of electricity, 4 MW, for internal power needs thus pulling down the average.

The projects average three boilers, and produce 575 kWh of electricity per ton of RDF burned. The RDF has an average Higher Heating Value (HHV) of 5363 Btu/lb. Each system generates an average of 421,913 lb/hr of steam when operated at design capacity. As indicated on the table, most of these projects employ electrostatic precipitators for air emission control. Some of the projects combine gas scrubbing or fabric filters with their electrostatic precipitators while others employ dry scrubbing and fabric filters. Expressed as a percentage of the weight of MSW feed, the average amount of ash generated from the RDF produced is 16.6%. This indicates a good burnout, and some materials recovery associated with these projects. RDF ash is disposed of in either a sanitary landfill or dedicated ash fill.

There has been a significant change in the companies involved in the RDF segment of the resource recovery industry in the late 1980s and early 1990s from those of the mid to late 1970s. Many of the large companies interested in solid waste management and waste processing have entered and left the business (e.g., Allis Chalmers, American Can Co., Combustion Equipment Associates, Monsanto, Union Carbide, Occidental Petroleum/Garrett Research, Parsons-Whittemore/Black-Clawson, Teledyne, Boeing, and General Electric Company, among others).

During this same period, there was a clear trend toward simplification of RDF systems. Use of dedicated RDF boilers, and very simple fuel preparation systems such as the "shred and burn" system in Hamilton, Ontario involving simply shredding and magnetic separation came into vogue. New facilities were constructed such as Albany, New York and Columbus, Ohio based upon the shred and burn principle. Systems designed to prepare high quality fuel by air classification and screening such as Niagara Falls, New York and Akron, Ohio were redesigned and simplified. Materials handling problems were reduced with an attendant increase in reliability and availability.

TABLE B-13. FACILITIES FIRING RDF IN SEMI-SUSPENSION SPREADER STOKERS MAJOR FEATURES (adapted from 387)

FACILITY	DESIGN CAPACITY (TPD)	ACTUAL CAPACITY (TPD)	RATIO ACT/DES CAPACITY	NUMBER OF BOILERS	GROSS PWR OUTPUT (MW)	NET PWR OUTPUT (MW)	RATIO GROSS/NET PWR OUTPUT	GROSS KWH PER TON PROCESSED	POUNDS PER HOUR STEAM	BTUs PER POUND
Akron Recycle Energy Systems (RES)	1000	965	0.97	3	4	N/A	N/A	N/A	280000	4800
Anoka County/Elk River R.R. Project	1500	1500	1.00	3	35	N/A	N/A	700	333600	5500
ANSWERS Plant/Albany Steam Plant	800	720	0.90	2	N/A	N/A	N/A	N/A	200000	N/A
City & County of Honolulu	2160	1740	0.81	2	55	46	1.20	550	506000	4800
Columbus S.W. Reduction Facility	2000	1600	0.80	4	37	32	1.16	N/A	700000	4800
Dade Co. S.W. Resource Recovery Project	3000	2800	0.93	4	77	62	1.24	480	540000	5000
Greater Detroit Res. Recovery Facility	4000	2900	0.73	3	65	N/A	N/A	N/A	686000	N/A
Lawrence & Haverhill (RDF)	900	610	0.68	1	21	17	1.24	N/A	185000	6000
Maine Energy Recovery Company (MERC)	607	607	1.00	2	22	20	1.10	N/A	210000	6200
Mid-Connecticut RDF/MWC	2000	2300	1.15	3	90	69	1.31	N/A	693000	5500
Niagara Falls	2000	1800	0.90	2	50	30	1.67	N/A	460000	N/A
Palm Beach County (North) MWC/RDF	2000	2000	1.00	2	61	49	1.24	600	532000	4865
Penobscot Energy Recovery Company (PERC)	750	750	1.00	2	25	21	1.20	545	250000	6200
Ramsey & Washington Counties	1000	1175	1.18	2	22	20	1.13	N/A	240000	5500
SEMASS	1800	1800	1.00	2	52	45	1.16	N/A	560000	5000
Southeast Tidewater Energy Project	2000	1400	0.70	4	40	35	1.14	N/A	375000	5550
NUMERICAL AVERAGE OF NON-ZERO VALUES	1720	1542	0.92	3	44	37	1.23	575	421913	5363
STANDARD DEVIATION	874	704	0.14	1	23	16	0.14	73	179806	508

N/A = Not Available

TABLE B-13. FACILITIES FIRING RDF IN SEMI-SUSPENSION SPREADER STOKERS MAJOR FEATURES (cont)

FACILITY	APC DEVICES USED	ASH RESIDUE (TPD)	RATIO ASH TO ACT TPD	PERCENT ASH RESIDUE	ASH DISPOSAL	DISPOSAL SITE OWNER	TIP FEE $/TON
Akron Recycle Energy Systems (RES)	ESPs	250	0.26	25.9	Dedicated Ashfill	Public	42
Anoka County/Elk River R.R. Project	Dry Scrubbers, Baghouse/FF	204	0.14	13.6	Dedicated Ashfill	Private	70
ANSWERS Plant/Albany Steam Plant	ESPs	140	0.19	19.4	Sanitary Landfill	Public	58
City & County of Honolulu	ESPs, Dry Scrubbers	348	0.20	20.0	Dedicated Ashfill	Public	54
Columbus S.W. Reduction Facility	ESPs	400	0.25	25.0	Sanitary Landfill	Public	20
Dade Co. S.W. Resource Recovery Project	ESPs	560	0.20	20.0	Dedicated Ashfill	Public	28
Greater Detroit Res. Recovery Facility	ESPs, Dry Scrubbers	175	0.06	6.0	Dedicated Ashfill	Private	60
Lawrence & Haverhill (RDF)	ESPs	163	0.27	26.7	Dedicated Ashfill	Private	60
Maine Energy Recovery Company (MERC)	Dry Scrubbers, Baghouse/FF	67	0.11	11.0	Dedicated Ashfill	Private	30
Mid-Connecticut RDF/MWC	Dry Scrubbers, Baghouse/FF	288	0.13	12.5	Sanitary Landfill	Public	45
Niagara Falls	ESPs	400	0.22	22.2	Sanitary Landfill	Private	20
Palm Beach County (North) MWC/RDF	ESPs, Dry Scrubbers	232	0.12	11.6	Sanitary Landfill	Public	85
Penobscot Energy Recovery Company (PERC)	Dry Scrubbers, Baghouse/FF	105	0.14	14.0	Dedicated Ashfill	Private	15
Ramsey & Washington Counties	ESPs, Baghouse/FF	94	0.08	8.0	Sanitary Landfill	Private	67
SEMASS	ESPs, Dry Scrubbers	350	0.19	19.4	Dedicated Ashfill	Public	21
Southeast Tidewater Energy Project	ESPs, Baghouse/FF	137	0.10	9.8	Dedicated Ashfill	Public	29
NUMERICAL AVERAGE OF NON-ZERO VALUES		245	0.17	16.6			
STANDARD DEVIATION		133	0.06	6.4			

N/A = Not Available

Notwithstanding the trend toward more simplified RDF systems, a part of the RDF waste-to-energy market continued to support more complex processing systems normally involving several stages of shredding, screening, and magnetic separation.

The 16 facilities listed in Table B-12 can be divided into four general processing designs based upon the firm having the greatest influence over the process system design and selection of technology:

1. Design: Shred and Burn -- Coarse Shred and Magnetic Separation Only

   Vendor: Tricil/G. Sutin, Hamilton, Ontario (RDF-2)

   Examples: Akron, Ohio; Albany, New York; Columbus, Ohio; Niagara Falls, New York; Rochester, Massachusetts.

   Most of these projects utilize a Detroit Stoker grate system. Akron, Columbus and Albany utilize B&W boilers while Niagara Falls utilizes Foster Wheeler boilers. Rochester, MA utilizes a Riley boiler.

2. Design: Flail Mill, Trommel, Disc Screens, Air Knife, Magnetic Separation, Secondary Shredding.

   Vendor: National Ecology Inc. (RDF-3)

   Examples: Anoka County, Minnesota; Newport, Minnesota; Orrington, Maine; Saco-Biddeford, Maine; Palm Beach County, Florida. (Note: The Maine facilities although similar in design, do not use an air knife.)

   Most of these projects utilize B&W boilers and a Detroit spreader stoker; Orrington uses a Zurn boiler.

3. Design: Vertical Shaft Pulverizer, Magnetic Separation, Trommels.

   Vendor: Heil (RDF-3)

   Examples: Haverhill, Massachusetts; Miami, Florida (after latest retrofit, previously Parson Whittemore's influence); Portsmouth, Virginia

   Haverhill uses B&W technology, Miami uses Zurn, and Portsmouth uses C-E/ABB.

4. Design: Flail Mill, Multi-stage trommels, Magnetic Separation

   Vendor: Combustion Engineering/ABB (RDF-3)

   Examples: Detroit, Michigan; Hartford, Connecticut; Honolulu, Hawaii.

   These projects utilize C-E/ABB combustion VU-40 boilers and C-E stokers.

B.2.5 d-RDF Production

Ideally, in order to either replace or be co-fired with stoker coal, d-RDF should exhibit similar physical and thermal properties as those of coal. However, it has been reported (876) that on an equivalent input basis, RDF has very different properties:

	Ratio of RDF Properties Relative to Equivalent Heat Content of Coal
Weight of RDF	1.7 x
Volume of RDF	2 x
Ash Content of RDF	4 x
Volatile Content of RDF	3 x
Fixed Carbon Content of RDF	1/3 x

In order to produce a densified RDF which more closely approximates coal, both the fluff RDF (used to form the d-RDF) and the densification process have to be controlled. The most common methods of compressing the low density RDF are pelletizing and cubing; other possible methods are briquetting and extruding (875). Such densification devices do not provide for size reduction. Thus, particle size must be sufficiently fine to account for stringy materials and sheet plastics, which would interfere with the production and quality of d-RDF pellets.

Further, the non-combustible content of the fluff RDF must be reduced to reduce the ash resulting from d-RDF combustion. Coal ash can vary between 6% and 20%. The combustible portion of the d-RDF pellet (e.g., paper, corrugated) has an ash content of about 6% to 8% (873). Each percentage point of glass, grits, or other inert material, which may be in the fluff RDF, increases the amount of d-RDF ash by an additive fashion. An overall ash content of between 10% and 15% is recommended in order to decrease erosion of the pelletizer during production of the d-RDF and slagging of the boiler during combustion of d-RDF (874).

Moisture control of the fluff RDF is a critical factor in d-RDF production. In addition to detracting from the fuel value of the pellet, moisture also affects d-RDF production by acting as a die lubricant. At moisture contents less than 12%, hard, stable pellets are produced because of the increased friction between the die and the extruded material. However, production rates suffer with this high friction. As moisture content increases, the friction decreases such that when moisture increases beyond 25%, the decrease in die friction decreases the temperature and compaction of the d-RDF. Resultant pellets have poor surface features, are loosely compacted, and demonstrate lower integrity during handling (873). Thus, moisture content of the fluff RDF should be maintained under 25% (873, 874).

Although MSW typically has a moisture content higher than 20%, and the non-combustible materials (ferrous metals, non-ferrous metals, glass) recovered do not contain moisture, the removal of moisture from the RDF can occur through processing operations such as shredding, air classifying and air drying during conveying, or by adding drying capability prior to densification. To further reduce moisture prior to pelletizing, materials with low moisture content can be added to the fluff. Viewed as binders, these additives can also enhance the resultant pellet integrity. In one demonstration program (874), a number of binders were researched; receiving the most attention were coal fines, slaked lime, graphite dust, coal ash, and lignosulfonate. The coal fines additive was selected based upon: long-term availability, delivered price, contribution to heating value, combustion emissions, affect upon ash content in the finished product, and overall affect on pellet stability.

In the mid-1980s, the U.S. Department of Energy sponsored research examining more than 200 types of binders. It was determined that the best additive was calcium hydroxide, or lime. The researchers reported that the calcium hydroxide assisted in the formation of strong, water-resistant pellets, helped to biodegrade harmful substances in the refuse, was plentiful, and was inexpensive. In addition, the lime tended to neutralize acid gases produced upon the combustion of sulfur in the waste (880).

Early work in the U.S. on producing d-RDF was conducted by the now defunct National Center for Resource Recovery, under contract to the U.S. Environmental Protection Agency and the Department of Energy (1976 to 1979). There were several other pellet producers in the 1970s (873). Commercial attempts at d-RDF production were made by Teledyne National (now National Ecology Company) in the late 1970s and early 1980s and Raytheon Service Company in the 1982 to 1984 time frame.

Pellet mill manufacturers reported in the literature include Buhler-Miag and Sprout-Waldron of the United States; Buhler-Miag of Switzerland; Esbjerg Matador Maskiner of Denmark; Amandas Kahl Mill and Volkseigen Betrieb Muhlenbau of Germany; and Simon-Barron Limited of Great Britain (873). (Note that the Sprout-Waldron unit has been acquired by ABB, and is now called Sprout-Bauer.) Manufacturers have reported throughputs from 4 to over 10 tons per hour. Nonetheless, reported throughputs for U.S. tests have indicated maximum continuous throughput levels of 2 to 4 tons per hour (874, 873). Because the roller surface presses against the inner die surface, it is very difficult to process stringy materials such as textiles. Thus, particle size must be adequately controlled prior to feeding to the pellet mill. In addition, wires, glass and ceramics should be removed from the RDF prior to pelletizing in order to alleviate the erosive effects of these materials.

United States cubing equipment manufacturers include Kirby Manufacturing Inc.; Lundell Manufacturing Company, Inc.; Papakube Corporation; and Warren and Baerg Manufacturing, Inc. (873). Reported advantages of cubers over pelletizers include the shearing action that is caused by the intermeshing press wheel and die, the ability to manufacture the die out of smaller, replaceable pieces, and a greater open space (die hole) area (873).

United States briquetter manufacturers are Bepex Corporation and Fero-Tech. Because briquetters use compression but do not use extrusion, they operate at lower temperatures than pelletizers or cubers. However, a controlled particle size is important to eliminate stringy materials in order to produce good briquette integrity. Extruders have been used only experimentally for d-RDF production (873). They are commonly used for plastic pellet production and have been used for other types of biomass production than RDF, but appear to have low throughput rates when employing RDF (873).

Government Advisory Associates 1990 data (387) show two d-RDF facilities in construction, two in shakedown, and five in operation. These are listed in Table B-7. The major features of the five operating d-RDF facilities are provided in Table B-14. Lundell supplied four of the facilities, with a total design capacity of 450 tons per day, while Reuter/Buhler-Miag is listed as having one operating facility in Hennepin County, Minnesota, with a design capacity of 800 tons per day. Each vendor has one additional facility listed, either in construction or start-up.

The United Kingdom has had at least two plants producing d-RDF since the early 1980s. The Byker plant, owned and operated by the Tyme and Wear County Council, was commissioned in 1979/80 (876), and the Doncaster plant, originally owned and operated by the South Yorkshire County Council, was commissioned in 1980/82 (878). The Byker plant reported throughput rates of approximately 28 tonnes per hour, while the Doncaster refuse processing plant reported throughput rates of 15 tonnes per hour. Both plants have gone through modifications since their initial commissioning. The Byker facility has the Simon Barron 1200 W.P pellet mill, and the Doncaster plant has the California Pellet Mill (7000 Series). It is not believed that there was a system vendor for either facility.

Although GAA data shows five operating facilities with additional facilities coming on line, it is not apparent that any have consistently produced and sold d-RDF on a continual basis. In addition, the overall economics of these facilities and the yield of d-RDF, compared to the quantity of waste accepted at the facility, are not readily available. One factor that can help in the development of this technology is the higher tipping fee of the 1990s, compared to those of the late 1970s and early 1980s, which is the time period when most of the literature cited evolved.

TABLE B-14. d-RDF PRODUCTION FACILITIES -- MAJOR FEATURES (adapted from 387)

FACILITY	DESIGN CAPACITY (TPD)	NUMBER OF BOILERS	GROSS PWR OUTPUT (MW)	NET PWR OUTPUT (MW)	RATIO GROSS/NET PWR OUTPUT	GROSS KWH PER TON PROCESSED	POUNDS PER HOUR STEAM	BTUs PER POUND	CENTS PER KW
Hennepin County (Reuter)	800	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Iowa Falls	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Muncie	150	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Thief River Falls	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Yankton	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NUMERICAL AVERAGE OF NON-ZERO VALUES	250	0	0	0	0.00	0	0	0	0.00
STANDARD DEVIATION	276	0	0	0	0.00	0	0	0	0.00

N/A = Not Available

FACILITY	APC DEVICES USED	ASH RESIDUE (TPD)	RATIO ASH TO ACT TPD	PERCENT ASH RESIDUE	ASH DISPOSAL	DISPOSAL SITE OWNER	TIP FEE $/TON
Hennepin County (Reuter)	Baghouse/FF	56	0.12	11.9	Sanitary Landfill	Private	90
Iowa Falls	Nothing Used	N/A	N/A	N/A	Sanitary Landfill	Private	30
Muncie	Baghouse/FF	N/A	N/A	N/A	Sanitary Landfill	Private	20
Thief River Falls	Nothing Used	5	0.10	10.0	Sanitary Landfill	Public	45
Yankton	Nothing Used	N/A	N/A	N/A	Sanitary Landfill	Public	8
NUMERICAL AVERAGE OF NON-ZERO VALUES		31	0.11	11.0			
STANDARD DEVIATION		26	0.01	1.0			

N/A = Not Available

B.2.6 Case Studies

B.2.6.1 RDF Production and Suspension Cofiring with Pulverized Coal

This section presents case studies for: 1) Lakeland, Florida where a new power plant and associated RDF production facility were constructed; and 2) Madison, Wisconsin where an existing power plant and RDF processing facility were modified to enable the cofiring of RDF and coal.

B.2.6.1.1 Lakeland, Florida (484, 621). In 1975, the City of Lakeland projected a need for more electric generating capacity by 1981 than provided by its then-existing three oil-fired power plants. A moratorium on new oil-fired plants coupled with a feasibility analysis indicating that a 250-MW coal-fired plant would not be economical, led to the development of a 364-MW coal and refuse-fired facility. It was estimated that, at full load, the plant would consume 900,000 tons of coal per year and 75,000 tons of refuse. On a joint venture basis with the Orlando Utility Commission (60% owned by the City and 40% owned by Orlando), the City began construction of the C.D. McIntosh Unit No. 3 power plant in 1981; commercial operations started in 1983.

Process Description. A flow diagram of the process is shown in Figure B-17. It consists of a single line, low cost system with a nominal capacity of 40 TPH. Incoming waste is fed to a 50-TPH Williams hammermill. The shredded MSW passes under an Eriez style 740 magnetic separator for ferrous metals removal as it is being conveyed to a rotary disc screen, manufactured by Rader Pneumatics. The screen removes oversize materials (larger than 1 inch) which are returned to the tipping floor and fed back into the hammermill. An air-classifier bypass is installed in the system so that the screen undersize material can be conveyed either to the air classifier (designed by Rader Pneumatics) or to a distribution bin. The light fraction produced by the air classifier is conveyed to the distribution bin which is a 40-ton capacity Atlas storage silo; representing about 1 hour's fuel supply to the boiler. Four variable speed discharge conveyors feed Rader rotary feeders which pneumatically convey the RDF to the boiler.

The power plant was designed to fire eastern Kentucky bituminous coal and a combination of pulverized coal and 10% RDF. The B&W boiler has dual register burner units which are of the opposed firing design, and is equipped with a Detroit Stoker dump grate. The nameplate rating is 2,510,000 lb steam/hr at 2640 psig and 1005^o; actual steam capacity is 2,670,000 lb/hr at 2520 psig and 1005^o. The tandem compound 2-flow single reheat turbine generator was manufactured by General Electric and is a 364 MW unit with inlet pressure of 2400 psig and 1000^o and an exhaust pressure of 1.83 psig and 630^o (484).

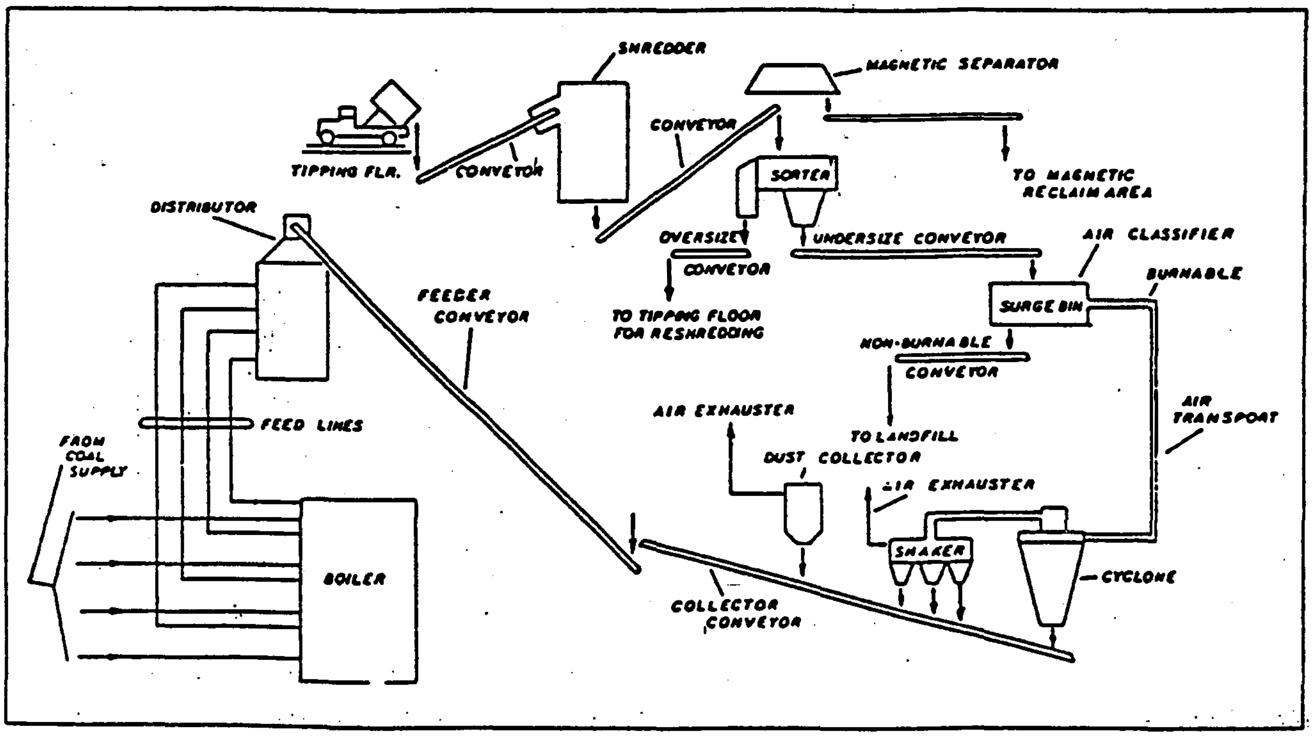


Figure B-17. Lakeland, FL Process Flow Diagram (621)

Operations. As can be seen from Figure B-17, redundant pieces of equipment were not included in the original design. This has resulted in an availability of 55% to 70%. Designed to process 40 TPH, the system's highest continuous rate has been 27 TPH. This is primarily the result of primary shredder capacity in order to hold particle size limits. To increase the capacity beyond 27 TPH would require the addition or replacement of the shredder (621).

In 1985, the plant processed 381 TPW of MSW (19,800 TPY) and produced 324 TPW of RDF. As-produced RDF characteristics are as follows: particle size - 90% passing 1.25 inches; density - 8 lb/cu ft; moisture content - 29.5%; ash content - 22.03%; heat content - 4,700 Btu/lb; and sulfur content - 0.17% (484).

During the month of August, 1989, the coal displaced was estimated to be 993 tons and the plant availability was reported to be 46% (621). In 1990, on a combined basis (RDF processing and power plant), the facility burned 63,250 tons of RDF and 900,000 tons of coal. This represents an increase in capacity of over 300% since 1985. The plant was operated 230 days/year which equates to 275 tons per day of MSW, 92% of design capacity (387). RDF represented only 2% of the annual average fuel heat input (387).

In 1989, Garing (621) noted that the processing system had been the most consistent part of the material flow path. The Atlas storage bin, boiler combustion, and bottom ash handling equipment caused the largest decrease in system availability and would require modifications. He further noted that proper preventive maintenance schedules and planned component overhauls had been implemented that would result in increased production.

Emissions. The boiler is equipped with a flue gas desulfurization system (B&W wet limestone scrubber) which removes sulfur dioxide while burning coal. An electrostatic precipitator removes stack gas particulates. Emission test results in 1985 showed 0.06 lb/MMBtu particulate concentrations as compared to a standard of 0.10. SO_2/NO_x measured in 1983 was 0.017/0.042 lb/MMBtu as compared to a standard of 1.2/0.70 (484).

The original permit was based on using secondary wastewater effluent from the Lakeland wastewater treatment plant as make-up water for the cooling tower. As a result of public comment, an additional wastewater treatment facility was added to clean up blowdown water which was originally going to be discharged and cleaned in a settling pond.

Due to the close proximity to residential areas, a noise monitoring program was implemented to ensure that specified limits of noise emissions were monitored and controlled. In addition, the design was modified to add valve silencers and covers over the feed pump turbine (484). Another significant feature of the plant is the use of sludge from the flue gas desulfurization system for road base material and concrete products (484).

Economic Data. In 1981, the entire cost of the 364 MW plant was $236 million; adjusted to 1991 dollars, this amounts to nearly $305 million (387) The incremental installed cost of the waste processing facility was estimated to be about $5.7 million in 1981 dollars (387), or 3% of the total.

In 1985, energy sales were $545,000 while tipping fees, ferrous revenue and other revenue added $224,280 for a total of $769,280. Operating and maintenance costs were $453,051 with $24,000 for overhead and other annual costs bringing total costs to $477,051. Net income was thus $292,229 (484).

A summary of revenues and costs was reported (621) for the month of August, 1989. This data is presented in Table B-15.

TABLE B-15. LAKELAND, FL FINANCIAL DATA - AUGUST, 1989 (adapted from 621)

	Tons	$/Ton	Mo. Total (August)	Annualized
Revenues				
Tipping Fees	2,951.87	14.55	42,946.57	515,359
Ferrous	79.09	47.73	3,774.97	45,299
Total Revenue		15.83	46,721.54	560,658
Costs				
Heavies Removed	174.18	19.50	3,396.51	40,758
O&M		11.57	34,160.21	409,923
Capital		17.62	52,000.00	624,000
Total Costs		30.34	89,556.72	1,074,681
Net Cost of RDF	2,698.60	15.87	42,835.18	514,023

At an estimated heating value of 9 MMBtu/ton, the 2,700 tons of RDF fired during August 1989 resulted in the boiler being supplied with approximately 24,300 MMBtu. At a net cost for the fuel of nearly $43,000, the unit (capital) cost of RDF of $1.76/ton compares favorably to the cost of Kentucky coal (over $2.00/ton).

Revenue is realized from the savings in coal plus tipping fees charged or transferred from the City's Department of Public Works which are 60% of the local landfill rate paid by the City to the County. Additional savings result from reduced hauling since the landfill is more distant from the McIntosh power plant; however, these savings do not show up in the operation of the power plant, but rather in the DPW budget (621). Beginning in 1988, additional revenue was received from local independent haulers permitted to tip at the plant. In 1988, about 75 tons per day were received from these haulers generating revenues of $19.50 per ton (the tipping fee levied by the county landfill).

Combined operations and maintenance costs, or incremental costs for firing RDF into the boiler are not reported in the literature. The economics calculated for firing RDF do not take into account the additional ash generated by the RDF, nor do they take into account any loss in efficiency of the boiler operation from combustion of RDF such as from changes in exit gas temperature.

In summary, the Lakeland data indicate that, even when tipping fees are very low, averaging less than $15/ton, the cost of RDF is less than the cost of coal in railcar quantities. Thus, the community can preserve a low tipping fee while the utility saves on cost of fuel. The Lakeland facility has now been operating for 8 years. It would seem, by normal standards, that this would be viewed as a successful RDF project in which RDF is produced reliably and cofired into a base-loaded pulverized coal utility boiler to generate electricity.

B.2.6.1.2 **Madison, Wisconsin** (622, 484). In 1974, Madison Gas and Electric (MGE) and the City began planning a joint energy recovery project involving the cofiring of RDF and coal. Two boilers at MGE's Blount Street Generating Station, located in downtown Madison, were modified to burn RDF from the City's Olin Avenue RDF processing plant 3 miles away. The RDF plant had been operating since 1967 as part of a shred-fill operation. Modifications were made to produce RDF of the quality necessary for acceptable suspension firing. Operation of the RDF processing plant and firing of RDF in MGE's boilers have been continuous since mid-1979.

Process Description. A flow diagram of the 400-TPD, single-line RDF process is shown in Figure B-18. Incoming waste is fed to a 50 TPH flail mill. The shredded waste is conveyed through a single-stage drum-type magnetic separator which removes ferrous material. The remaining material is processed in a trommel screen unit for removal of most glass, nonferrous metals, and other noncombustibles. The oversize material is conveyed to a Heil vertical shaft secondary shredder equipped with a full air-swept pneumatic takeaway system which serves as an air classifier removing any remaining heavy noncombustibles and some textiles from the final RDF product. The RDF is pneumatically conveyed through a cyclone to stationary packers, and transported via City-owned 75-cubic yard semi-trailers from the Olin Avenue site to the Generating Station. Each trailer holds 12-15 tons.

The receiving station (a modified Miller-Hoft type system) is divided into two parts: 1) a receiving room, maintained by the City and large enough to store two trailers; and 2) two RDF storage bins and associated feeding systems operated by MGE. Each bin feeds one boiler. RDF is pneumatically transported to the two B&W 50-MW boilers. Each boiler has a capacity of 425,000 lb steam/hr at 1,250 psig and 950°. These are front-fired pulverized coal boilers with natural gas back-up fuel. There are six burners located two each at three elevations. The boilers are equipped with both mechanical collectors and electrostatic precipitators. The bottom ash is collected in a dry ash pit at the base of the boilers. Drop grates were installed above the ash pits at the boiler neck to maximize burn-out of RDF and prevent clinkering in the ash pit.

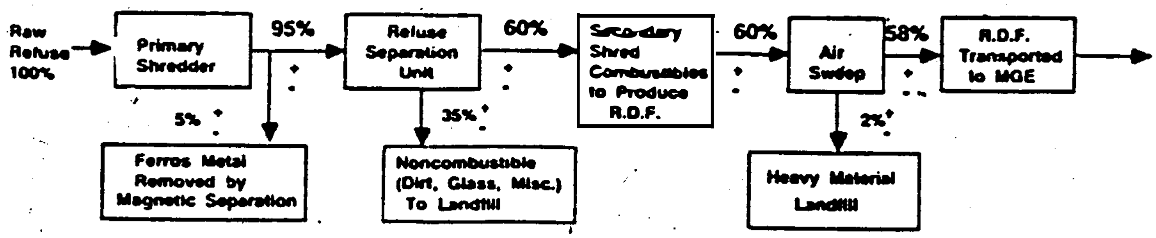


Figure B-18. RDF Processing Plant, Madison, WI (622)

<u>Operations</u>. During the period from 1980 to 1988, the City processed 260,000 tons of MSW, producing 130,000 tons of RDF. The weighted average quality of the RDF is reported as: 5,700 Btu/lb (as received HHV), 12% ash, 25% moisture, and a particle size of 90% passing 3/4-inch screen opening. Of the 130,000 tons produced, 14,000 tons were landfilled because there was no market. The remainder was burned by MGE. Most of the landfilling of RDF took place during 1985 to 1987 when MGE experienced a down market. In 1988, virtually no RDF landfilling occurred.

At a 10 to 15% replacement rate, MGE fires about 5 to 6 tons per hour of RDF per boiler. The operating plan is that a minimum load of 70% on the boiler is required before the RDF feed system is engaged for firing. Once 70% load is achieved, RDF feed rate is relatively independent of boiler load. If the boilers are kept on-line 24 hours per day, MGE has the potential of burning 240 tons or more of RDF/day.

Because the Blount station is a peaking station, it is not fired continuously. The station is typically cycled on and off line daily and is frequently off line on weekends. RDF is fired usually only Monday through Friday for 10 to 15 hours per day. The RDF operating staff is scheduled for two 8-hour shifts of RDF firing per day. RDF is always burned when boiler load is sufficient.

At the outset of the project, the City processed during the daytime hours on the first shift. However, when MGE was ready to bum RDF on the first shift, it was often not yet available. Further, electric costs for the RDF production plant were higher on the first shift. To take advantage of lower electric rates and increased RDF firing availability, City operations were shifted to the nighttime hours.

The availability of the City's processing plant and MGE's boilers and the RDF receiving station have all been "excellent" (622). With the exception of an occasional large clinker, no RDF related forced outages of the boilers have occurred. In the event of a short stoppage or outage, the load is picked up by coal alone with no interruption in electrical generation.

When RDF is burned, there is a tendency to form clinkers on and above the grate in the boiler. RDF quality control has been employed at Olin Street as the best way to minimize the impact from clinkers. Close monitoring by MGE operating personnel in grate dumping and dumping hourly has also proved effective. Occasionally, large clinkers have formed which have required the boiler to be taken off line. Typically, they can be knocked off the walls during operation with a rod. Also, because the ash system is dry, ash pit fires have been encountered in Madison. This has created secondary problems with the dump grate operation.

No significant effects of burning RDF have been noted in the boilers. There has been no noticeable corrosion, and there are no slagging problems. Some fly ash erosion is occurring on tubes in the upper flue gas passes, but this is not believed to be related to RDF. A 1.5% loss in boiler efficiency is experienced primarily due to the introduction of cold ambient air to the furnace from the overfire/underfire grate blowers and outside air from the blowers which pneumatically convey the RDF into the boilers. Flue gas temperatures rise 25 to 30 ^{o}F when RDF is burned.

<u>Emissions</u>. The principal environmental regulation of immediate concern to MGE and the City is the new Wisconsin air toxics rules, NR445, which took effect in 1988. Coal, oil and gas are exempt from these rules, but RDF is not. Several "toxic emissions" are regulated under this rule. Air emission stack testing was performed in 1988 for one boiler burning coal only and then cofiring coal and RDF. Substances analyzed included particulates, SO_2, HCl, CO_2, CO, trace metals, dioxins and furans. Of all substances tested, only the threshold limits on HCl and As were exceeded. No logical explanation for the high arsenic levels has been found. Retests were conducted in August 1989, but the current 1991 status of the results has not been reported in the literature.

Economics. The capital investment by the City for the processing plant modifications, City-owned process equipment, site improvements, and engineering totaled $2.72 million. MGE's final capital investment for the Blount Street RDF receiving station, including building, RDF feed equipment, site improvements, engineering, and startup costs was approximately $1.05 million. The modifications to the two boilers at the generating station including installation of the dump grates, overfire/underfire grate blowers, RDF piping and injection nozzles, engineering and start-up costs were approximately $0.5 million. All these costs were amortized over the 10-year life of the project.

MGE in essence entered into the agreement with the City as a public service on the basis that it would neither make nor lose money. MGE paid the city the amount for RDF that it saved in coal costs after taking into account incremental operations and maintenance costs. At least up until 1987, there was no net cost to MGE, its stockholders or its customers, and likewise there was no benefit. (This may have changed in a new contract which was under negotiation in which there were certain incentives.)

The City of Madison's annual budget for producing RDF is $150,000 to $200,000 or approximately $10 to $12 per ton delivered to MGE. This cost is over and above the cost for landfilling residue from Olin Street. In 1988, the tipping fee was $17.50 per ton. The sum of processing, delivery, and disposal results in a net cost to the City of approximately $27 to $30/ton in 1988. This is above landfilling costs in 1988 but is approximately the cost anticipated in 1992 when the current landfill is closed. Mandatory curbside collection of recyclables is also expected in Madison.

B.2.6.2 Case Studies: RDF Production and Firing in Semi-Suspension Spreader Stokers

Two projects considered representative of current RDF technology have been selected as case studies: 1) the SEMASS Project located in Rochester, Massachusetts; and 2) the Mid-Connecticut Resource Recovery Project located in Hartford. SEMASS utilizes the shred and burn technology where the only processing prior to combustion is removal of bulky objectives, shredding, and magnetic separation. The Mid-Connecticut Project utilizes a flail mill and multi-stage trommels in addition to magnetic separation. The Mid-Connecticut Project was also the subject of a comprehensive characterization and performance evaluation conducted jointly by Environment Canada and the U.S. EPA.

B.2.6.2.1 Rochester, Massachusetts (SEMASS)

SEMASS is a $208 million, 1900 TPD, 54 MW project. Employing the shred and burn technology, the system ensures that virtually all the combustibles reach the boiler. Non-combustible materials are recovered for recycling at the plant's ash processing facility. Startup and testing began in August, 1988; commercial operations followed at the end of January 1989. The facility services 32 communities in southeastern Massachusetts including 14 of the 15 communities on Cape Cod. Electricity is sold to Commonwealth Electric Company under a 27-year guaranteed revenue power sales agreement.

A unique aspect of the project is the rail transport of MSW to the facility. Bay Colony Railroad designed a short-line operation utilizing a simple, rotary dumping system which empties rail cars from the top. The system employs 60-ft boxcars, each holding approximately 40 tons (267).

Process Description (522). A process flow diagram of the SEMASS project is shown in Figure B-19. Solid waste is deposited on a tipping floor in an enclosed 80,000 sq ft receiving building capable of holding 3,000 tons of MSW. Following inspection for non-processibles and dangerous objects, the waste is pushed by front-end loaders onto conveyors leading to the shredding system composed of three hammermill shredder processing lines. An inspection station aside the shredder feed conveyors allows for further examination of the waste for removal of unprocessible or dangerous objects.

The 100-TPH shredders (manufactured by Jeffrey Division of Dresser Industries) are horizontal shaft, single direction, down-running mills powered by 1500 hp motors. Each shredder is housed in its own reinforced concrete enclosure and is protected with a Fenwall explosion suppression system. A vapor detection system and explosion relief vents in the roof are also employed for further safety. The MSW is shredded to a size of 99% passing 6 inches.

The three shredders discharge onto a common transfer conveyor that feeds a single Eriez two-stage magnetic separator. Each magnet is designed to handle 112.5 TPH. In this design, magnetic material is picked up by the first magnet, dropped onto a transfer conveyor, and then recaptured by the second magnet. The separator removes 60 to 70% of the ferrous metal from the waste stream.

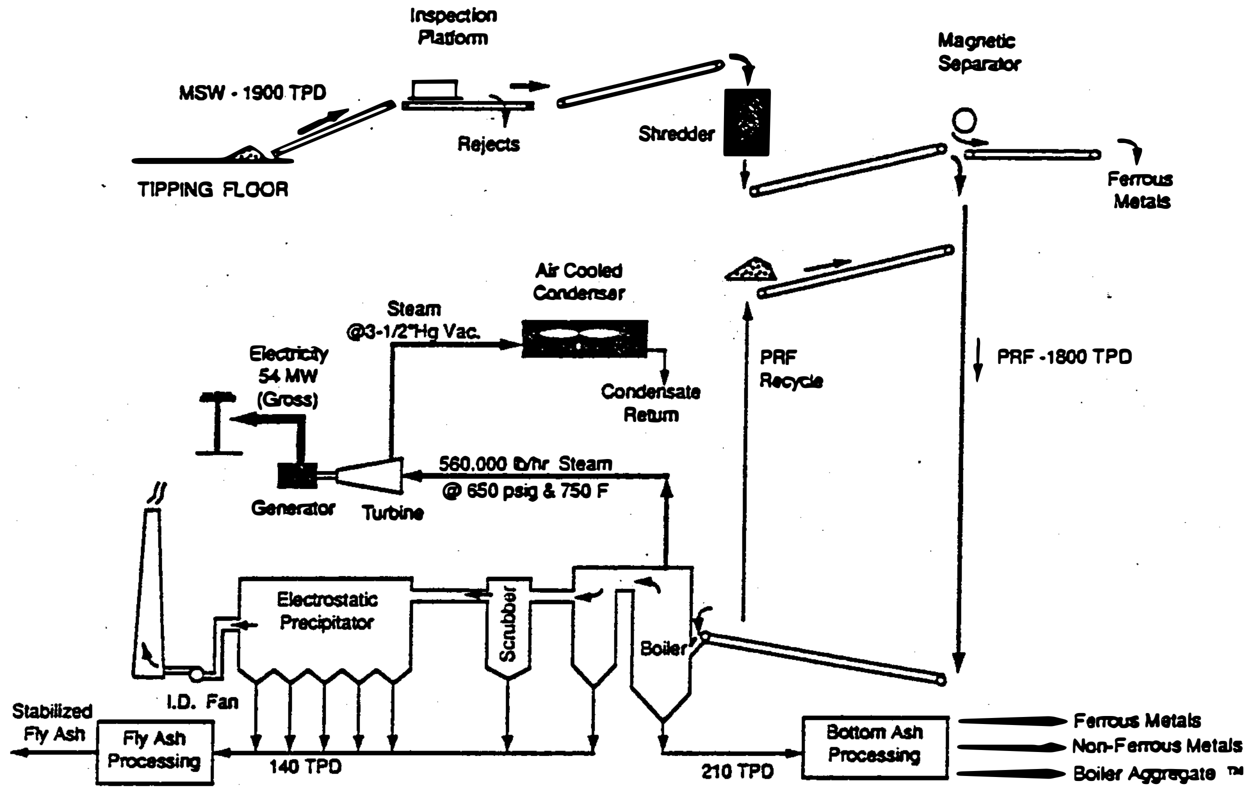


Figure B-19. SEMASS Process Flow Diagram (522)

The processed RDF (called "PRF") is then conveyed to the boiler feed system. Flow variations are evened out through the use of ten vibrating feed bins (five for each of the two boilers). These hold approximately 5 minutes feed at full load. Excess fuel is recycled back to the storage area and can be fed back to the boiler by an independent feed system without passing through the shredders a second time. Typically, a 4 to 8 hour supply of back-up fuel is in storage at all times.

The PRF is combusted in two waterwall, semi-suspension stoker boilers (Riley Stoker). The light fraction burns in suspension while the heavier fraction burns on the grate. Each boiler has the capacity to process 900 TPD of RDF and is available 85% of the time; the unit also has the capability to fire 100% full load on oil back-up. The RDF Higher Heating Value (HHV) is estimated at 5200 Btu/lb. Steam production for each boiler is 280,000 lb/hr at 650 psig and 750°F at full load. Heat release on the grate is rated at 600,000 Btu/hr/sq ft, which is relatively low compared to the normal 750,000 Btu/hr/sq ft for an RDF-fired boiler. Other features include evaporator screen tubes at the exit of the furnace to protect the superheater from erosive ash or "sparklers."

The ash produced by the boilers is handled in a dry system that conveys the bottom ash and the fly ash to processing facilities. Through a series of unit operations including magnetic separation, screening and size reduction, bottom ash is processed into three products: ferrous metals, nonferrous metals, and Boiler Aggregate*tm*. The fly ash is stabilized before landfill disposal.

__Operations__. The SEMASS operation employs 91 full-time personnel: 8 in management and administration, 71 in operations (including supervision), and 12 in the maintenance group (including supervision). MSW processing takes place 7 days per week, 24 hours per day, utilizing one of the three available shredding lines.

Waste throughput has been climbing steadily since the plant started up. As of November, 1989, the last month reported in the literature reviewed (522), the monthly capacity was up to about 50,000 tons per month, or 1675 TPD(7). During the first 12 months of operation, the net power generation was 582 kWh/ton of RDF combusted.

During 1989, about 2.5% of the incoming refuse was separated out by the magnetic separator. The ash facility separated out another ferrous fraction that represented approximately 1.5% of the incoming waste. The nonferrous product recovered through ash processing amounted to approximately 0.4% of the MSW. The total weight of the ash produced from the facility was 19.4% of the incoming waste. The total Boiler Aggregate*tm* product was 10% of the incoming waste while the fly ash averaged approximately 7.5% of the refuse.

The mass balance for the facility provided in Table B-16 is based upon data extracted from the Official Statement used in August 1991 to obtain public financing for expansion of SEMASS to 2800 TPD (894).

__Emissions__. The flue gas exiting the boilers is treated for acid gas removal via direct contact with a rotary atomized lime slurry mixture inside one of two spray dryer absorber (SDA) units (267). This is followed by two parallel five-field electrostatic precipitators, the largest known unit to be installed on any refuse-fired plant (522). Air emission results during acceptance testing were as follows (522):

Emission	Limit	Average Values
SO_2	65% removal	68%
HCl	90% removal	93%
Particulate	0.03 gr/dscf @ 12% CO_2	0.01 gr/dscf

The Commonwealth of Massachusetts has established total dioxin emission guidelines of 2.2 picograms/m^3 for gaseous emissions and 1.1 picograms/m^3 for particulate emissions.

TABLE B-16. SEMASS PROJECT MASS BALANCE (adapted from 894)

	Production 1 Jan-31 Jul 1991	Annualized TPY
Average MSW Processing Rate	1,713 TPD(7)	625,442
Average RDF Processing Rate*	1,552 TPD(7)	566,480
kWh/Ton RDF (7 mo. average)	587 kWh/T	
Nonferrous Metal	0.46%	2,892
Ferrous Metal (pre/post)	4.19%	26,217
Bypassed Waste	6.00%	37,512
Nonprocessibles	1.66%	10,377
Bottom Ash	7.43%	46,451
Fly Ash	7.88%	49,284
Electricity		332,209 MWh

* 86.2% of Design Capacity

The avoidance of ground water pollution was of particular importance to this project since it is located in the middle of the largest cranberry growing region in the U.S. Thus, this facility has a "zero discharge" of water. All wastewater except septic sewage is consumed by the plant. An air cooled turbine exhaust steam condenser is employed avoiding a cooling tower. All of the industrial wastewater generated by the plant, such as boiler blowdown, general process drains, demineralizer regeneration waste, etc., are consumed inside the facility. The primary wastewater consumer is the spray dryer absorber which uses the recycled wastewater as dilution water for the lime slurry.

The fly ash is conditioned and stabilized using cement kiln dust injection. The process chemically binds the residual heavy metals contained in the ash and prevents them from leaching into the environment. The kiln dust/fly ash mix hydrates into a hard, stable, concrete-like substance which enhances its suitability for conventional landfill disposal.

Special attention was also paid to ensure that noise levels emanating from the plant would be extremely low. In particular, modifications were made to the air cooled condenser, a substantial noise generator. This resulted in a sound pressure level of 50 dB on the "A" weighted scale at the site boundary.

Economic Data. The cost data provided in Table B-17 was developed based on annualizing the cost information reported for the first 7 months of 1991 in the Official Statement utilized to obtain public financing of the proposed SEMASS expansion (894).

TABLE B-17. SEMASS FINANCIAL DATA (adapted from 894)

	1 Jan-31 Jul 1991	Annualized TPD
REVENUES		
Average Tipping Fee	$33.46/T	$20,926,289
Average Electricity	$0.073/kWh	$24,252,000
Materials Sales	$54.53/T	$ 1,587,428
TOTAL		$46,765,717
OPERATING EXPENSES		
RDF & Boiler Plant	$21.20/T MSW	$13,258,285
Maintenance	$ 0.64/T MSW	$ 402,857
Ash Facilities	$15.17/T Ash	$ 1,453,117
Landfill Transportation	$ 5.89/T Ash	$ 564,000
Landfill Costs	$14.04/T Ash	$ 1,344,000
Mgmt, Insurance, Other	$ 5.34/T MSW	$ 3,341,143
Host Fee (Rochester)	$ 1.70/T MSW	$ 1,068,000
TOTAL		$21,435,811
NET OPERATING INCOME	$40.50/T MSW	$25,329,906
ANNUAL DEBT SERVICE	$31.10/T MSW	($19,452,000)
INTEREST INCOME		$ 805,714
NET SURPLUS*	$10.68/T MSW	$ 6,683,620

* The net surplus was utilized for operation of transfer stations, capital improvements to the plant, and for debt service coverage.

B.2.6.2.2 <u>Hartford, Connecticut</u>. The 2,000-TPD Mid-Connecticut Resource Recovery Facility consists of a waste processing facility (WPF) that produces RDF, and a power block facility (PBF) that combusts either RDF or coal to produce steam for the generation of electricity. Combustion Engineering, Inc., now Asea Brown Boveri (ABB), designed and constructed the facility for the Connecticut Resources Recovery Authority (CRRA). Construction began in 1985, start-up in the fall of 1987, and full-scale commercial operations commenced in the fall of 1988.

The PBF is located at a Connecticut Light & Power (CL&P) generating station where coal-fired boilers were previously removed and the building subsequently rebuilt and retrofitted with new boilers. The WPF is located adjacent to the PBF. ABB operates the power block facility, while the processing portion of the plant is operated by a local public authority, the Metropolitan District Commission. The overall resource recovery system also includes transfer stations, a landfill, and an electric generating facility operated by CL&P (629). A layout of the Mid-Connecticut Facility site is shown in Figure B-20.

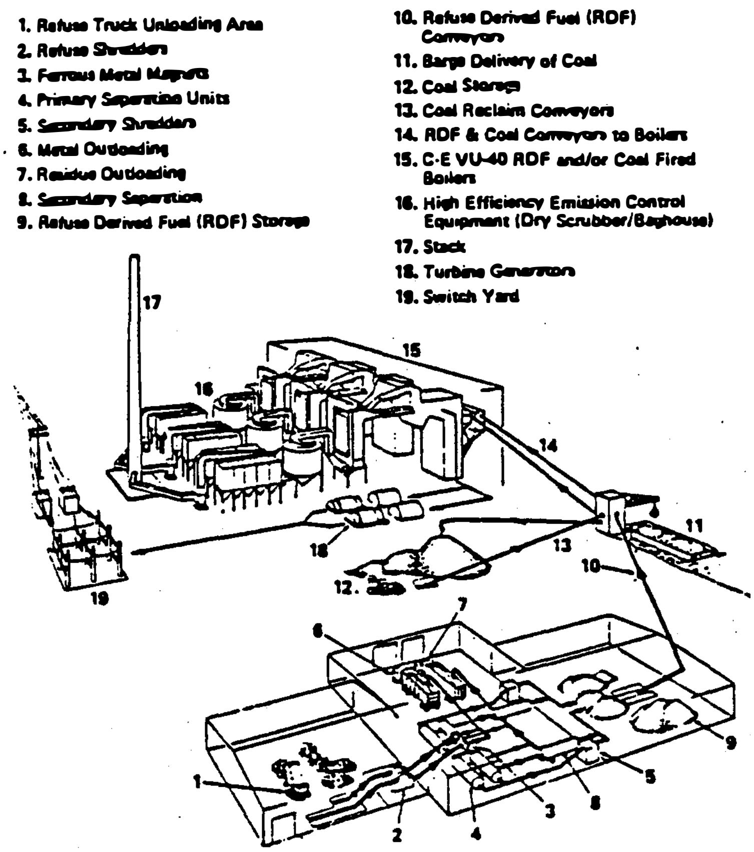


Figure B-20. Mid-Connecticut Facility Layout (24)

Process Description (524, 887, 895). The RDF production process is depicted in Figure B-21. Incoming waste is discharged onto the receiving area tipping floor which has a capacity of 3,000 tons. The waste is inspected for nonprocessibles and hazardous materials as front-end loaders sort and stockpile the material.

There are two parallel, identical processing lines, each designed to process 100 TPH. The loaders remove material from the stockpile and feed each of two horizontal infeed conveyors which, in turn, feed two additional conveyors to progressively reduce the burden depth so that nonprocessibles can be removed as the waste passes a picking station. The waste is then fed to a flail mill enclosed in a blast resistant bunker for explosion protection. Following coarse shredding, a double drum magnetic separator removes ferrous metals which are recovered and transported to an air classifier for removal of contaminants.

The mostly non-magnetic waste stream is then split into two streams and fed into two primary trommel screens in each process line. The undersize residue material from the trommels consists of sand, glass, dirt, and a small quantity of combustible materials. The sized combustible fraction is transported to a secondary trommel screen for further processing. Oversized material, consisting mainly of paper and cardboard, is conveyed to a secondary shredder for size reduction prior to transport to RDF storage. The secondary trommel screen produces two streams: an undersize residue, and a sized RDF stream (90% passing 4 inches). A stationary packer is used to discharge the RDF from each process line into the storage area. The RDF storage area has a capacity of 2,000 tons. A front-end loader stockpiles RDF within the area and loads it onto conveyors for transport to the power block facility (PBF).

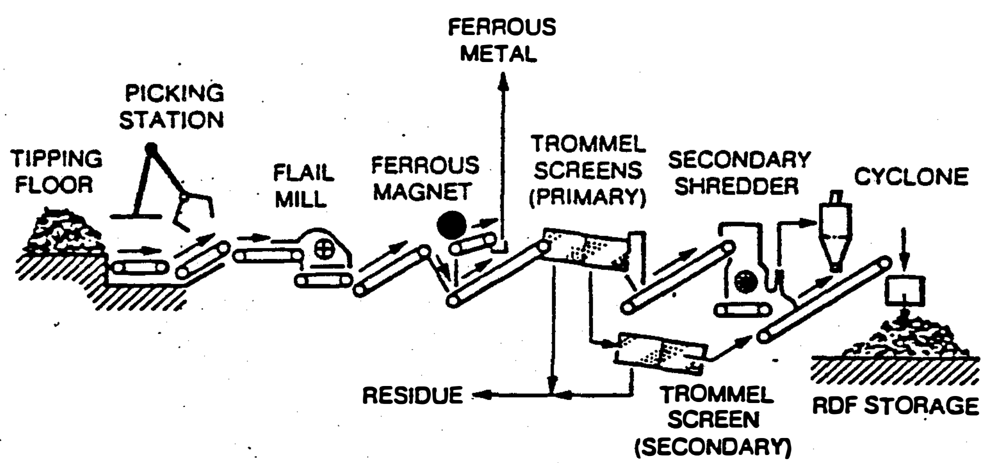


Figure B-21. Waste Processing System Diagram - Hartford, CT (629)

Figure B-22 provides a diagram of the power block and electric generating facilities. The PBF consists of three C-E VU40 spreader-stoker boilers, each with a rated throughput of 677 TPD RDF. Four feed chutes on each boiler are fed by a metering bin with live bottom augers. The RDF has an average heating value of 5500 Btu/lb (387). The boilers generate 231,000 lb/hr of steam while firing 100% RDF, and 188,000 lb/hr of steam while firing 100% coal. The steam is headered to either of two 45 MW, 465,000 lb/hr turbine generators. Typically, two boilers combust RDF while the third unit fires coal on a rotation basis (629). RDF and coal can be fired in any combination to generate up to 231,000 lb/hr of steam. When two units are burning RDF and one unit is burning coal, the total steam capability is 650,000 lb/hr at 880 psig and 825 degrees F (524). Although the boilers are capable of co-firing RDF and coal, this was done only during the acceptance testing period (887). Coal is transported to the facility by river barges and conveyed to a transfer building from which it is either directed to the coal silo or to the coal yard. The yard provides storage for 30,000 tons of coal.

A dry scrubber/baghouse system removes acid gases and particulate matter from the flue gas stream. The facility also utilizes continuous emissions monitoring equipment. The bottom ash and fly ash are combined and stored in a bunker for subsequent transport to the landfill for disposal.

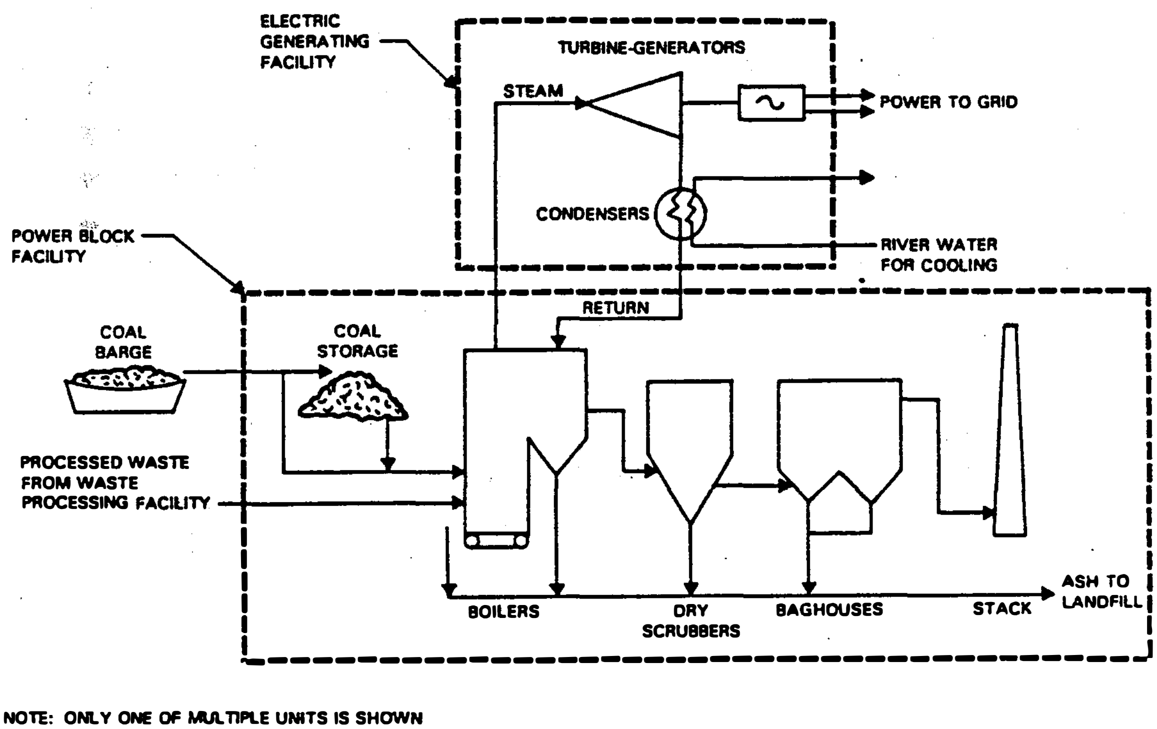


Figure B-22. Power Block Diagram - Hartford, CT (895)

Operations. The Mid-Connecticut Facility receives residential, commercial, and light industrial waste from 44 contracted cities and towns as well as 11 other communities on a spot basis. Flow-control legislation guarantees the delivery of MSW to the facility (387), either by direct haul or through transfer stations.

The waste processing facility is operated by 63 employees; the power block facility employs 85. Of the total 148 employees, 14 are management and 134 are non-management (387). Waste processing takes place an average of 5.5 days per week, 16 hours per day. The PBF burns 2000 TPD, operating 7 days per week. Since 1989, the WPF has operated at 25% above its design capacity of 2,000 TPD. In 1990, the facility processed 624,000 tons of MSW (387). RDF yield averages approximately 83% (by weight) of the MSW processed with an ash content of 10 to 15% by weight. Noncombustibles (residue fraction) account for 11% of the waste stream, with ferrous metals recovered at 4% and nonprocessibles at 3%. Steam generator thermal efficiency has averaged 77% for the three units; and boiler availability has averaged more than 89% (887). A total combustible loss of 6.7% in the process residue and power plant ash was also reported (524).

Problems experienced during facility start-up resulted in redesign of the ash handling system, upgrading of the bottom ash conveying system, and modifications to process equipment (887). Information is not available on modifications made on proprietary equipment (896). A significant incident reported in the literature was the rupture of a boiler waterwall shortly after commercial operation began. Investigation disclosed excessive tube corrosion in all boilers primarily due to lead chloride. The ruptured boiler was retubed and Inconel (a high nickel content material) was applied to the tubing of all three boilers. This incident resulted in a two-week total plant shutdown. The application of Inconel is reported to have corrected the problem of accelerated boiler tube corrosion (524).

As noted above, the facility has achieved high processing rates and boiler availability. During performance testing, contractor guarantees were met or exceeded for facility and process line capacities, steam generator thermal efficiency, and overall facility combustible loss. The guarantee for ferrous metal removal efficiency of 90% was not met; the recovery efficiency is approximately 80%. The contractor (ABB/C-E) and the CRRA agreed not to add equipment that would permit the 90% level to be met. The CRRA is presently investigating methods for upgrading the ferrous product.

Emissions. A spray dryer absorber (SDA) for each boiler removes acid gases with lime, resulting in a dry end product for disposal. Each SDA is followed by a fabric filter (baghouse) for particulate matter collection. The U.S. EPA participated in the first emissions tests conducted in May/June 1988, prior to commercial operation (October 1988). Test results for the flue gas emission control system, while firing 100% RDF, are provided in Table B-18. Emission levels were well within the limits established by the Connecticut Department of Environment Protection (DEP). Further, the PCDD/PCDF, particulate matter, and HCl levels were also within the limits established by the proposed 1990 Performance Standards and Emission Guidelines for New and Existing MWC Facilities. (The 1991 New Source Performance Standards are provided in Appendix A, Mass Burn Technologies.) Emission levels were reported to be among the lowest of all operating waste-to-energy plants (629, 887).

TABLE B-18. MID-CONNECTICUT PROJECT EMISSIONS TEST DATA, MAY/JUNE 1988 (524)

Emission	Connecticut DEP Standard	Average Measured Emission Value (All Boilers)
PCDD/PCDF[a]	1.95 ng/Nm^3	<0.0278
Particulate Matter (PM)	0.015 gr/DSCF @ 12% CO_2	0.0057
Hydrochloric Acid (HCl)	90% removal or	99.5
	50 ppm at 12% $CO_2$2	1.7
Sulfur Dioxide (SO_2) (100% RDF)	0.32 lb/million BTU	0.01
Nitrogen Oxides (NO_x)	0.6 lb/million BTU	0.34
Carbon Monoxide (CO/CO_2 Ratio)	0.002	0.00156
Volatile Organic Compounds (VOC)	70 ppmdv at 12% CO_2	<1

[a]2, 3, 7, 8-TCDD Toxic Equivalent

An extensive emission study was conducted jointly by the U.S. EPA and Environment Canada in early 1989 to evaluate RDF combustion practices, control device performance and resultant emissions, and ash/residue from the Mid-Connecticut facility. Designed to be conducted in two phases, the results of the characterization tests were used in establishing the combustion and flue gas cleaning system operating conditions to be used in the performance tests. While the multi-volume study report including summary will not be available until later in 1992, highlighted results are presented in Section B.5, Environmental Emissions.

Economics. It was noted in the literature (896) that detailed cost data for the Mid-Connecticut Project would not provide meaningful comparative information due to the uniqueness of the project. This project was the first demonstration of a new RDF technology as developed by C-E/ABB; similar prepared-fuel systems have since been installed in Detroit, MI and Honolulu, HI. Further, a portion of the facility was a retrofit, both RDF and coal fuel burning capabilities were provided, and operational as well as construction responsibilities were divided. Costs associated with start-up and process modifications were borne by C-E such that there was no financial impact on the communities involved because of project delays. In 1988, C-E agreed to commit an addition $7 million for capital modifications, partial debt service, and landfill disposal costs. In addition, C-E costs associated with the boiler tube failure amounted to $3.8 million (887).

The CRRA portions of the project -- WPF, PBF, transfer stations, and landfill -- were financed through $309.9 million in municipal bonds sold in January 1985. Connecticut Light & Power agreed to spend $62.6 million for the refurbishing of the electric generating facility. The GAA Yearbook (387) provides an original capital cost estimate of $176 million (1987 dollars) for the Resource Recovery Facility (WPF and PBF). Adjusted capital cost in 1990 dollars is $187.6 million. GAA also lists additional capital costs of $23.8 million (1992 dollars).

Operation and maintenance costs, for 1990, are listed as follows (387):

$78.41/T -- $48.9 million with debt service

$30.66/T -- $19.1 million without debt service

The tip fee is variable with $45/ton for host waste (household and light commercial); $50/ton for spot waste; and $75/ton for commercial bulky waste. The fee includes MSW hauling to the facility as well as hauling and disposal of the ash residue. Energy is sold to Connecticut Light & Power at 8.5 cents/kWh, with 1988 annual sales given as 439,000 mWh (887).

A contractual guarantee provides for the CRRA to receive all PBF revenues from steam sales up to 80% of the design capacity of the facility with ABB/C-E receiving 25% of revenues above that 80%. As noted earlier, boiler availability has averaged more than 89%. Further, there is an economic incentive to burn less coal in that ABB/C-E receives a percentage of the avoided-cost savings when RDF displaces coal as the primary fuel (887).

B.3 ECONOMIC DATA

Capital costs vary widely for resource recovery projects in the U.S., in part because of the large number of project-specific variables. For example, the methods, terms and implementation of financing can constitute a significant portion of the total bond issue or degree of system vendor equity participation. Factors that affect RDF project capital costs in particular include the degree of materials processing required for the type of energy system, air pollution control equipment, energy market requirements and energy delivery systems, taxes, architectural and construction details, degree of systems redundancy and types of materials recovered (799).

Based on a representative (or averaged) 1700 TPD RDF facility, including a dedicated boiler designed to meet current air pollution requirements, the total capital cost in 1988 dollars is given as $187 million, with a range of $85,000 to $135,000 per TPD capacity (799). The cost elements (and their percentage of the total capital construction cost) are identified below.

- Site Preparation (6%) - mobilization, earthwork, paving, utility connections, landscaping, fences
- Buildings, Structures, Foundations (16%) - receiving area, pit equipment area, office building, scalehouse, scales, cranes
- Combustion Equipment (37%) - boilers, grates, ash handling, water treatment, instrumentation and control (I&C), cooling tower, condenser ancillaries
- RDF Processing Equipment (10%) - process equipment, conveyors
- Electric Generating Equipment (9%) - turbine generator, substation, interconnection
- Air Pollution Control (8%) - dry scrubber, lime equipment, baghouse, ductwork, stack
- Miscellaneous (2%) - vehicles, office furnishing, insurance, etc.
- Engineering, Permits, Construction Management (10%)
- Startup and Testing (2%)
- Land Purchase (<<1%)

The above reference cites averaged historical data for RDF facilities. The facility service fee, which includes labor, maintenance, materials, administration, and miscellaneous costs, is given as $20 to $35 per gross ton processed (799). Utility requirements will typically add 90-100 kWh per ton of MSW processed and nearly 600 gallons of water per ton processed for potable water uses and sewer requirements. Water usage and sewer discharge are a function of steam or electrical sales, condensate return, and once-through or recirculation of cooling water. Further, insurance can account for an additional $0.50-2.25 per ton processed while the transportation of residue is $0.06-0.33 per one-way mile per ton of as-received waste. The latter depends heavily on key assumptions such as the moisture content of the ash and the percentage process rejects on an as-received basis (799).

Costs vary considerably for operations, maintenance, utilities, insurance, and transportation and disposal of residue and rejects. These costs are in tum significantly influenced by community needs, current landfill operations, location of landfills, systems operator (public vs. private), contractual arrangement for operations, and plant technology and design (799). Labor typically includes O&M personnel, scale operators, supervisory and office personnel. Maintenance and materials include supplies, spare parts, equipment reserve fund and other allocations for vehicles, shop equipment, building funds and site maintenance contract. In addition, annual O&M can include administration charges, insurance, and miscellaneous costs such as service contracts. Because they are highly dependent on local conditions such as tipping fees and transportation distances, residue transportation and disposal costs are typically not included in economic analyses of annual O&M costs.

In the following subsections, facility capital and O&M cost factors and data are identified as a function of RDF production and combustion modes. This is followed by a brief presentation of the comparative economics of RDF and mass bum technologies.

It should be noted that, due to its relative abundance in the published literature, the presentation of RDF cofiring economics is emphasized heavily herein. The Electric Power Research Institute (EPRI) developed an extensive model of RDF cofiring which rigorously evaluates the cost impacts of various modes of plant operation relative to the cofiring of RDF with coal, alone or in combination. Since only highlights of that extensive study could be presented in this report, the reader is referred to the primary references for details (805, 806, 807).

B.3.1 RDF Cofiring in Suspension with Pulverized Coal

As noted above, an extensive analysis of the impact of RDF cofiring on power plant capital, operation, and maintenance costs was conducted and reported by EPRI in 1988 (806). Estimates (in 1984 dollars) were developed through comprehensive modeling of incremental total capital requirements, fixed and variable O&M costs, and fuel costs resulting from RDF cofiring for three cases: 1) an existing two unit, 50-MW (per unit) pulverized coal-fired plant, retrofitted to cofire RDF; 2) a new two unit, 200-MW (per unit) pulverized coal-fired plant equipped with a wet flue gas desulfurization (FGD) system; and 3) a new two unit, 500-MW (per unit) pulverized coal-fired plant equipped with a wet FGD system. Each case is evaluated for three different coals: 1) Eastern Pittsburgh bituminous, 2) Midwest Illinois bituminous, and 3) Wyoming subbituminous. Further, four different types of RDF-3 were considered based upon particle size which is either fine (1 inch) or coarse (2.5 inch) and ash content which is either low (12%) or medium (16%).

A simplified plan view of a reference or "standard" facility (in most ways typical of modem coal-fired utility power plants) is provided in Figure B-23. The RDF processing plant is assumed to be located at another site; and capital, operations and maintenance costs are recovered from the value of the RDF, ferrous metal sales, and tipping fees. The Madison, WI RDF system served as the basis of design for the conceptual retrofitted 50-MW plant. RDF system costs include RDF receiving, storage, and pneumatic conveying; and boiler and ancillary equipment modifications.

In the case of a new plant (with either 200 or 500 MW boilers), the plant is assumed to include two or more contiguous baseload units which receive coal in 100 car unit trains. The plant is base-loaded and operates at 65% annual capacity factor. At least one unit is scheduled for loading in the cofiring range 16 hours/day on weekdays and 8 hours/day on weekends. Thus, the plant can bum RDF for 5000 hours per year and each unit can bum RDF for 4000 hours per year (806).

As shown in Figure B-15 (Section B.2.3.2), each unit operates within the cofiring range 75% of the time, and up to 86% of the annual generation could be derived from cofiring both RDF and coal simultaneously. The actual unit duty cycle is a function of system economic dispatch and power pool unit production costs. Unit production costs are in tum sensitive to coal costs and relatively insensitive to the costs of cofiring RDF (806).

B.3.1.1 Total Capital Requirements and Incremental Costs

The total plant cost developed in the EPRI study (806) involves the following on-site systems: coal handling, RDF system, boiler, ash handling, wastewater treatment, and particulate emission control. Landfill residue disposal costs are also included. As indicated earlier, the EPRI study provides a detailed analysis and evaluation. The total plant cost is considered as a portion of the overall capital requirement which further includes all direct and indirect construction costs, engineering and home office costs, interest and escalation during construction, preproduction, start-up, inventory, and land costs. The components of the total capital requirement are shown in Figure B-24.

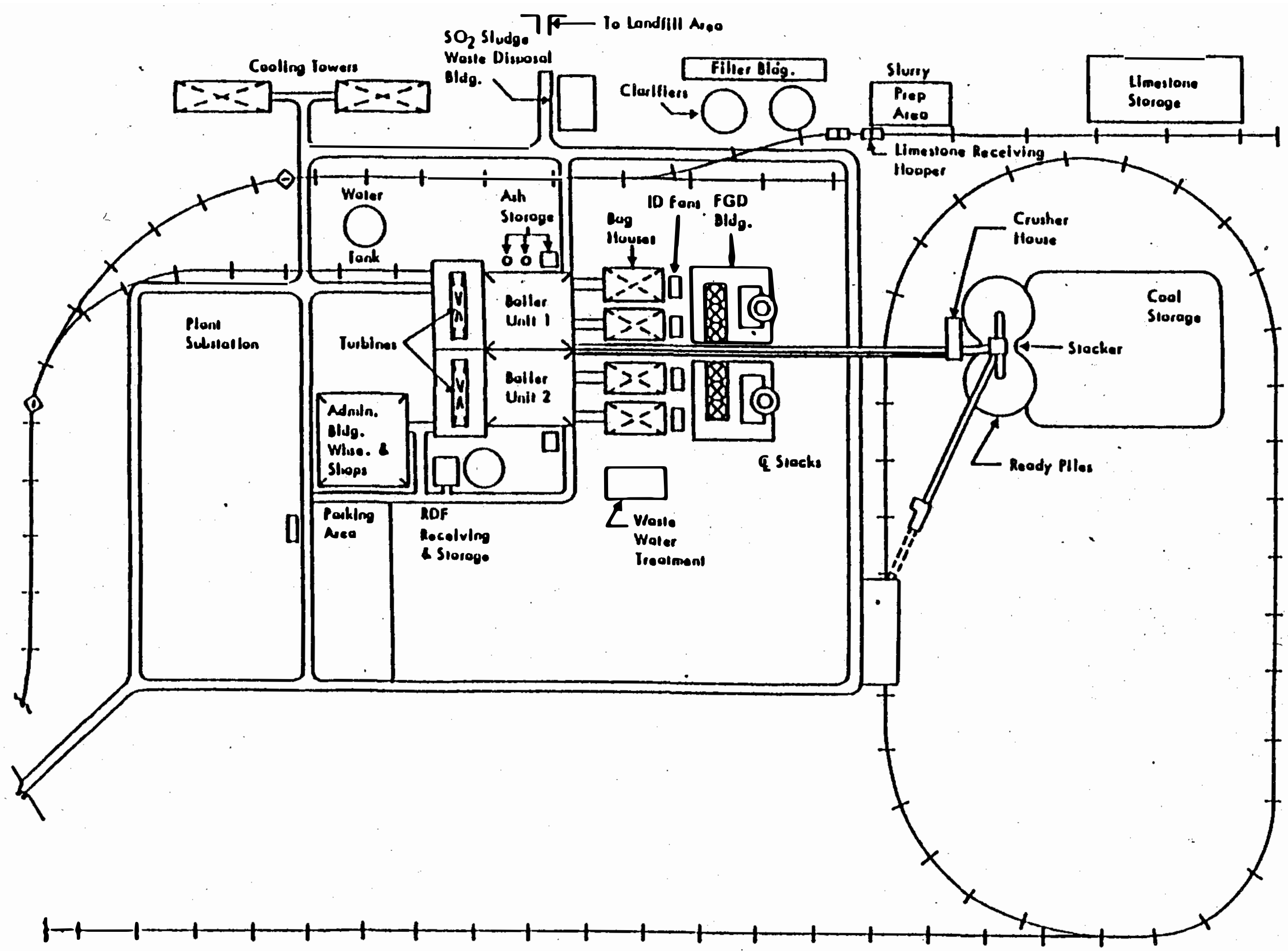


Figure B-23. Plan for Conventional Coal-Fired Power Plant Site (806)

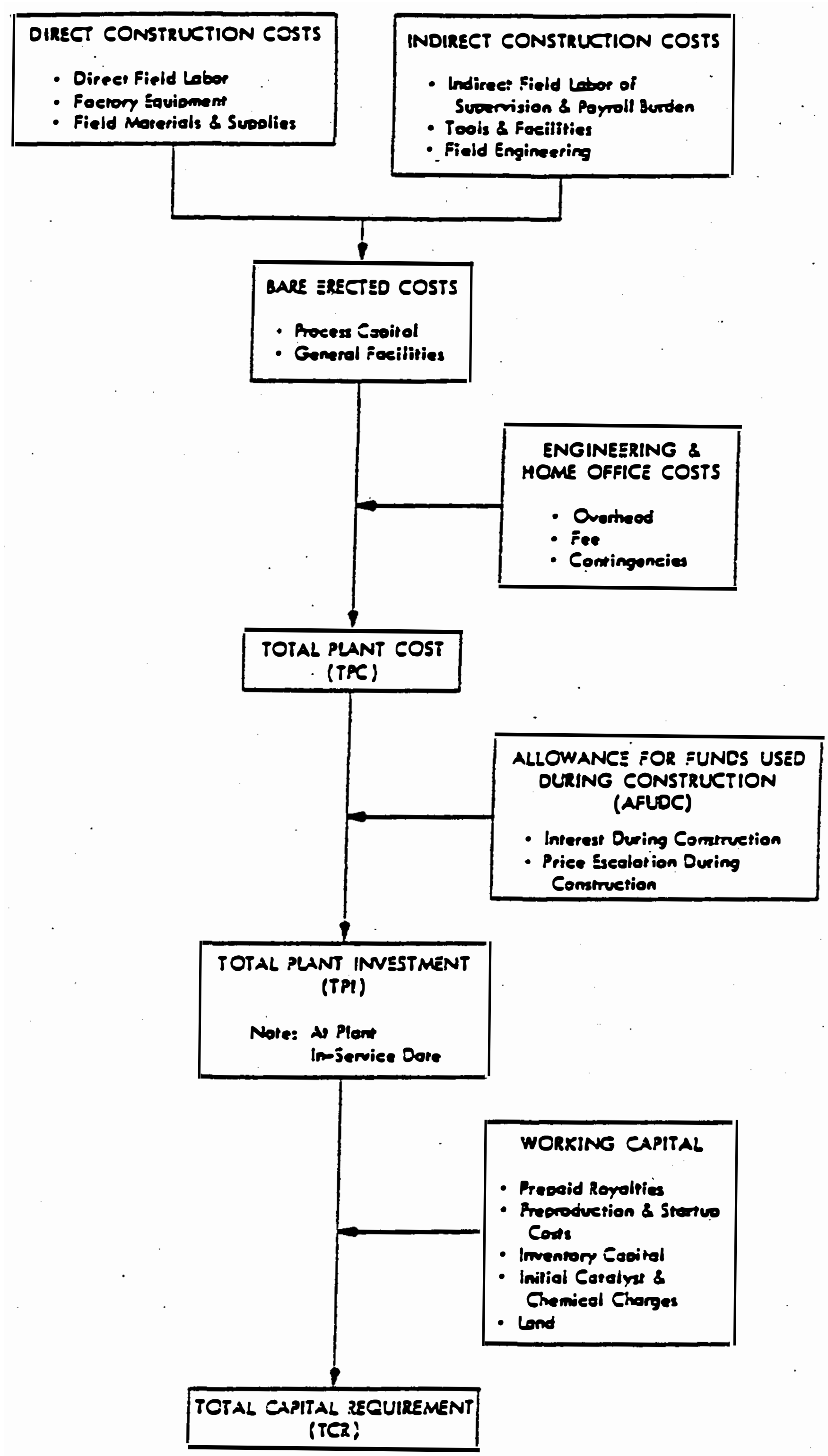


Figure B-24. Components of Total Capital Requirement (806)

Tables B-19 and B-20 summarize the incremental capital and O&M costs (and fuel savings) resulting from RDF cofiring for the three coal types and three plant sizes evaluated (806). In each case, the net difference between coal-fired only and coal/RDF-fired plants is indicated. It should be noted that the economic assumptions are based on the EPRI Technical Assessment Guide, Vol 1, Electricity Supply-1986, EPRI P-4463-SR, Dec 1986; and the EPRI "Economic Premises for Electric Power Generating Plants," 1987.

In the case of O&M costs, the net cost savings (which are thus available to pay for the fuel) are marginal for the 50-MW case, and increase to 0.5-0.9 mills/kWh for the 200-MW case and then to 0.7-1.1 mills/kWh for the 500-MW case. RDF cofiring increases power plant O&M labor requirements by 11% to 17%. RDF cofiring at 15% heat input increases net heat rate by 250-300 Btu/kWh. For high sulfur coal units with wet flue gas desulfurization systems, RDF cofiring can reduce consumables costs due to reduced SO_2 removal requirements.

B.3.1.2 Economic Value of RDF

A utility must not only be capable of using the RDF produced, but the net cost of producing the RDF should not exceed the value of the coal displaced. It is thus important to obtain an estimate of the net RDF fuel credit since this determines the revenue generated by sale of the RDF to the utility. The factors to be considered in determining the RDF effective fuel credit are shown in Figure B-25.

The value of RDF to a utility can be arrived at through sensitivity analysis. The breakeven RDF value to a utility is defined as the difference between fuel savings and incremental O&M plus fixed charges due to the incremental investment of RDF cofiring. Therefore, it is quite sensitive to parameters that effect either fuel savings or incremental costs. Further, the RDF price paid by the utility can be positive or negative depending on the relative magnitude of these two components. Key parameters that affect this trade-off include coal type, RDF quality, unit size, capacity factor, RDF heat input, and the fraction of annual power generation derived from RDF cofiring.

TABLE B-19. TOTAL CAPITAL REQUIREMENT ESTIMATES[a] (806)

Basis: End-of-Year 1984 Dollars

15% Heat Input from RDF

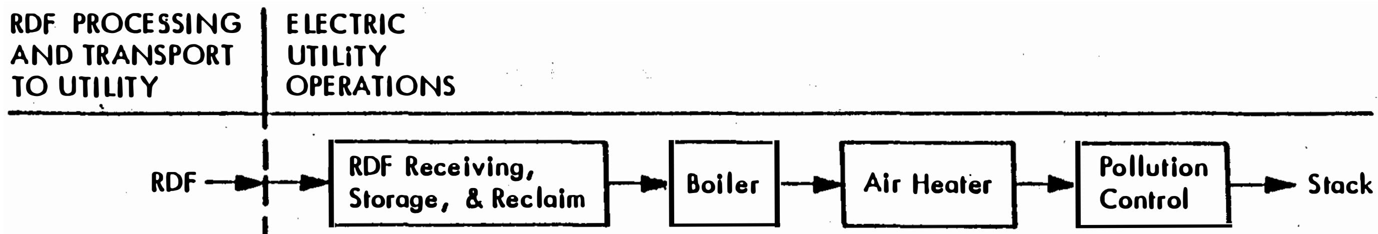
Coal:	Coal E Eastern Bituminous	Coal I Illinois Bituminous	Coal W Wyoming Subbituminous
50-MW Retrofit Unit			
Net Capacity (MW)	50	50	50
Total Capital Requirement ($/kW)			
Book value	$ 66	$ 66	$ 66
20-yr life extension	200	200	200
Incremental RDF cofiring	40	40	40
Total	$306	$306	$306
200-MW New Unit (210 MW)			
Net Capacity (MW)	200	200	200
Total Capital Requirement ($/kW)			
Coal-only design	$1701	$1792	$1690
Incremental RDF cofiring	27	28	28
Total	$1728	$1820	$1718
Added costs for cofiring	1.6%	1.6%	1.7%
500-MW New Unit (515 MW)			
Net Capacity (MW)	500	500	500
Total Capital Requirement ($/kW)			
Coal-only design	$1334	$1407	$1345
Incremental RDF cofiring	17	18	19
Total	$1351	$1425	$1363
Added costs for cofiring	1.2%	1.3%	1.4%

[a]Includes 15% contingency for power plant and 30% for RDF facilities. Design is based on medium quality RDF-C/D with heat content of 5900 Btu/lb and 12% ash.

TABLE B-20. INCREMENTAL CAPITAL AND O&M COST AND FUEL SAVINGS ESTIMATES (806)

Basis: End-of-Year 1984 Dollars
15% Heat Input from RDF
60% Power Generation from RDF Cofiring
65% Capacity Factor

Coal:	Coal E Eastern Bituminous	Coal I Illinois Bituminous	Coal W Wyoming Subbituminous
50-MW RETROFIT UNIT:			
Net Capacity (MW)	50.0	50.0	50.0
Incremental Cost/Savings:			
Capital ($/kW)	39.7	39.7	39.7
Fixed O&M ($/kW-yr)	3.70	3.70	3.70
(mills/kWh)	0.65	0.65	0.65
Variable O&M (mills/kWh)	0.35	0.35	0.35
Consumables O&M (mills/kWh)	0.08	0.06	0.10
Fuel (mills/kWh)	-1.07	-1.16	-1.48
200-MW RETROFIT UNIT:			
Net Capacity (MW)	200.0	200.0	200.0
Incremental Cost/Savings:			
Capital ($/kW)	28.5	29.6	28.9
Fixed O&M ($/kW-yr)	1.97	1.97	1.97
(mills/kWh)	0.35	0.35	0.35
Variable O&M (mills/kWh)	0.19	0.19	0.19
Consumables O&M (mills/kWh)	0.02	-0.14	0.05
Fuel (mills/kWh)	-1.06	-1.16	-1.49
500-MW RETROFIT UNIT:			
Net Capacity (MW)	500.0	500.0	500.0
Incremental Cost/Savings:			
Capital ($/kW)	17.2	18.6	19.1
Fixed O&M ($/kW-yr)	1.18	1.19	1.19
(mills/kWh)	0.21	0.21	0.21
Variable O&M (mills/kWh)	0.11	0.11	0.11
Consumables O&M (mills/kWh)	0.02	-0.14	0.05
Fuel (mills/kWh)	-1.06	-1.15	-1.48



[Net RDF Payment to Fuel Supplier] = Coal Replacement Value − Power Plant Cofiring Operating Cost − Debt Service Cost − Risk Compensation Costs

Power Plant Cofiring Operating Cost

- Boiler Efficiency Decrease
- Increased Power Costs
  - RDF Handling
  - ESP
  - Ash Handling
- Increased System Maintenance
  - Labor
  - Materials
- Increased Operating Labor
  - Supervision
  - Plant Engineering
  - Unit Operators
  - Startup Crew
- Power Replacement for Load Reduction When Cofiring if Unit is Limited Due to:
  - Particulate Emissions
  - Steaming Capacity
  - Convection Pass Velocity
  - ID Fan Capacity
  - Ash Handling Capacity

Coal Replacement Value

Cost of Coal Btu's Replaced by RDF

Debt Service Cost

Debt Service of Capital Cost for:

- RDF Receiving, Storage, Reclaim, Flow Metering and Boiler Injection System
- Pollution Control Increased Capacity
- Ash Handling Increased Capacity
- ID Fan Increased Capacity
- Ash Disposal Costs

Risk Compensation Costs

- Cost of Greater Risk of Unit Downtime
- Cost of Premature Project Termination (Cost of Project Termination Before Investment in Power Plant Facilities is Paid Off)

Figure B-25. Factors Contributing to Determination of RDF Effective Fuel Credit (805)

Figure B-26 illustrates the breakeven RDF values for the 200-MW new unit cases, fired by three types of coal: eastem bituminous (E), Illinois bituminous (I), and westem subbituminous (W) (806). For each coal type, the breakeven RDF value is at first negative, then becoming positive, first for RDF against the most expensive W coal and last for the less costly E coal.

Figure B-27 compares breakeven RDF values over the initial 10 years for the 2x50-MW retrofit and 2x200-MW and 2x500-MW new plants cofiring eastern bituminous coal with 12% ash RDF. Economies of scale and greater RDF consumption favor the larger plants in arriving first at a positive breakeven RDF value.

B.3.1.3 Power Plant Retrofit

Since economic performance is marginal and thus quite sensitive to slight changes in revenues or cost, it is important to review the assumptions made in the EPRI analysis (806). In retrofitting existing 50-MW coal fired units, the average "total plant cost" is given as $1.8 million per unit. However, the overall "total capital requirement" is given as $15.3 million. This data assumes that a life-extension capital improvement program on the boilers would be conducted to extend their useful life to be congruent with the life of the RDF processing plant. The key components of the overall cost are a depreciated book value of $3.3 million; a $10 million capital improvement program; and approximately $2 million on retrofit costs for cofiring RDF including electrostatic precipitator improvements. For comparison purposes, it should be noted that the cost to retrofit both units in Madison, WI was $1.3 million in 1979 (which equates to $1.8 million in 1984), without ESP or other improvements.

B.3.1.4 New Power Plants

For base coal-fired units, total capital requirement costs are given as $338 to $358 million (dependent upon the type of coal) for a new 200-MW plant and $667 to $704 million for a 500-MW plant. A 15% contingency was included and a 6-year total contract period was assumed. Allowances were not made for environmental impact studies, legal fees, and owner's overhead.

For RDF/coal-fired units, the same approach was applied, but a contingency of 30% was provided. The total capital requirement cost for the RDF system varies from $5.4 to $5.6 million for the 200-MW case and $8.5 to $9.5 million for the 500-MW case. Thus, the overall total capital requirement costs are given as $344 to $364 million for the 200-MW case, and $676 to $713 for the 500-MW case.

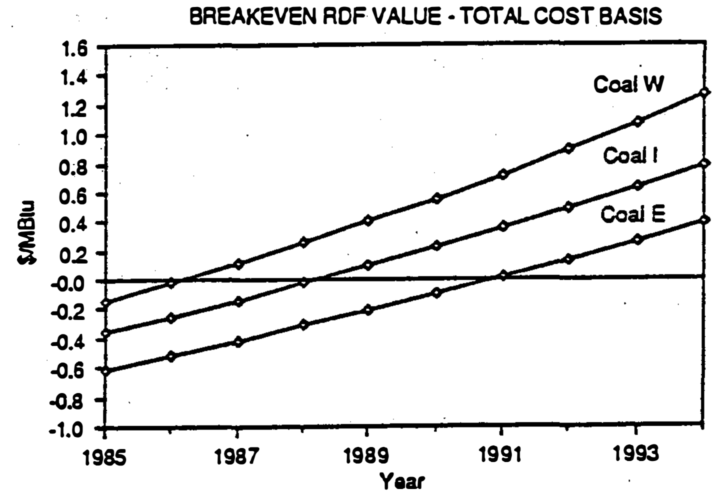


Figure B-26. Sensitivity of Breakeven RDF Values on a Total Cost Basis to Coal Type for 2x200-MW New Plant, 12% Ash (806)

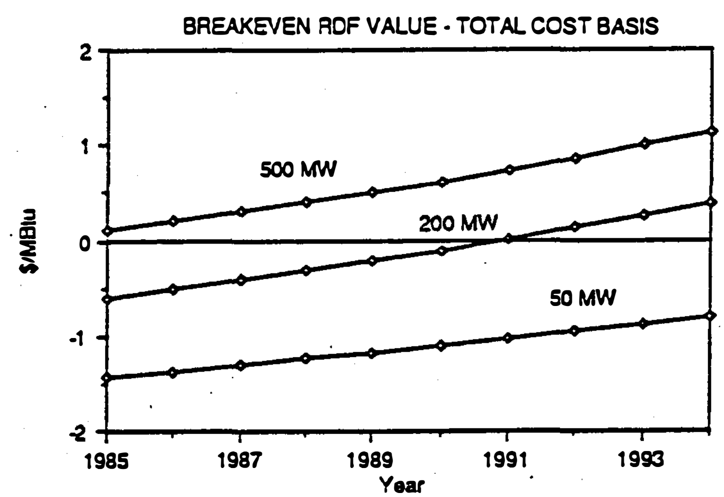


Figure B-27. Sensitivity of Breakeven RDF Values on a Total Cost Basis to Unit Size for 2x200-MW New Plant, Eastern Bituminous Coal and 12% Ash (806)

B.3.2 RDF Dedicated Semi-Suspension Boilers

B.3.2.1 Capital Costs

Cost data, as compiled from the GAA 1991 Resource Recovery Yearbook (387), for selected RDF semi-suspension, spreader stoker combustion projects are presented in Table B-21. The original capital costs listed are also shown adjusted to 1990 dollars using appropriate ENR Building Cost Indices. Accounting for the effects of inflation, the ENR index measures the effect of wage and price changes on the value of the construction dollar. A 20-city average is taken on a monthly basis of the wage rates of skilled laborers (bricklayers, carpenters, structural iron workers, etc.), as well as the prices of structural steel, lumber, and Portland cement, etc. in order to estimate the increased (or decreased) cost of construction. Original capital costs provided in post-1990 dollars were not subjected to any modification or adjustment. Also reported are additional capital costs such as costs for upgrading air emission controls as in Detroit, MI; or costs to retrofit units that were built but did not perform as specified, as in Akron, OH.

The total costs presented in Table B-21 include both the original and additional costs. For example, in Akron, an RDF storage facility was originally designed into the facility and was thus included in the original capital cost by the original designer/operator, GPD (Glaus, Pyle, Schomer, Burns and DeHaven)/Teledyne National. As part of a modification program, it was later removed at considerable expense by the second designer/operator, Tricil Resources Inc., because it could not be made to work. The third operator, wTe Corporation, added fuel storage back into the system at considerable expense in order to increase the availability of the RDF to the boilers during equipment maintenance and repair. The costs reported reflect all of these changes. If the fuel storage had been designed and built as presently installed, the costs of the original system and the removal would have been eliminated from total capital cost.

TABLE B-21. RDF DEDICATED BOILER FACILITIES -- CAPITAL COST DATA (adapted from 387)

ALL COSTS IN MILLIONS OF DOLLARS

FACILITY	DESIGN CAPACITY TPD	ORIGINAL CAPITAL COST	ORIGINAL COST IN 1990 $	ADDITIONAL CAPITAL COST	ADDITIONAL COST IN 1990 $	TOTAL CAPITAL COST	TOTAL COST IN 1990 $	ORIGINAL COST/TON, 1990 $	TOTAL COST/TON, 1990 $	BOILER COST INCLUDED
Akron Recycle Energy Systems (RES)	1000	54.50	81.14	21.80	23.23	76.30	104.37	0.081	0.104	Yes
Anoka County/Elk River R.R. Project	1500	68.00	72.47	N/A	N/A	68.00	72.47	0.048	0.048	Yes
ANSWERS Plant/Albany Steam Plant	800	30.60	39.52	N/A	N/A	30.60	39.52	0.049	0.049	Yes
City & County of Honolulu	2160	200.00	200.00	N/A	N/A	200.00	200.00	0.093	0.093	Yes
Columbus S.W. Reduction Facility	2000	200.00	224.08	12.00	13.09	212.00	237.17	0.112	0.119	Yes
Dade Co. S.W. Resource Recovery Project	3000	156.00	232.24	88.00	90.27	244.00	322.51	0.077	0.108	Yes
Greater Detroit Res. Recovery Facility	4000	245.00	267.20	100.00	100.00	345.00	367.20	0.067	0.092	Yes
Lawrence & Haverhill (RDF)	900	99.50	113.02	20.00	20.52	119.50	133.54	0.126	0.148	Yes
Maine Energy Recovery Company (MERC)	607	67.00	73.07	N/A	N/A	67.00	73.07	0.120	0.120	Yes
Mid-Connecticut RDF/MWC	2000	176.00	187.57	23.80	23.80	199.80	211.37	0.094	0.106	Yes
Niagara Falls	2000	100.00	139.52	50.00	56.02	150.00	195.54	0.070	0.098	Yes
Palm Beach County (North) MWC/RDF	2000	184.00	188.74	N/A	N/A	184.00	188.74	0.094	0.094	Yes
Penobscot Energy Recovery Company (PERC)	750	68.00	74.16	N/A	N/A	68.00	74.16	0.099	0.099	Yes
Ramsey & Washington Counties	1000	43.00	45.83	6.25	6.25	49.25	52.08	0.046	0.052	Yes
SEMASS	1800	208.00	231.99	N/A	N/A	208.00	231.99	0.129	0.129	Yes
Southeast Tidewater Energy Project	2000	153.00	170.64	5.00	5.00	158.00	175.64	0.085	0.088	Yes
NUMERICAL AVERAGE OF NON-ZERO VALUES								0.086	0.097	
STANDARD DEVIATION								0.025	0.027	

N/A = Not Available

The capital cost per ton of design capacity is given in Table B-21 based on original costs and on total cost including additional cost, in 1990 dollars. As can be seen, the average cost per installed ton of capacity in 1990 dollars is $97,000. The standard deviation is $27,000 per installed ton. In all cases, the boiler and the RDF production facility are included in the costs. However, the reader is cautioned that the figures are per ton of design capacity and do not reflect the actual operating capacity which has been achieved in practice. Also, it is more practical to look at actual throughput rather than design throughput. For example, in the Maine Energy Recovery Company (MERC) project, both the design and the actual throughputs are reported to be 607 tons. This is the correct figure for design, but is incorrect in terms of actual operating throughput. In general, the distinction between actual and design capacity is very important and needs to be incorporated in the database.

Further, the reader should note that capacity is not uniformly defined in terms of daily capacity. For example, the design basis for the Akron Project is 1000 TPD. The actual throughput is stated at 965 TPD. This figure is reported on the basis of the RDF processing plant which operates 5 days per week. The boiler portion of the plant, which operates 7 days per week, operates at 5/7ths of this capacity, or 689 TPD (e.g., 5/7 x 965 TPD(5) = 689 TPD(7)). Using 1000 TPD could create an error of as much as 31% in the results. The Columbus, Ohio facility, on the other hand, reports an actual throughput of 1600 TPD. This is not MSW, but rather RDF after the ferrous has been removed. Further, this is based upon TPD(7) results since it was calculated by taking the annual input of RDF which was 584,000 tons in 1990 and dividing by 365 days. It is not consistent to compare the capital cost per ton for Columbus to the capital cost per ton for Akron since the basis for the figures is different by at least 30%.

Capital costs for RDF processing and dedicated boilers combined are represented in Figure B-28 for various plant capacities from about 800 TPD(7) of MSW to 1400 TPD(7) of MSW (348). In addition, data are presented for RDF processing only and dedicated boilers only; when added together, these components produce the "combined" data. These costs are expressed, in 1984 dollars, for: 1) steam only, 2) cogeneration of steam and electricity, and 3) for electricity only. Retrofit only data is also presented but would be viewed as highly suspect based upon recent data at Anoka County/Elk River (Table B-21). As can be seen from the figure, electricity production is the most expensive from a capital cost standpoint. Typically, the capital costs (1984 dollars) range from about $40 million to $75 million for plants sized at 800 to 1400 TPD(7), respectively. For a 1000 TPD(7) plant, the costs are about $50 million, and thus about $50,000 per installed daily ton of capacity in 1984 dollars.

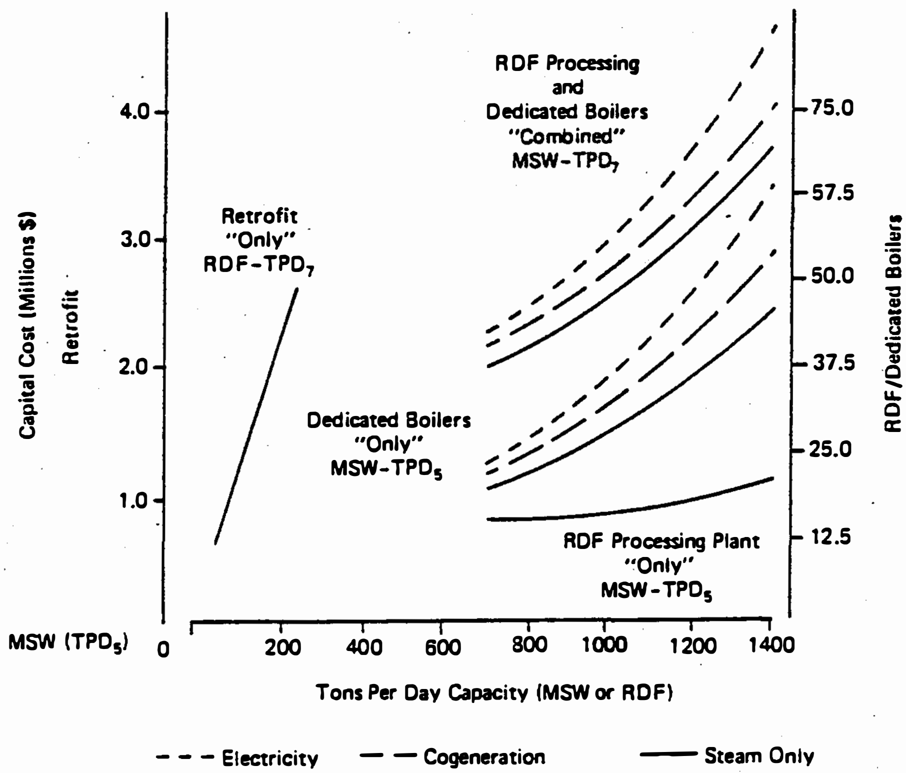


Figure B-28. RDF Facilities Estimated Direct Capital Costs (1984 Dollars) (348)

B.3.2.2 O&M Costs

Operations and maintenance costs (from the GAA database) for RDF/dedicated boiler facilities, both with and without debt service, are reported in Table B-22. Many of the same database limitations discussed above for capital costs also apply to O&M costs. In addition, the reported debt service figures can also be misleading. For example, the debt service for Akron has been properly reported for 1990, but it does not include capital recovery of the original plant since the bonds were defeased and no debt service is paid on the original capital costs. The only debt service reported is for the modifications and capital improvements on which the City of Akron continues to pay debt service.

The Akron plant's O&M costs are properly reported, but they are not necessarily comparable to the other projects since a substantial part of the operation's labor and materials costs go toward maintaining the district heating and cooling systems and operating three back-up boilers which fire coal and natural gas. As part of the Akron Project, there is a major labor effort to maintaining all the steam lines and manholes for the steam district heating system ivolving 18 miles of steam lines throughout the City. In addition, a hot water and chilled water district heating and cooling system is also maintained including reading and invoicing for all meters.

In Columbus, there is some uncertainty regarding whether the cost of substation maintenance and power distribution is included in the O&M costs which were reported. In most projects, the O&M costs are for on-site cost of power production up to the property boundaries only without including the costs of power distribution. Further, the costs of ash disposal or disposal of by-passed wastes may not be included in other projects such as Anoka County and Ramsey Washington.

The operations and maintenance costs for an RDF dedicated semi-suspension boiler are provided in Figure B-29 in 1984 dollars. O&M costs are shown to be on the order of \$20-25/TPD(5). Note that this is on a different basis than capital costs which are reported on a TPD(7) basis. The combined data is the sum of the processing plant only and dedicated boiler only. The RDF processing plant costs are fairly flat as a function of capacity being on the order of \$10/TPD(5). Costs of the dedicated boiler are on the order of \$10-15/TPD(5) depending upon whether steam, cogeneration, or electricity only is assumed. The costs presented for RDF retrofit, reported on a TPD(7) basis, appear to be inaccurate. It should be noted that costs depend heavily upon the avoided cost for fuel under the Public Utilities Regulatory Policies Act of 1978 (PURPA), and thus can vary widely from project to project (348).

TABLE B-22. RDF DEDICATED BOILER FACILIITES – O&M COSTS WITH AND WITHOUT DEBT SERVICE (387)

FACILITY	ACTUAL THRUPUT (TPD)	O&M COST W/DEBT SVC $/TON	O&M COST WO/DBT SVC $/TON	O&M COST W/DEBT SVC ANNUAL $	O&M COST WO/DBT SVC ANNUAL $	ASH DISPOSAL $/TON
Akron Recycle Energy Systems (RES)	965	58	53	15260000	14000000	N/A
Anoka County/Elk River R.R. Project	1500	26	16	12130000	7284000	55
ANSWERS Plant/Albany Steam Plant	720	N/A	50	N/A	7312000	58
City & County of Honolulu	1740	62	27	37000000	16000000	N/A
Columbus S.W. Reduction Facility	1600	72	41	42000000	24000000	5
Dade Co. S.W. Resource Recovery Project	2800	24	13	24916940	12985165	N/A
Greater Detroit Res. Recovery Facility	2900	N/A	N/A	N/A	N/A	N/A
Lawrence & Haverhill (RDF)	610	N/A	N/A	N/A	N/A	N/A
Maine Energy Recovery Company (MERC)	607	N/A	N/A	N/A	N/A	38
Mid-Connecticut	2300	78	31	48930000	19130000	N/A
Niagara Falls	1800	N/A	N/A	N/A	N/A	N/A
Palm Beach County (North)	2000	87	26	54000000	16000000	N/A
Penobscot Energy Recovery Company (PERC)	750	N/A	65	N/A	14000000	25
Ramsey & Washington Counties	1175	N/A	N/A	N/A	N/A	N/A
SEMASS	1800	N/A	N/A	N/A	N/A	N/A
Southeast Tidewater Energy Project	1400	37	32	13420000	11700000	N/A
NUMERICAL AVERAGE OF NON-ZERO VALUES	1542	55	35	30957118	14241117	36
STANDARD DEVIATION	704	22	16	15641910	4794678	20

N/A = Not Available

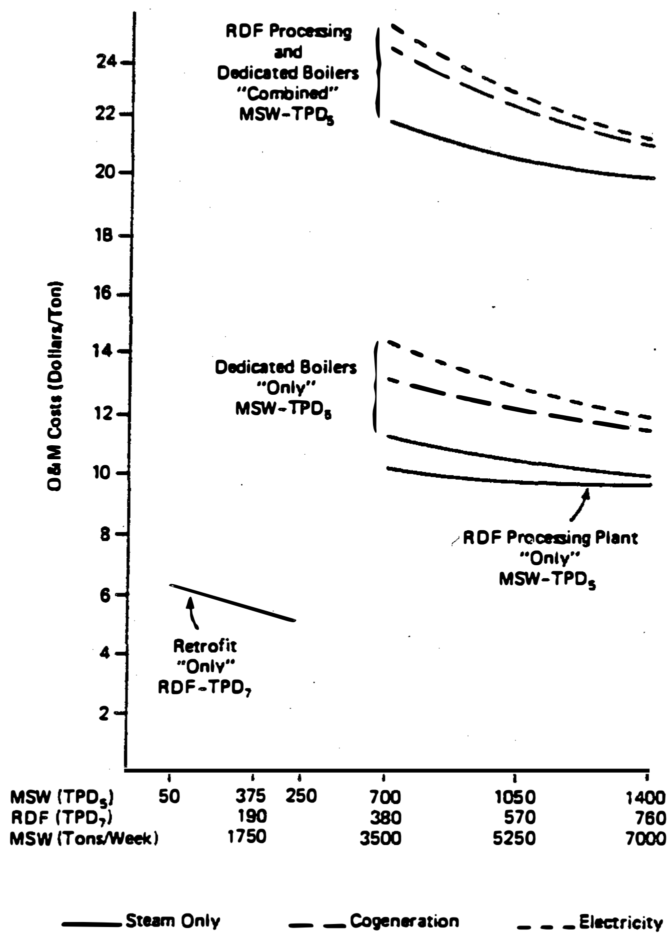


Figure B-29. RDF Dedicated Boiler Systems -- O&M Costs (348)

B.3.2.3 Economic Analysis and Assumptions

In order to make sound comparisons of cost data, it is necessary to ensure that costs are reported on a uniform basis. However, in assessing the potential costs of a waste-to-energy system, one should always be aware that no two projects are the same. Even if the technical parameters of two plants are similar, the site topography, climate, soil conditions, local construction costs, state of the general economy, or a change in energy sales conditions and other factors could affect final project costs. Two plants could be identical, but financing them 12 months apart could lead to significant interest rate changes that also would affect the comparable economics of the projects (348).

It is possible to have private contractors operating or alternatively owning and operating the facilities. If the private contractor only operates the facility, it would typically charge a management fee on the order of 10% of O&M costs and perhaps require a share of product sales revenues as a performance incentive. If the contractor contributes equity and assumes ownership and operating responsibilities along with their attendant risks, it would likely require a greater share of product sales revenues or cash flow from the project to provide a sufficient return on equity beyond the tax benefits of ownership that would be available (348).

Life cycle costing is an especially useful tool in making accurate economic comparisons since this approach accounts for the fact that the cost and revenue streams differ from year to year. The escalation of individual cost and revenue elements may not be at equal rates. Therefore, an economic analysis based on the first year of operation or on the first several years of operation could be misleading. A life cycle analysis incorporates these changing costs and indicates how the cash flows interact to alter annual total costs (348).

An example of the factors that must be considered in a typical economic analysis to develop data on a comparable basis is provided in Table B-23. It is important to note that the financing parameters must include the project's construction time frame as well as operations lifetime (348). Rather than comparing only initial capital costs among options, life cycle costing compares differences in total economic impact over the life of the project (348). [Author's Note: These assumptions differ from those used in the EPRI study in the development of cost information for suspension co-firing of RDF with pulverized coal presented in Section B.3.1. In order to compare the results, it is necessary to normalize the data, especially with respect to project life and return on equity.] Normalized cost data are presented in Figures B-28 and B-29.

TABLE B-23. TYPICAL ECONOMIC ANALYSIS ASSUMPTIONS (349)

Technology Option to Be Considered:

- Prepared fuel (RDF) dedicated boilers/cogeneration of steam and electricity

Financing Parameters:

• Date of financing (all scenarios)	7/1/85
• Capital cost estimates	7/1/83 dollars
• Escalation period to date of financing	2 years
• Capital cost escalation rate	6%/year
• Construction period (including start-up/acceptance tests)	36 months
• Plant operating period (from 7/1/88)	20 years
• Interest rate on debt (tax-exempt revenue bonds)	10%/year
• Term of capitalized interest	36 months
• Debt service reserve fund	1 year's principal/ interest payment
• Contingency reserve fund	3 months' O&M cost
• Rate of interest earnings on funds during construction period	10%/year
• Private equity contribution of total direct construction costs (includes escalation)	25%
• Bond underwriting fees, legal expenses, and other bond issuance costs (% of total bond issue size)	4%
• Final bond sizing includes escalation during construction	6%/year on balance outstanding

System Parameters:

• Project technology	RDF processing plant/dedicated boiler
• RDF processing plant throughput— MSW (tons/yr)	321,000
• RDF dedicated boiler plant throughput (tons/yr)	281,700
• Design size (tons/day)	Processing 1,400$_{5\frac{1}{2}}$[a] Boiler 960$_{7}$[b]
• Waste delivery arrangement	
RDF transfer hauling	10 miles one way
• Energy forms sold	
Steam	X
Electricity	X
• Boiler plant assumptions	
Number of combustion lines	2
Assumed boiler efficiency (%)	72
Internal steam usage (% of generation)	15
Steam pressure/temperature	635 psig/750°F
Total residue to landfill (% MSW)	37.5
RDF combusted (as % of MSW processed)	87.7

Operating/Maintenance Cost Related:

- Facility O&M costs escalate at 6%/year
- Residue haul costs escalate at 6%/year
- Residue/bypass waste disposal costs:
  - Base cost—$13.75/ton (7/1/84)
  - Escalation @ 6%/year on operations component

Project Revenues (during operations period):

- Escalation rates:
  - Natural gas @ 8%/year from 1987 through 2007
  - Oil @ 8%/year from 1987 through 2007
  - Electricity @ 6%/year
- Earnings on project reserve funds—10%/year

Other Assumptions:

- Front-end project development costs (through construction/start-up/acceptance): included in bond issue, estimated at 1% of the installed capital costs.
- Administrative costs (during 20 year plant operations period): one-half person year with fringes ($18,000).
- Payment in lieu of taxes (PILOT): $1/ton of waste.
- Heating value of MSW is 4,500 Btu/lb; heating value of RDF is 5,000 Btu/lb.

[a]Operating week = 5½ days.
[b]Operating week = 7 days.

B.3.3 Economics of Densified RDF

The cost of d-RDF production is sensitive to the throughput capacity of the d-RDF production equipment, and depends greatly on the added costs required to produce the fluff RDF with the proper particle size, moisture and ash control. Early work tended to underestimate the costs involved in producing the proper RDF and, further, overestimated the throughput capacity of the densification equipment. As an example, the cost of d-RDF, in 1977 dollars, was given as between $4.00 and $6.00 per ton (881). Whereas the cost of fluff RDF was valued at zero dollars per ton, this is the differential cost per ton for producing d-RDF. Also, a 10 ton per hour densification unit production rate was assumed. Other testing has shown that the production rate of 2 tons per hour is the maximum achievable densification throughput rate (874). Thus, the added costs of producing d-RDF according to these data would be at least $20 to $30 above the cost of producing the fluff RDF.

By 1981, an estimated cost per ton to produce the RDF based upon a 10 ton per hour throughput rate was $8.28 per ton (873). This would scale to over $41.00 per ton based upon throughput rates of 2 tons per hour. Table B-24 shows a cost estimate prepared for a densification system which would be fed with a 3/4-inch nominal fluff RDF containing an ash content of 15% and moisture between 10% and 20%. The estimate assumed a densification system capacity of 8 tons per hour and included two pellet mills. (It is not clear whether each pellet mill operates at 8 tons per hour, or if each operates at 4 tons per hour). The estimate included such appurtenances as screening and return conveyors for removing fines from the pellets and a pellet cooler. Total capital costs for the densification module were given as $10.67 per ton, operating on a two-shift basis, and $13.33 per ton, operating on a one-shift basis (873).

Table B-25 gives overall MSW processing system costs including the production of fluff RDF (873). This table shows an estimated cost of $34.86 per ton on a two-shift basis and $42.96 per ton on a one-shift basis. For this estimate, 82% of the municipal solid waste was expected to be recovered as RDF. The remaining 18% was assumed to be removed as ferrous product (6%) and minus 5/8-inch screen undersize (12%). The RDF preparation system was assumed to be a tipping floor, picking platform, shear shredder, magnetic separator, secondary trommel and secondary vertical hammermill in order to produce the RDF. The costs shown are in costs per ton of RDF product. It should also be noted that the disposal fee is $1.10 per ton of RDF produced ($1.34 per ton of MSW infeed), or about $7.45 per ton of disposed material. Assuming that the pelletizer capacity was 4 tons per hour, and that the two pelletizers combined could produce 8 tons per hour, by doubling the densification module cost estimates and adding those estimates to the MSW processing portion to produce the fluff RDF, the total d-RDF production costs are $56.20 for a two-shift operation and $69.62 for a one-shift operation.

TABLE B-24. DENSIFICATION MODULE CAPITAL AND OPERATING COST ESTIMATE (873)

(1985 Dollars)

	($)
Capital Costs	
Two single speed pellet mills (includes rollers, shear pin protection, inline feeder, centrifeeder, four 32-in. dies, and all motors including two 300-hp main motors)	198,800
One live-bottom feeder (includes all motors and hydraulics)	25,000
Conveyors (includes both infeed and takeaway conveyors and motors)	16,900
Fines screen and return (includes motors)	7,000
Pellet cooler--optional (includes fan and all motors)	40,000
Motor control center (includes automatic controls)	25,000
Installation	46,900
Contingency (30%)	107,900
Total Capital Cost	467,500
Annual Capital Cost (at 13% per year, 20 years)	66,550
Capital Cost (one shift[a])	5.33/ton
Capital Cost (two shifts[b])	2.67/ton
Costs	
Die and roller replacement	4.00/ton
Electricity	2.23/ton
Maintenance and materials	0.50/ton
Insurance	0.28/ton
Labor ($16.80/h)	0.29/ton
Contingency (10%)	0.70/ton
Total Operating Cost	8.00/ton
With Capital (one shift)	13.33/ton
With Capital (two shifts)	10.67/ton

a. 12,480 tons per year = (shifts/day) x (8 tons/h) x (8 h/shift) x (260 day/yr) x (0.75).

b. 24,960 tons per year.

TABLE B-25. MSW PROCESSING SYSTEM CAPITAL AND OPERATING COST ESTIMATE (873)

(1985 Dollars)

	One Shift ($)	Two Shifts ($)
Capital Cost		
Site Preparation	179,000	209,000
Building/Structures	424,000	530,000
Utilities	87,000	93,000
Equipment	645,000	645,000
Equipment Installation	301,000	301,000
Mobile Equipment	83,000	83,000
Engineering	172,000	186,000
Construction Manager	138,000	149,000
Contingency	608,000	659,000
Total Capital Cost	2,637,000	2,855,000
Annual Capital Cost (at 13% over 20 yr)	187,800	203,210
Per Unit Capital Cost	14.67/ton	7.94/ton
Operating Costs		
Maintenance and Materials	3.62/ton	3.24/ton
Insurance	1.54/ton	0.84/ton
Transportation	3.12/ton	3.12/ton
Labor[a]	11.39/ton	11.39/ton
Electricity	1.59/ton	1.59/ton
Tailings Disposal	1.10/ton	1.10/ton
Contingency (10%)	2.24/ton	2.13/ton
Operator Fee (15%)	3.69/ton	3.51/ton
Total Operating Cost	$28.29/ton	$26.92/ton
With Capital	$42.96/ton	$34.86/ton

a. Includes two equipment operators, one loader operator, and one foreman.

In a 1984 sensitivity analysis on machine throughput, pellet consumption, die and press roll life, and substitution rate of coal fines as a binder, best case costs of about $28.00 per ton to worst case costs of $72.00 per ton were calculated for a densification module (874). The expected production cost was approximately $35.00 per ton. These costs did not include the production costs for the fluff RDF, but did include paying $5.00 per ton for that fluff RDF. The value of $5.00 per ton was based upon a sale price of $10.00 ($1.00/MMBTUs) minus a $5.00 per ton transportation cost to the major fluff RDF purchaser. The overall sensitivity to pelletizer throughput rate was noted. When production rates were halved from 3 tons per hour to 1.5 tons per hour, the production costs nearly doubled to $50.00 per ton.

B.3.4 Comparison of Mass Burn and RDF System Economics

The 1991 GAA Resource Recovery Yearbook (387) has been used throughout both the mass burn and RDF technology appendices as one of the most reliable single sources of design and operating data. However, such cost data, even though adjusted to 1990 dollars and including retrofits for control equipment and additional combustion equipment, only allow statistical comparison of overall costs for MWC technologies. Further, reporting inaccuracies coupled with limited cost detail make any conclusive comparison between facilities and technologies very difficult.

Additional insight into the economics of mass burn versus RDF systems derives from more detailed engineering studies where individual component costs are developed for both technologies on a consistent basis. The following paragraphs briefly describe such a comparison including both capital and O&M costs as well as the basis for estimating energy and secondary materials revenues.

The Solid Waste Management Plan for Will County, Illinois compared construction and annual operating costs for a proposed 550 TPD municipal waste combustion facility (716). It was assumed that the facility would sell electricity rather than steam and that it would employ dry scrubbers, fabric filter collectors and selective non-catalytic reduction for the control of air emissions. The comparative costs in 1990 dollars are shown below.

	Mass Burn	RDF
Construction Cost ($x10^6)	63.2	73.5
Annual Operating Cost ($x10^6)	5.97	7.12

From Lake County, Illinois' Solid Waste Management Plan, estimates of capital costs are presented in Table B-26, representing the mid-range of costs for RDF and mass burn facilities that were evaluated (799). As mentioned earlier, the resource recovery facilities' capital construction costs can vary considerably due to site-specific factors. Conservative estimates of the accuracy for each type of municipal waste combustor's capital costs presented are: ± 30 percent for the 100 TPD modular facility; ± 25 percent for the RDF facility; and ± 20 percent for both the 300 and 2000 TPD field erected facilities.

Table B-27 presents averaged results for the service fees, utilities, insurance, and residue transportation components of annual costs (799). These data are based on financed, existing, or proposed facilities, excluding taxes. Although comparative residue transportation costs for each technology are presented, they are also highly site-specific. In particular, residue disposal costs for RDF systems are highly dependent on the markets for the recovered materials. When markets for these materials are weak, residue disposal becomes a more significant fraction of total annual costs.

In determining revenue from resource recovery facilities, one must consider the sale of secondary materials as well as energy. As described in Section B.4, Mass and Energy Balance, the steam and electrical generation rates are a function of the quality of the fuel, design temperature and pressure of the boiler and heat recovery efficiency of the technology (799). Table B-28 presents the energy production rate parameters that form the basis of estimating revenue from the sale of energy from technology options being considered for Lake County.

Revenues from recovered materials depend on which materials are recovered as well as the market availability, materials net pricing and length of contract. Due to its recoverability either before or after combustion (i.e., from the ash), ferrous metals are most often recovered. In preparing an economic analysis of any type of RDF or mass-burn facility from which secondary materials are intended to be recovered, it is essential to conduct sensitivity analyses to determine the effect of landfilling versus selling secondary materials (799).

TABLE B-26. CAPITAL CONSTRUCTION COST ESTIMATE FOR MASS BURN AND RDF RESOURCE RECOVERY FACILITIES (1988 Dollars) (799)

Category	100 TPD Modular (1)	300 TPD Field Erected	2,000 TPD Field Erected	1,700 TPD RDF (2)
Site Preparation (mobilization, earthwork, paving utility connections, landscaping fences)	$ 339,000	$ 1,250,000	$ 8,040,000	$ 10,677,000
Buildings, Structures, Fdns. (receiving area, pit, equipment area, office building, scale house, scale, cranes)	850,000	5,002,000	30,740,000	30,126,000
Combustion Equipment (boilers, grates, ash handling, water treatment, I&C, cooling tower, condenser ancillaries) (3)	2,825,000	14,391,000	87,900,000	70,162,000
RDF Processing Equipment (process equipment, conveyors)	--	--	--	18,121,000
Electric Generating Equipment (turbine generator, substation, interconnection)	1,189,000	3,960,000	22,600,000	16,905,000
Air Pollution Control (dry scrubber, lime equipment, baghouse, ductwork, stack)	625,000 (4)	3,545,000	25,120,000	15,914,000
Miscellaneous (vehicles, office furnishing, insurance, etc.)	140,000	624,000	3,520,000	3,722,000
Engineering, Permits, Construction Management	732,000	3,332,000	18,180,000	18,250,000
Startup and Testing	283,000	834,000	3,760,000	2,973,000
Land Purchase	17,000	62,000	140,000	150,000
TOTAL	$ 7,000,000	$33,000,000	$200,000,000	$187,000,000
Dollars per tpd capacity	$50,000-90,000	$90,000-130,000	$80,000-120,000	$85,000-135,000

Notes:
(1) Assumes excess air system and a reduction in level of equipment redundancy which lowers capital costs.
(2) Includes dedicated boiler for RDF combustion.
(3) I&C stands for instrumentation and control.
(4) 100-tpd unit has precipitator in lieu of dry scrubber/baghouse.

TABLE B-27. HISTORICAL DATA ON FACILITY OPERATION & MAINTENANCE[1]

(1988 Dollars) (799)

Description	Unit Value	Mass Burn	Modular Mass Burn	RDF
Facility Service Fee (2)	Dollars per gross ton processed	$15-25	$20-35	$20-35
Utilities				
In-plant Electrical	kWh per ton processed	50-65	60-80	90-100
Water (3)				
potable uses	Gal per ton processed	20-70	460-870	488(4)
non-potable uses	Gal per ton processed	160-730	N/A	N/A
total	Gal per ton processed	180-800		
Sewer (3)	Gal per ton processed	100-500	80-750	60-100(4)
Insurance	Dollars per ton processed	$0.50-2.25	$0.50-1.75	$0.50-2.25
Residue Produced (5)	Percent by dry weight of as-received waste	15-25	20-35	30-40(6)
Transportation of Residue (7)	Dollars per one-way mile per ton of as-received waste	$0.04-0.25	$0.05-0.35	$0.06-0.33

Notes:

(1) Based on planned or operational facilities.
(2) Includes labor, maintenance, materials, administration, and miscellaneous costs. Per ton costs are dependent o actual throughput and contractual requirements.
(3) Water usage and sewer discharge are a function of steam or electrical sales, condensate return, and once-through or recirculation of cooling water.
(4) Limited information available on facilities with dedicated boilers.
(5) Excludes recovery of secondary materials and scrubber residue.
(6) Composed of 25-30% process rejects and recoverable materials and 5-10% dry ash on an as-received waste basis o 8-15% dry ash per ton of RDF. Depending on the type of RDF produced and the amount of materials recovered, th residue and dry ash produced could be as high as 60%.
(7) Assumes $0.20-0.75 per one-way ton-mile transportation costs and 25% moisture in the ash. RDF costs assume 5-10% dry ash and 25-30% process rejects on an as-received waste basis.

TABLE B-28. ENERGY PRODUCTION RATES[1] (799)

Description	Modular	Field-Erected	RDF[(2)]
MSW Higher Heating Value of Incoming Municipal Solid Waste (Btu/lb)	4,500	4,500	4,500
Steam Conditions for Electric Generation (psig/^{o}F)	600/600	625/755	625/755
Feewater Temperature (^{o}F)	300	300	300
Boiler Efficiency (%)	40-60	65-70[(3)]	70-78
Gross Steam Flow Output (lb/ton)[(4)]	3,500-5,300	5,200-5,700	4,700-6,000
Gross Electrical Output (kWh/ton)[(4)]	320-480	520-570	470-600
Net Electrical Output (kWh/ton)[(4)]	290-430	470-510	390-525

Notes:

(1) Energy input and outputs are based on waste with a higher heating value of 4500 Btu/lb, the usual "industry standard". Studies have indicated that the higher heating value of waste is rising, and it is expected to continue to rise. Therefore, the energy inputs and outputs shown would increase.

(2) Using dry RDF.

(3) Waterwall furnace efficiency. Refractory furnace efficiencies may be as low as 60%.

(4) All per-ton quantities based on per ton of as-received waste.

B.4 MASS AND ENERGY BALANCE

RDF or prepared fuel processing plants typically remove most noncombustibles from the waste stream prior to firing. Through a series of size reduction and separation processes, which can be both labor and energy intensive, the RDF produced is more uniformly sized and has a higher energy content than raw MSW, can be stored and easily handled, and can be fired in conventional boiler systems. RDF can also be co-fired with conventional fossil fuels in industrial and utility boilers after appropriate modifications. Finally, the removal of noncombustibles raises the performance of the boiler and reduces slagging and jamming of the combustor grates. (472)

This section examines the tradeoff in the expenditure of energy in the front end processing of MSW into RDF versus higher heat release rates for RDF over MSW during combustion. Other technical and economic factors to be considered in such a tradeoff, include but are not limited to: the additional cost for corrosion resistant materials required for co-firing of RDF with fossil fuel; the relative abundance of less expensive (economically competitive) alternate fuels, such as wood chips or bark; and the non-uniformity in RDF quality, supply and perceived ease of usage.

B.4.1 Energy Requirements - RDF Processing Unit Operations

As discussed in Section B.2, RDF production may encompass a variety of unit operations for processing raw MSW into an acceptable fuel for subsequent combustion in dedicated boilers or co-fired with fossil fuel in industrial or utility boilers. Processing steps may include size reduction or shredding, air classification, screening, magnetic separation, materials (glass and aluminum) recovery, disc screening, and conveying.

The primary factors determining energy usage for the processing of MSW in typical RDF production facilities, is the quality of the RDF being produced and amount of waste being processed. Obviously, the more mechanized the facility is, the more energy it will consume. An analysis of the energy requirements for the pre-processing stage of MSW compost production (Appendix G), indicates that size reduction is the most energy intensive process step, followed by segregation (air classification, magnetic separation, trommeling, etc.) and finally, conveying (756).

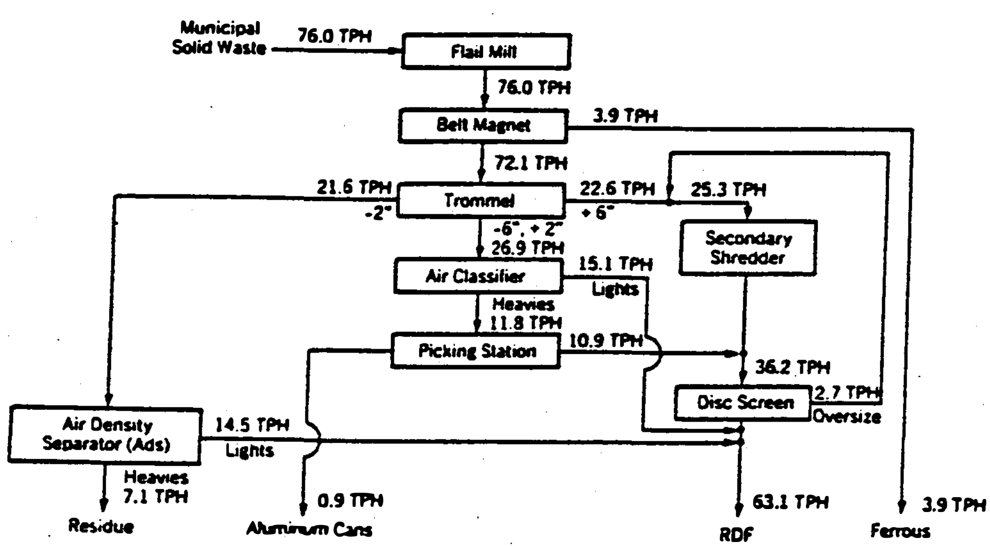
Energy requirements for reducing the particle size have been shown to increase sharply as increasingly small particle sizes are produced. For example, measurements taken during shredder operation showed that the specific energy (gross energy minus the freewheeling energy divided by the throughput of the material) requirement increased from about 5 kWh per ton to produce approximately a 1-1/2 inch particle size, to about 45 kWh per ton for a 1/4 inch particle size which is a size more consistent with composting requirements than RDF combustion (753). Approximately 13.6 kWh per ton is expended to size reduce MSW to a particle size of approximately 1 inch, which is the nominal particle size produced in RDF-3 (RDF fluff). Energy usage by air classifiers ranges from 3.1 to 3.8 kWh per ton of throughput. Energy consumption by trommel screens is approximately 0.7 to 1.0 kWh per ton of materials produced (756).

All of these unit processes have been used commercially and also demonstrated through continuous operation at the Delaware Reclamation Project since the 1970s. While the froth flotation of glass is not commonly used today, eddy current separation of aluminum has been installed at a few large RDF facilities including the 2000 TPD Palm Beach, Florida RDF plant. Figure B-30 is a block flow diagram depicting the material mass flow rates and size fractionation for this facility prior to installation of the eddy current separation system.

A fairly extensive study sponsored by Argonne National Laboratory in the early 1980s documented models of unit operations that were developed for typical RDF processing systems (888). The models are based largely on empiricism and governing theory and, to the extent possible, supplemented with field test data and literature sources. Table B-29 presents selected generalized conclusions from that comprehensive work regarding energy consumption in the preparation of RDF.

B.4.2 Energy Requirements - d-RDF Production

In the production of d-RDF, energy is required for the densification module which can include conveyors, shredders, screens, drying devices, dust control devices, metering feeders, and the densifier. As noted in Section B.2, the rotary-die extrusion mill, the "pellet mill," is the most commonly used densification device in commercial operation today. A survey of pellet mill manufacturers indicates that the power consumption of the pellet mill would range between 30 and 42 kWh per ton under "ideal" conditions (873).



Note: Evaporative Water Loss Not Shown

Figure B-30. Waste Process Schematic/Mass Balance

Palm Beach, FL RDF Plant (889 as cited in 472)

TABLE B-29. PREDICTED ENERGY REQUIREMENTS FOR RDF PROCESSING

(compiled from 888)

UNIT OPERATION	SPECIFIC ENERGY [Eo, (kWh/Mg)]	COMMENTS / ASSUMPTIONS
SIZE REDUCTION	Eo (Ferrous) = 12.3 Eo (Newsprint) = 12.9	The general form of the specific energy equation for size reduction relates MSW feed and RDF product particle sizes to specific energy through empirically derived coefficients based on material shearing resistance. For example, for newsprint, particles are assumed to be reduced from 25.7 cm to 3.4 cm; for ferrous metals the size reduction is 11.3 cm to 5.2 cm. Field measurements performed under comparable conditions yielded specific energy values of 12.0 kWh/Mg for ferrous metals and 13.7 kWh/Mg for newsprint.
AIR CLASSIFICATION	Eo (Baltimore) = 6.8 Eo (Ames) = 8.7	The power to operate an air classifier is an empirical function of the air column velocity to separate the light from the heavy fractions as well as the volumetric air flow rate. Measured and predicted power values are provided for Baltimore, MD and Ames, IA, based on median values obtained from three tests. The specific energy in kWh/Mg, although not reported, has been calculated from reported kW and estimated mass throughput, viz, 50 Mg/hr for Baltimore and 15 Mg/hr for Ames.
TROMMEL SCREENING	Eo = 0.4	Since theoretical analysis considerably underpredicted power requirements from trommel screening compared to test results, actual test data from the Baltimore County, MD trommel study were used as the basis of the empirical power relationship. The specific energy value cited is based on a mass flow rate of 10 Mg/hr.
FERROUS METAL SEPARATION	Eo = 0.36	Both the type of magnet (viz, electromagnet or permanent magnet) and the size of the motor driving the belt, determine the energy consumed. For a mass flow rate of 40 to 100 Mg of shredded waste per hour, the electromagnet requires 0.26 kWh/Mg of waste and the motor about 0.1 kWh/Mg of waste.
NON FERROUS METAL SEPARATION	Eo = 1.0	The power requirement for a non-ferrous eddy current separation system is comprised of the power for the screen, eddy current separator and air knife.
CONVEYING	VARIABLE	For belt conveyors and apron conveyors, the specific energy relationship is an empirically determined function dependent on material density, mass flow rate, length of conveyor, height of lift, belt velocity, and belt width.

In a detailed work presented by Warren Spring Laboratory for the United Kingdom's Byker facility (876), a breakdown of the energy consumption is given for the entire d-RDF system: primary shredder - approximately 11 kWh per tonne; secondary shredder - 25.5 kWh per tonne; primary pellet mills - 18.9 kWh per tonne; final pellet mill - approximately 35 kWh per tonne; air classifier/dryer and secondary screen circuit - approximately 2.2 kWh per tonne; motor control center - 1.2 kWh per tonne; dryer/deduster - approximately 10 kWh per tonne; process deduster - approximately 3.8 kWh per tonne; and the storage deduster - approximately 3.8 kWh per tonne. The total specific power consumption for the system was on the order of 45 kWh per tonne, based upon the tonnage of feed input to the system; and 200 kWh per tonne, based upon the total quantity of pellets produced. It was also noted that the dryer efficiency was on the order of 52% to reduce the moisture content from approximately 28% down to 11%.

The United Kingdom's Doncaster plant reported (878) a specific power consumption measurement of 38.6 kWh per tonne for the pellet mill, and approximately 150 kWh per tonne for the fuel circuit, which is comprised of a knife mill, pellet mill, dryer and pellet screen/cooler, and all associated conveyors and fans. Further, the overall plant specific power consumption based upon the material delivered to the facility was about 40 kWh per tonne. The overall plant refers to the initial MSW processing, including feed mechanisms, trommels, magnets, air classifiers, hammermills; the fuel circuit; and dust control equipment. A flowsheet of the Doncaster plant is shown in Figure B-31.

For the Doncaster facility, the dryer was approximately 39% efficient in reducing RDF moisture from 27% to 10%. It was also noted that significant energy savings could occur when a wet, semi-densified pellet was produced, as compared to a hard pellet.

B.4.3 RDF Production/Combustion

Because of the heterogeneity of MSW and the inherent limitations of separation technologies to completely separate the desired waste fractions, potential fuel material is lost to the residue fraction whenever noncombustibles and other impurities are removed. Hence, a trade-off between fuel quality and quantity exists (57, 484). Richards et al (484) note that attempting to produce a high quality fuel by removing a high proportion of the noncombustibles results in the removal of a significant proportion of the combustible fraction. Conversely, if the objective is to maximize the quantity of fuel recovered, a relatively high content of non-combustibles in the fuel is inevitable (484). Fuel quality as determined by material separation is critical when RDF is produced for sale to an industry or utility for cofiring applications (57).

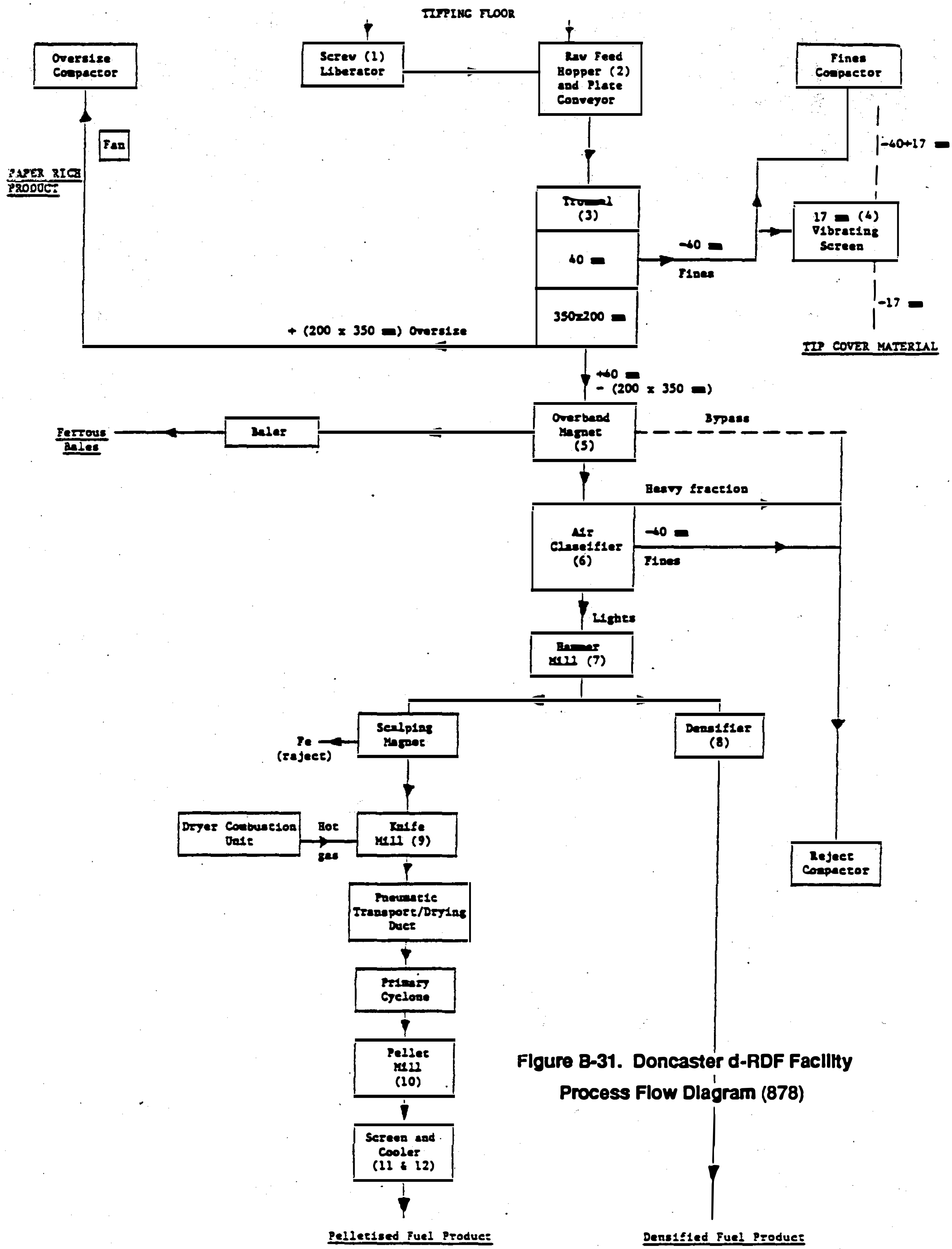


Figure B-31. Doncaster d-RDF Facility Process Flow Diagram (878)

The Electric Power Research Institute (EPRI), in developing standard cost analyses for RDF cofiring with coal (805, 806, 807), assumed a "standard" RDF production process as shown in Figure B-32. The figure includes materials balances for the various products and by-products of MSW processing. Although there can be many variations on this particuiar series of unit operations or the number of stages employed, these are considered to be the basic processing steps based upon the current state of the art for producing RDF for suspension firing with coal in a utility boiler.

As shown on Figure B-32, the mass yield, or recovery of RDF by weight, is presented as only 53% of the total MSW feed. (The energy yield, or recovery of combustibles by heat content is 69%.) In comparison, actual RDF mass yields have been reported (67, 484, 621) as follows: in excess of 91% for Lakeland, 80-85% for St. Louis, 74% for Ames, 70% for Chicago, about 60% for Rochester, 54% for Madison, 49% for Bridgeport, and 46% for Milwaukee.

For the EPRI "standard" processing approach, the undersize rejects and heavy rejects amount to 42% of the total MSW feed. Unless there is some other application for this material (such as firing in a mass burning or spreader stoker combustor), this material would be disposed in a landfill. Additionally, the ash from combustion of the RDF would also contribute to the quantity of material landfilled. Ash in the RDF is estimated by EPRI to be 12% of the RDF by weight, but it varies quite dramatically for each of the processing systems which have been placed in service. For example, comparative RDF ash measurements are about 10% at Ames, 28% at Milwaukee, 22% at Lakeland, and 12% at Madison (67, 484). Thus, the ash from the "standard" process would contribute an additional 6% of the MSW to the total residuals (12% ash x 53% RDF = 6.36% ash from RDF combustion). For both the RDF production system and the combustion system, total residuals are estimated to be 48%. Ferrous is estimated to be an additional 4% of the incoming MSW.

The RDF produced by the process shown in Figure B-32, based upon standard feed material, is estimated to have a higher heating value (HHV) of 5900 Btu/lb and 24% moisture (805). By comparison, HHVs and moisture content at actual operating facilities are reported (484), respectively, as: 4,700 Btu/lb and 29.5% at Lakeland; 7,700 Btu/lb and 25% at Madison; and 6,100 Btu/lb and 22% at Ames.

There are several factors that affect RDF yield, ash content, moisture, and HHV. Although the processing system is clearly one of these factors, it may also be a result of the type and composition of MSW (e.g., wet or dry) which is processed and the feed rate. The larger plants seem to have higher moisture, higher ash, and lower higher heating values. Another factor could be the composition of the waste itself. Table B-30 provides a comparison of the variations in composition and properties of unprocessed MSW at four facilities along with the EPRI-assumed values.

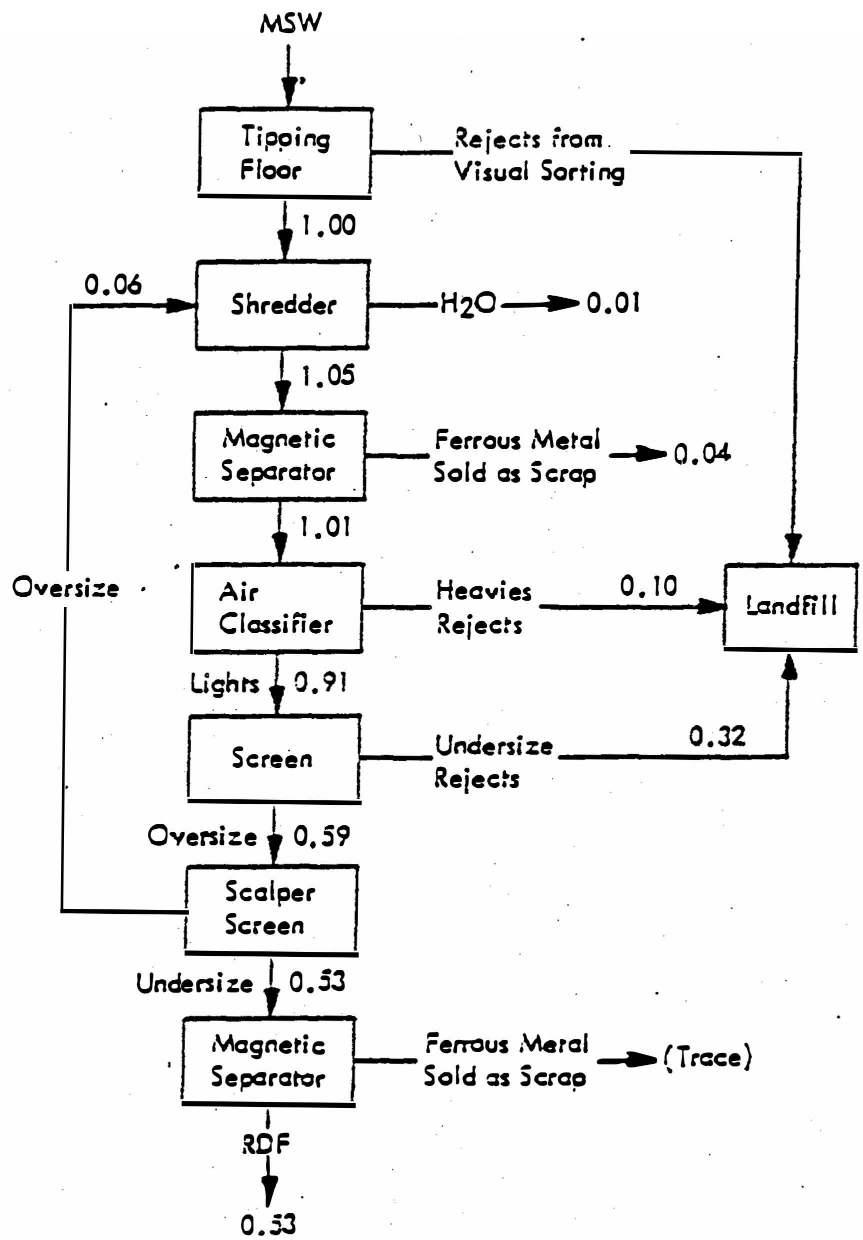


Figure B-32. Flow Diagram and Mass Balance of " Standard" RDF Processing System for Cofiring in Utility Boilers (numbers shown are normalized mass balance) (806)

TABLE B-30. VARIATIONS IN COMPOSITION AND PROPERTIES OF UNPROCESSED MSW (806)

As-Received MSW	St. Louis	Ames	Chicago	Bridgeport	EPRI Standard Process
Heating Value	4482	4831	4380	4700	5900
Moisture, % by Wt	25.3	24.2	25.0		30.0
Ash, % by Wt	24.2	22.7			25.0
Composition, % by Wt					
Paper & Cardboard	51.0	46.6	44.9	49.3	45.0
Plastic	4.5	3.2	4.1	1.9	6.0
Wood	3.8	6.4	2.2	(a)	
Glass	3.2	9.5	(b)10.1	12.0	9.0
Ferrous Metal	5.6	5.5	9.1	10.1	5.0
Nonferrous Metal	0.6	0.9	0.8	1.1	1.0
Organics (c)	6.3	9.0	17.4	21.3	31.0
Misc & Fines	25.0	18.9	11.4	4.3	3.0
	100.0	100.0	100.0	100.0	100.0

(a) Wood included in organics and other category
(b) Glass category at Chicago includes ceramics and stones
(c) Organics include yard wastes, food wastes, textiles, leather, rubber, and tar

A detailed comparison of MSW properties and the properties of the RDF as produced by EPRI's "standard" process is provided in Table B-31. As indicated on Table B-30, the paper, plastic and other organics make up 45%, 6% and 31%, respectively, of the waste for a total of 82% combustibles content. Since the assumed yield (shown on Table B-31) is 53%, one might assume that only 65% or less of the combustibles in the MSW are recovered in the RDF product (e.g., 53% RDF/82% Combustibles = 65% Combustible Yield). Actually, some of the non-combustibles are also contained in the RDF and thus the yield is lower than the theoretical maximum value.

Figure B-33 depicts a mass and energy balance developed for a 550 TPD RDF facility with a dedicated boiler. In this case, approximately 82% of the incoming waste is converted to RDF for use as fuel. Of the remaining 18% removed, 4% is ferrous and non-ferrous metals, 11% is front-end processing rejects from the trommel screens and air classifier, and 3% is moisture loss. Of the total waste input to the system, the ash produced is approximately 12% on a dry basis (16% wet) compared to 23% for mass burn (30% wet). However, the total weight of RDF residue to be landfilled, including the rejects from front-end processing, approximates the amount of mass burn ash residue requiring landfilling (716).

On the energy side, RDF front-end processing equipment recovers approximately 90% of the 5500 Btu per pound available in the MSW, which results an RDF product containing 4500 Btu per pound. Dedicated RDF boiler efficiencies range between 73 and 78%. Assuming that 25% of the available energy in the RDF is lost in the bottom and fly ash, flue gas and through the furnace walls, the overall efficiency becomes 67.5%. This results in an energy recovery of approximately 3375 Btu/lb of waste on an as received basis. On an annual basis, approximately 92 million kWh can be generated for sale to a local utility (716).

B.4.4 Thermal Conversion

As indicated previously, boiler efficiency is an important measure of thermal conversion performance improvements and is often used to compare performance ratings across different systems. However, from a systems guarantee standpoint, the RDF plant operator is typically more interested in pounds of steam generated per pound of refuse or the kilowatt hours per ton of refuse fired (255).

TABLE B-31. PROPERTIES OF RDF AND UNPROCESSED MSW

(Dry basis except where noted) (806)

PROPERTY	RECOMMENDED RDF	UNPROCESSED MSW
MAXIMUM PARTICLE SIZE, (IN.)	LTE 2.5 (a)	LTE 10 (a,b)
BULK DENSITY, (LB/FT3)	4	12
PROXIMATE ANALYSIS, (% BY WT.)		
ASH	16	36
VOLATILE MATTER	71	64
FIXED CARBON	13	-
	100	100
ULTIMATE ANALYSIS, (% BY WT.)		
CARBON	44.0	32.6
HYDROGEN	6.0	4.3
NITROGEN	0.7	0.6
OXYGEN	32.6	25.7
SULFUR	0.3	0.2
CHLORINE	0.4	0.6
ASH	16.0	36.0
	100	100
HEATING VALUE, (BTU/LB)		
AS RECEIVED	5800	4500
DRY BASIS	7700	6400
ASH YIELD, (LB ASH / MMBTU)	21	56
AS-RECEIVED MOISTURE CONTENT, (% BY WT.)	24	30
PROCESS CHARACTERISTICS		
TOTAL SPECIFIC ENERGY , (kWh/T, MSW)	16.20	-
RDF MASS YIELD, (T, RDF / T, MSW)	0.53	-
GROSS ENERGY YIELD, (BTU AS RDF / BTU AS MSW)	0.69	-

NOTES:
(a) LTE - LESS THAN OR EQUAL TO
(b) 90% OF UNPROCESSED MSW IS TYPICALLY LESS THAN 10 IN. IN SIZE.

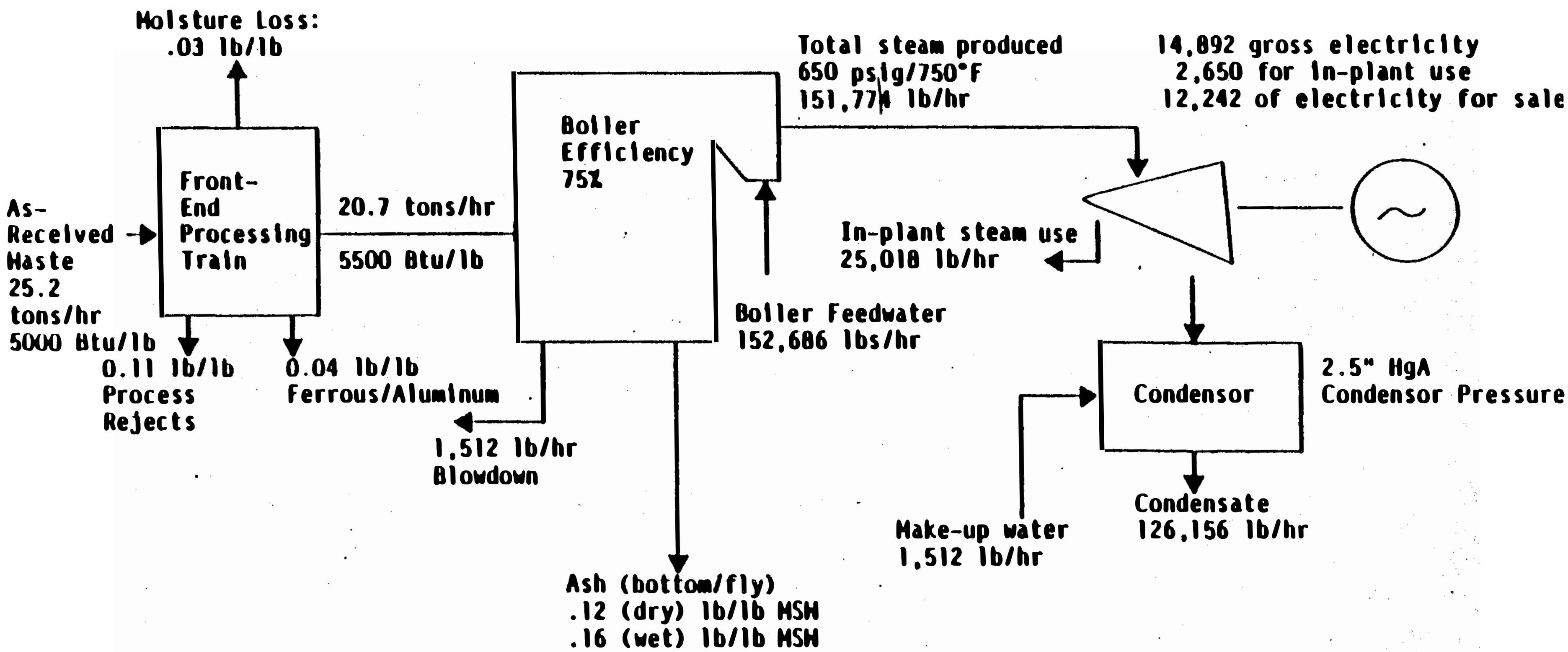


Figure B-33. Mass and Energy Balance - 550 TPD RDF/Dedicated Boiler Facility (716)

Tests performed under controlled RDF production and combustion conditions revealed that improved RDF quality can significantly increase steam produced. As illustrated in Table B-32, these tests demonstrated that steam production could be increased from approximately 3 lb steam/lb RDF to over 4 lb steam/lb RDF (255). Additional processing will likewise increase the RDF's higher heating value and carbon content, while lowering ash content, sulfur and nitrogen. In a fuel preparation process used by Combustion Engineering (now ABB/C-E), approximately 90% of the combustible material in the raw waste is burned, constituting about 95% of the available Btus. As a further example, the dedicated RDF spreader stoker boiler in Haverhill, MA produces 4 lb steam/lb of refuse fired (255).

Table B-33 presents summary statistics from the GAA database (387) describing the net to gross power output ratings for mass burning, modular units and all RDF processes in the U.S. This ratio is based on data from 132 waste-to-energy projects that provided information regarding both net and gross power output ratings. The ratio of the net to gross power output rating is 0.79 for this group.

TABLE B-32. STEAM PRODUCTION AND RDF QUALITY (255)

RDF type	Total RDF burned, tons	Total yield incoming MSW, % by wt	Total steam produced, lb	Specific steam production, lb stm/lb RDF	Specific steam production, lb stm/lb incoming MSW
A/B Improved	1288	89	9,062,000	3.52	3.13
C/D Improved	158	85	1,113,000	3.52	2.99
E Improved	103	73	847,000	4.12	3.01
Crude RDF	12,717	93	79,008,000	3.13	2.91

A/B Improved: Air-classified light fraction produced from shredded RDF at 95.5/4.5%

C/D Improved: 37.5 tons of 67.4/32.6% light fraction, mixed with 75.6 tons of 90/10% light fraction, and 44.7 tons of crude RDF

E Improved: Air-classified light fraction produced from unshredded MSW, and then screened over 1/2-inch screen

TABLE B-33. RATIO OF NET TO GROSS POWER OUTPUT RATING (387)

Sample	Type of Process	Mean	Standard Deviation	N
All Facilities	–	0.81	0.13	132
(Minimum = 0.26; Maximum = 0.95)	a. Mass Burning	0.82	0.11	91
	b. Modular Units	0.71	0.20	18
	c. All RDF Processes	0.84	0.08	23
Planned Facilities	–	0.84	0.07	56
(Minimum = 0.47; Maximum = 0.95)	a. Mass Burning	0.84	0.08	47
	b. Modular Units	0.87	0.05	3
	c. All RDF Processes	0.82	0.04	6
Existing Facilities	–	0.79	0.15	76
(Minimum = 0.26; Maximum = 0.95)	a. Mass Burning	0.80	0.14	44
	b. Modular Units	0.67	0.20	15
	c. All RDF Processes	0.85	0.08	17

In comparing mass bum technology with RDF technology, the data show little difference in this ratio, despite the expectation that pre-processing of raw MSW yields an easier to bum fuel which results in more electrical energy output per pound of MSW processed. Since the parasitic energy demands associated with the steam/electrical generating equipment are equivalent in both cases, combustion efficiency gains with RDF technology would appear to be out-weighed by the increased energy requirements associated with front-end processing, particularly the size reduction equipment. Supporting data for this summary comparison is provided in Table B-34 (716). Both systems are projected to generate approximately 490 kWh of electricity for sale to the utility for each ton of waste processed.

For existing facilities, RDF units reported a higher average value (0.85) for net to gross power output ratio than mass bum (0.80), as shown in Table B-33. However, for those facilities currently in the planning stages, this ratio is reportedly higher for mass bum (0.84) than for RDF processes (0.82) (387). The explanation could be due to increased recycling, which removes non-combustibles from the waste stream and increases the unit heating value of the refuse fuel; general improvements in mass bum combustor technology; or an economy of scale effect due to a general increase in the size of planned facilities.

B.5 ENVIRONMENTAL RELEASES

The major environmental releases from an RDF facility are the air emissions discharged from the stack, the residue discharged as bottom ash from the furnace and as fly ash from the air pollution control equipment, storm water run-off from the site, and sanitary wastewater generated at the facility.

B.5.1 Emissions from RDF Production (806)

While the air emissions from RDF combustion have been reported in the literature, little information exists regarding emissions from the MSW handling and unit process operations that constitute RDF production. Environmental emissions from RDF receiving, handling, and storage potentially include particulate emissions, spillage, odors, liquid wastes and gaseous emissions (806).

TABLE B-34. COMPARISON OF PERFORMANCE FOR MASS BURN AND RDF SYSTEMS (716)

UNIT BASIS

SYSTEM	WASTE HHV (Btu/lb)	WASTE RECOVERED AS RDF (% by weight)	ENERGY RECOVERED IN RDF (% of Btu)	BOILER EFFICIENCY (%)	ENERGY RECOVERED AS STEAM (Btu/lb of waste)
Mass-burn	5000	NA	NA	66	3,300
RDF Boiler	5000	82	90	75	3,375

ANNUAL BASIS

SYSTEM	WASTE INPUT (TPY)	FUEL PREPARATION				FERROUS RECOVERED FROM ASH (TPY)	ASH (WET BASIS)) (TPY)	ENERGY RECOVERED IN ELECTRICITY SOLD (kWh/yr)
		RDF (TPY)	RECOVERED FERROUS/ ALUMINUM (TPY)	MOISTURE LOSSES (TPY)	PROCESS RESIDUE (TPY)			
Mass-Burn	187,701	0	0	0	0	5,631	50,679	9.2×10^6
RDF Boiler	187,701	153,915	7,508	5,631	20,647	0	30,032	9.2×10^6

Generally speaking, in order to control fugitive dust emissions from the MSW tipping floor (and sometimes the RDF processing area as well), those areas are placed under a negative pressure. In contemporary plants, the exhaust will be ducted to a fabric filter collector. A portion of the exhaust may be used as RDF combustion make-up air. Alternatively, depending upon the prevailing ordinances and regulations and age of the plant, some (older) RDF facilities have relied solely on roof mounted vent fans.

Dust can also be generated at each point of processing MSW into RDF, including materials size reduction, segregation and conveying process steps. Specific RDF production operations that contribute to the generation and/or liberation of fine particulate emissions may include receiving hoppers (i.e., when air is displaced rapidly upon RDF charging), conveyor transfer points and pneumatic conveyor exhaust, and shredding and screening operations. Particulate emissions emanating from these RDF productions steps are typically captured in hooded enclosures and vented to a fabric filter collector, possibly preceded by a cyclone collection.

RDF spillage in and around receiving hoppers and mechanical conveyor transfer points can constitute a fire hazard (806). A safe operation that minimizes the release of airborne RDF can be achieved through proper design of hooded enclosures for size reduction, segregation and conveying operations coupled with controlled ventilation and good housekeeping practices. Further, while odor problems have not been a major problem in the production of RDF (806), properly designed ventilation and dust control systems coupled with adequate overall system operating capacity and sound cleanup procedures will help to ensure that any odors are minimized.

Liquid and gaseous emissions do not appear to cause a problem in RDF receiving, handling, and storage at the power plant (806). Liquids that may be contained in municipal solid waste are typically absorbed by the paper and cardboard in the RDF during processing. While it is possible that oils and solvents may potentially saturate RDF in some cases, gaseous emissions from this material are not expected to be released at the power plant. Certainly, liquid run-off does not occur by the time the RDF arrives at the power plant.

Further, gaseous emissions from refrigerant, propane, gasoline, solvent or spoiled food containers are typically liberated (opened to atmosphere) as a result of RDF processing. As such, the need to control gaseous emissions from RDF at the power plant has not been demonstrated (806). It should be noted that any container whose contents are likely to cause an explosion in an RDF size reduction (i.e., shredding) operation, will be removed, typically by a grapple crane, to avoid a personnel safety hazard and equipment damage.

B.5.2 Air Emissions from RDF Combustion

This section describes the magnitude and wide range of products of combustion from selected RDF combustion facilities. The reader is also referred to Section A.2.5 of Appendix A that describes air emissions from mass burn systems and municipal waste combustors (MWCs) in general. Included in that section is a description of the performance standards and emission guidelines for new and existing MWCs as well as a detailed description of the air pollution control equipment currently available for mass burn as well as RDF combustion facilities.

B.5.2.1 Comparison of Emissions from MWCs

HDR Engineering (799) reports on an analysis prepared by the California Air Resources Board in 1984 comparing uncontrolled and controlled criteria air pollutants and HCl from mass-burn and RDF facilities. The analysis showed that based on the use of good control technologies there is no difference in the controlled pollutant emission levels from the two types of facilities. A difference was noted between the two technologies in terms of uncontrolled particulate emissions. This difference is attributed to the smaller particle size of RDF and the fact that RDF is typically burned both in suspension and on the grate. The comparative data are presented in Table B-35.

TABLE B-35. COMPARISON OF UNCONTROLLED AND CONTROLLED CRITERIA AIR POLLUTANTS AND HCl FROM MASS-BURN AND RDF FACILITIES (799)

Air	Uncontrolled		Controlled	
Pollutant	Mass-Burn	RDF	Mass-Burn	RDF
NO_x	0.35-0.4	0.35-0.5	0.26-0.37	0.26-0.37
Particulate	4.5	9.0	0.02	0.02
SO_2	0.25-0.8	0.25-0.8	0.08	0.08
THC	0.045	0.045	0.45	0.45
CO	0.08-0.45	0.08-0.45	0.08-0.45	0.08-0.45
HCl	0.5-1.0	0.5-1.0	0.04	0.04

All values in pounds per million Btu.

Table B-36 presents additional summary data on emissions measured from RDF systems with varying levels of air pollution control and operating conditions (471).

TABLE B-36. SUMMARY OF EMISSIONS MEASURED FROM RDF COMBUSTORS[a] (adapted from 354)

Pollutant	Emission Level[b]
Particulate Matter	220 - 530 mg/Nm^3
	0.096 - 0.230 gr/dscf
Sulfur Dioxide	55 - 188 ppmdv
Nitrogen Oxides[c]	263 ppmdv
Carbon Monoxide	217 - 430 ppmdv
Hydrogen Chloride	96 - 780 ppmdv
Hydrogen Fluoride[c]	2.1 ug/Nm^3
Arsenic	19 - 160 ug/Nm^3
Beryllium[c]	21 ug/Nm^3
Cadmium	34 - 370 ug/Nm^3
Chromium[d]	490 - 6700 ug/Nm^3
Lead	970 - 9,600 ug/Nm^3
Mercury	170 - 440 ug/Nm^3
Nickel	130 - 3,600 ug/Nm^3
TCDD	3.5 - 260 ng/Nm^3
TCDF	32 - 680 ng/Nm^3
PCDD	54 - 2,840 ng/Nm^3
PCDF	135 - 9,100 ng/Nm^3

[a]Results from commercial-scale facilities only.

[b]All concentrations corrected to 12 percent CO_2.

[c]Data available for only one test.

[d]Total chromium emissions.

B.5.2.2 Emissions Measured from RDF Combustors

Table B-37 presents air emissions data for three RDF facilities: the MERC facility in Biddeford, Maine; the Mid-Connecticut facility in Hartford, Connecticut; and the SEMASS facility in Rochester, Massachusetts (28). All three facilities use a spray dryer for acid gas control. The Biddeford and Mid-Connecticut facilities utilize a fabric filter for particulate control, and the SEMASS facility uses an electrostatic precipitator, the largest known unit to be installed on any refuse-fired plant. Also included in Table B-37, for comparison purposes, are the 11 February 1991 Emission Guidelines for municipal waste combustors.

TABLE B-37. AIR EMISSIONS DATA FOR THE BIDDEFORD, MID-CONNECTICUT, AND SEMASS FACILITIES (28)

Emission	Biddeford Unit A (Large) 12/87	Mid-CT[a] Unit 11 (V Large) 2/89	SEMASS Unit 2 (V large) 4/89	Emissions Guidelines[b] Large	Emissions Guidelines[b] Very Large
Concentration					
SO_2, ppmdv @ 7% O_2	22.6	11 (1/89)	55	30	30
HCl, ppmdv @ 7% O_2	5.84	15 (1/89)	NA[c]	25	25
Particulate, gr/dscf @ 12% CO_2	0.014	0.0018	0.012	0.03	0.015
Dioxins/Furans, ng/dscm @ 7% O_2	4.38	0.368	311[d]	250	60
Chromium, ug/dscm @ 7% O_2	ND[e]	NA	15.6		
Lead, ug/dscm @ 7% O_2	159	NA	235		
Mercury, ug/dscm @ 7% O_2	ND	8.8	105		
Removal Efficiency, %					
SO_2	77.6	93.3	65.0	50	70
HCl	99.0	95.9	NA	50	90
Particulate	99.5	99.9	99.6		
Dioxins/Furans	99.4	99.9	NA		
Chromium	NA	NA	NA		
Lead	NA	NA	NA		
Mercury	100	NA	NA		

[a] All values for the Mid-Connecticut facility are referenced to dry gas with 12% CO_2.
[b] 40 CFR Part 60, p. 5516, for large and very large facilities.
[c] NA = Not Available or measured.
[d] Average value of 18.0, 6.6, and 907.
[e] ND = Not detected.

The test data for the Biddeford (1987) and Mid-Connecticut (1989) facilities fell within the 1991 Emission Guidelines for existing large and very large facilities, respectively. However, the April 1989 SEMASS emission tests exceeded the current NSPS for SO_2 and dixoins (CDD)/furans (CDF). It should be noted that, of the three tests combined to yield the CDD/CDF composite result, one value caused the exceedance, viz, 907 ng/dscm compared to 18.0 and 6.6 ng/dscm (28). No SEMASS data were available for HCl.

Table B-38 presents air emissions data for the West Palm Beach, Florida facility (886). This 2,000 TPD facility utilizes a dry scrubber for acid gas control and an electrostatic precipitator for particulate control.

TABLE B-38. AIR EMISSION DATA FOR THE NORTH COUNTY REGIONAL RESOURCE RECOVERY FACILITY, WEST PALM BEACH, FL[a,b] (886)

	Unit 1	Unit 2	FL Conditions of Certification and/or Permit Limits
Concentration, gr/dscf at 12% CO2			
Particulate	0.00126	0.00443	0.015
Concentration, ppmdv @ 12% CO2			
Carbon Monoxide	25	18	400
Emission Rate, lb/MMBtu			
Beryllium	<1.96E-007	<2.10E-007	7.3E-007
Hydrogen Chloride	0.0178	0.0241	- -
Hydrogen Fluoride	1.60E-004	7.30E-005	3.2E-003
Lead	4.47E-005	2.14E-005	4E-004
Mercury[c]	4.92E-005	2.07E-005	2.4E-004
Nitrogen Oxides as NO_2	0.353	0.354	0.32
Sulfur Dioxide	0.073	0.085	0.32
Sulfuric Acid	4.06E-003	3.66E-003	3.2E-005
THC as Methane[d]	8.33E-004	5.49E-004	0.016
Removal Efficiency, %			
Sulfur Dioxide	76%	70%	65%
Hydrogen Chloride	98%	97%	- -
Hydrogen Fluoride	98%	99%	- -
Sulfuric Acid	13%	-10%	- -
Acid Gases: HCl, HF, H_2SO_4	97%	97%	90%

[a]Data are averages of three repetitions.
[b]Measurements made at ESP outlet.
[c]Facility mercury limit is 3200 grams/day.
[d]PSD Permit has an allowable emission rate of 0.024 lb/mmBtu.

It should be noted that the West Palm Beach Authority applied for a modification to its permit from the Florida Department of Environmental Protection to raise the NO_x limit from 0.32 to 0.48 lb/mmBtu. The Authority made this request in concert with their proposal to the DEP to accept a more stringent limit on the emission of CO. As an aside, the negative sulfuric acid removal efficiency was viewed as unrepresentative of system performance. Apparently one test of the three averaged showed an unexplained -75 percent removal efficiency (893).

B.5.2.3 Performance Evaluation of Mid-Connecticut RDF Facility

Section B.2.6.2 mentioned the joint performance characterization program conducted at the Hartford facility by Environment Canada and the U.S. EPA. The final report has yet to be released, hence data evaluation is restricted. Preliminary data, however, has been published and are included herein in Tables B-39 through B-42 (892). Because the objective of the program was to evaluate the performance of the facility, the data cover a wide range of operating conditions and are not limited to the normal operating mode.

Fourteen performance tests were conducted during February and March of 1989 (890, 891, 892). One test did not meet the sampling protocol requirements and was consequently dropped from consideration. The combustion and flue gas cleaning (FGC) conditions for the performance tests were established from a series of 28 characterization tests conducted during January, 1989. All tests were run at a slightly de-rated load condition because of unusually wet RDF and insufficient combustion air fan capacity.

The combustion and FGC process conditions were adjusted independently to cover a wide range of operating modes. The combustion conditions were varied to result in both good and poor combustion. Thus, the effect of combustion quality on the organic concentrations at the spray dryer absorber (SDA) inlet could be observed. To vary the combustion conditions, the boiler steam load, underfire-to-overfire air ratio, and the overfire air distribution were varied. The criteria for judging good or poor combustion quality was the CO concentration at the SDA inlet. Table B-39 shows the combustion conditions and the results at the SDA inlet. Steam flow rates of low (L), intermediate (I), normal (N), and high (H) were tested.

TABLE B-39. COMBUSTION CONDITIONS AND RESULTS AT SDA INLET (892)

Test No. (PT)	Load 1000 kg/hr	Comb. Cond.[a]	Overfire Air TOFA[b]	Overfire Air ROFA[c]	Overfire Air OFA[d]	CO ppm	NO_x ppm	PCDD/PCDF ng/Sm^{3}[e]
13	71 (L)	G	2	nil	47	158	157	599
14	74 (L)	G	2	nil	49	70	177	428
10	87 (I)	G	2	nil	52	77	186	667
02	88 (I)	G	2	nil	52	108	184	946
05	84 (I)	P	1	65	38	903	149	1861
09	95 (N)	G	2	65	51	92	188	449
08	96 (N)	G	2	65	48	89	193	1162
11	96 (N)	G	2	65	52	68	175	536
07	101 (N)	P	3	nil	51	387	172	1003
04	98 (N)	P	3	nil	54	214	172	774
03	99 (N)	P	1	65	44	432	160	1008
12	117 (H)	G	2	65	53	116	180	282
06	118 (H)	P	2	nil	57	397	157	1202

[a] Good (G) or poor (P) combustion conditions
[b] Number of levels of TOFA
[c] Pressure in ROFA plenum, mm Hg
[d] OFA as a percentage of total combustion air
[e] Standard conditions: 25°C, 101.3 kPa

TABLE B-40. FLUE GAS CLEANING SYSTEM PERFORMANCE: ACID GASES (892)

Test No. (PT)[a]	FGC Cond. Temp./SO_2[b]	Concentrations, ppm — Inlet HCl	Inlet SO_2	Outlet HCl	Outlet SO_2	Removal, % HCl	Removal, % SO_2
02,05	L/H	470	173	20	121	95.7	30.1
03,11	H/L	416	187	20	17	95.2	90.9
04	H/M	471	186	31	44	93.4	76.3
06	M/L	404	192	10	32	97.5	83.3
07	L/L	399	183	8	17	98.0	90.7
08	M/H	538	184	41	126	92.4	31.5
09	H/H	432	178	98	189	77.3	-6.2[c]
10	L/M	429	194	19	74	95.6	61.9
12,13,14	M/M	444	187	18	59	95.9	68.4

[a] Values are averaged for multiple runs.

[b] High temperatures (H) ranged from 166 to 171°C (330 to 339°F), medium temperatures (M) from 141 to 142°C (285 to 287°F), and low (L) temperatures from 122 to 124°C (252 to 255°F) for the spray dryer outlet gas. Fabric filter SO_2 outlet concentrations were above 100 ppm for high (H) concentration, between 21 and 100 ppm for medium (M) concentration, and 20 ppm or less for low (L) concentration. All concentrations are referenced to 12% CO_2 in dry gas [25°C (77°F), 101.3 kPa (1 atm)].

[c] Desorption of SO_2 in the filter cake is suspected for low lime stoichiometry and relatively high HCl concentration.

TABLE B-41. FLUE GAS CLEANING SYSTEM PERFORMANCE: ORGANICS (892)

Test No. (PT)[b]	FGC Cond. Temp./SO_2[c]	Inlet Concentrations, ng/Sm^3[a] PCDD	PCDF	CB	CP	PAH	Removal, % PCDD	PCDF	CB	CP	PAH
02,05	L/H	397	1,007	10,860	62,938	60,176	99.9	99.9	96.2	97.4	92.0
03,11	H/L	161	611	6, 159	20,798	46,976	99.8	100[d]	95.2	99.1	92.2
04	H/M	151	623	5,964	16,964	25,519	99.8	99.9	98.4	99.0	92.2
06	M/L	317	885	9,403	41,588	88,626	99.9	100[d]	94.3	96.9	97.7
07	L/L	207	796	7,074	25,168	51,774	99.9	100[d]	98.5	99.1	97.3
08	M/H	211	951	7,071	20,226	10,259	99.9	100[d]	98.4	99.1	76.7
09	H/H	71	378	4,848	11,329	32,421	99.2	99.9	97.7	96.5	92.5
10	L/M	243	424	6,170	16,198	6,289	99.9	100[d]	99.3	99.9	58.6
12,13,14	M/M	95	341	4,647	14,419	7,747	99.6	100[d]	99.1	99.4	63.2

[a] Organics are: polychlorinated dibenzo-p-dioxins (PCDD) and dibenzofurans (PCDD), chlorobenzenes (CB), chlorophenols (CP), and polynuclear aromatic hydrocarbons (PAH).

[b] Values are averaged for multiple runs.

[c] High temperatures (H) ranged from 166 to 171°C (330 to 339°F), medium temperatures (M) from 141 to 142°C (285 to 287°F), and low temperatures (L) from 122 to 124°C (252 to 255°F) for the spray dryer outlet gas. Fabric filter outlet SO_2 concentrations were above 100 ppm for high (H) concentration, between 21 and 100 ppm for moderate (M) concentration, and 20 ppm or less for low (L) concentration. All concentrations are referenced to 12% CO_2 in dry gas [25°C (77°F), 101.3 kPa (1 atm)].

[d] Value is based on rounding off to three significant figures.

TABLE B-42. FLUE GAS CLEANING SYSTEM PERFORMANCE: PARTICULATE MATTER AND SELECTED METALS (892)

Test No. (PT)[a]	FGC Cond. Temp./SO_2[b]	Particulate Matter (PM) mg/Sm³		Inlet Concentration, µg/Sm³					Removal, %					
		Inlet	Outlet	As	Cd	Cr	Pb	Hg	PM	As[c]	Cd[c]	Cr	Pb	Hg
02,05	L/H	4,949	4.83	250	548	859	13,472	680	99.9	100	100	98.3	99.7	99.0
03,11	H/L	4,313	5.60	214	594	579	11,479	622	99.9	100	100	98.6	99.6	96.8
04	H/M	3,274	7.62	168	536	538	10,050	614	99.8	100	100	98.1	99.6	97.8
06	M/L	3,308	2.68	194	437	353	7,229	583	99.9	100	100	97.7	99.5	98.0
07	L/L	4,230	4.39	176	515	520	5,877	584	99.9	100	100	98.5	99.5	98.7
08	M/H	4,745	3.88	224	832	862	4,649	646	99.9	100	100	96.4	99.1	99.3
09	H/H	3,894	5.79	196	668	1,491	2,592	644	99.9	100	100	99.3	98.5	97.8
10	L/M	4,531	4.09	210	599	871	4,770	718	99.9	100	100	99.0	99.1	98.8
12,13,14	M/M	3,433	5.46	219	569	949	8,563	668	99.8	100	100	98.2	99.3	98.6

[a] Values are averaged for multiple runs.

[b] High temperatures (H) ranged from 166 to 171°C (330 to 339°F), medium temperatures from 141 to 142°C (285 to 287°F), low temperatures (L) from 122 to 124°C (252 to 255°F) for the spray dryer outlet gas. Fabric filter SO_2 outlet concentrations were above 100 ppm for high (H) concentration, between 21 and 100 ppm for medium (M) concentration, and 20 ppm or less for low concentration. All concentrations are referenced to 12% CO_2 in dry gas [25°C (77°F), 101.3 kPa (1 atm)].

[c] All outlet concentrations were nondetectable and assigned zero values for calculating removal.

In general, the combustion tests demonstrated important single and multiple parameter correlations between good combustion practice and emissions (892). For example, multiple regression analyses confirmed that steam load, combustion air flow, RDF moisture content, and other combustion parameters, can be used to control dioxin (PCDD), furan (PCDF), chlorophenol (CP), chlorobenzene (CB), and polynuclear aromatic hydrocarbon (PAH) concentrations at the SDA inlet. Further, CO or total hydrocarbon (THC) concentrations at the SDA inlet appear to reliably predict furnace emission of most trace organics of concern. Under good combustion conditions, the emission rate of particulate matter (PM) appears to be the principal variable affecting the furnace PCDD/PCDF emission rate. Further, CO appears to be an excellent indicator of PCDD/PCDF emissions for poor combustion (CO > 200 ppm), but not for good combustion (CO < 200 ppm). The predicted formation of PCDD/PCDF across the economizer was not observed. Finally, the concentration of metals in the flyash at the SDA inlet did not appear to correlate with combustion conditions.

The FGC system was evaluated by varying the gas temperature and the lime stoichiometry. Tables B-40 through B-42 show the preliminary FGC system data. The lime spray dryer absorber/fabric filter system performed very well in controlling emissions of acid gases, trace dioxin/furan, trace metal and particulate emissions (892). With highly reactive lime at high flows, stoichiometry and flue gas temperature, HCl and SO_2 removals of 95 percent and 90 percent, respectively, were achieved. PCDD and PCDF removals exceeded 99 percent under a variety of conditions, and acid gas removal proved to be more dependent on lime stoichiometry than flue gas temperature. As evidenced by the tables, the FGC system proved capable of high removals of acid gases, organics, metals, and particulate matter.

The ash/residue analyses revealed that the predominate metal was Pb (As was the least detectable), while both had similar concentrations in the SDA inlet. The concentration of dioxins and furans ranged from 74 to 509 ng/g of feed, and organics consistently had a higher concentration in the ash under poor combustion conditions.

B.5.2.4 Air Emissions from d-RDF Combustion

Densified RDF production can produce particulate emissions internal to the densification production facility, which are typically controlled by dust handling equipment in the production facility. The combustion of d-RDF should be no different than the combustion of RDF, with the possible exception of the effect of the binder material, if used.. In the case of using a lime (calcium hydroxide) binder, it is believed that the lime binder would neutralize and reduce sulfur oxide emissions during combustion (880). In most of the literature, emissions from the combustion of d-RDF are compared to emissions from the combustion of stoker coal, the fuel the d-RDF is to replace. This may be a valid approach in that co-firing limited amounts of d-RDF with stoker coal may be allowed without updating the coal boilers' pollution control equipment.

It has been surmised that in burning d-RDF/coal blends, particulate emissions, halogen emissions, and some heavy metals (lead, cadmium, zinc, chromium) increase while SO_x and NO_x emissions decrease compared to firing 100 percent stoker coal (873). The same has been found in analyses by the United Kingdom (876, 878). Of course, specific values depend on the type of coal combusted, the composition of the MSW, and the amount of processing to produce the RDF. Table B-43 shows a decrease in d-RDF heavy metal content with the addition of pre-trommeling.

TABLE B-43. RDF PELLETS, ASSAY VALUES (as received) (877)

	Before front end screening (1984)	After front end screening (July 1987)
Moisture wt %	7.5	7.8
Ash wt %	15.7	12.7
Gross Calorific Value MJ/Kg	17.2	17.8
Chlorine wt %	0.7	0.8
Sulphur wt %	0.3	0.2
Lead (pb) ppm	220	75
Cadmium (Cd) ppm	8	5
Mercury (Hg) ppm	2	0.6

As can be seen from Table B-44, emissions tests do not always follow the more commonly accepted trends. These data show decreases in particulates and increases in SO_2 and NO_x in some instances with the co-firing of coal and d-RDF compared to firing of coal alone.

TABLE B-44. EMISSIONS AND EFFICIENCY COMPARISON COMBUSTION TRIAL, ROCHESTER, NY PSYCHIATRIC CENTER (874)

RUNS 1, 2, & 3

	Avg. Particulate	=	0.248 lbs/MMBTU
Avg. Steaming Rate	Avg. SO_2	=	4.24 lbs/MMBTU
16,967/lbs/hr.	Avg. NO_x	=	0.163 lbs/MMBTU
Coal Only	Avg. Efficiency (%)	=	74.1

RUNS 4, 5, & 6

	Avg. Particulate	=	0.429 lbs/MMBTU
Avg. Steaming Rate	Avg. SO_2	=	4.65 lbs/MMBTU
19,167/lbs/hr.	Avg. NO_x	=	0.091 lbs/MMBTU
50:50 (Coal:d-RDF)	Avg. Efficiency (%)	=	68.4

RUNS 7, 8, & 9

	Avg. Particulate	=	0.211 lbs/MMBTU
Avg. Steaming Rate	Avg. SO_2	=	2.63 lbs/MMBTU
18,600/lbs/hr.	Avg. NO_x	=	0.152 lbs/MMBTU
50:50 (Coal:d-RDF)	Avg. Efficiency (%)	=	67.8

RUNS 10, 11, & 12

	Avg. Particulate	=	0.228 lbs/MMBTU
Avg. Steaming Rate	Avg. SO_2	=	2.37 lbs/MMBTU
19,667/lbs/hr.	Avg. NO_x	=	0.181 lbs/MMBTU
33:67 (Coal:d-RDF)	Avg. Efficiency (%)	=	67.9

B.5.3 Wastewater Discharge

The sources of wastewater discharge from an RDF facility include the following:

- o Continuous and intermittent blowdown
- o Equipment and facility washdown
- o Pretreatment filter backwater
- o Demineralizer-neutralizer reagent
- o Quench water
- o Site drainage
- o Sanitary wastewater

RDF ash typically contains about 25% moisture (799). For a 1,000 TPD facility generating 20% ash on a dry weight basis, about 16,000 gallons per day will be lost with the ash.

If the pretreatment filter backwash water and the demineralizer-neutralized regenerate are not used for quench water or other internal use, they are normally discharged to the sewer. Site drainage and sanitary wastewater are normally not a problem and are handled in the normal manner. However, facilities can be designed to minimize the wastewater discharged.

The SEMASS facility was designed for zero wastewater discharge in order to protect the surrounding environmentally-sensistive cranberry bogs (522). All of the industrial wastewater is consumed by the plant. Only treated sanitary sewage is discharged to a on-site disposal system. Use of an air cooled turbine exhaust steam condenser in place of a cooling tower significantly reduced the wastewater volume and allowed the "zero discharge" concept to work. The primary water consumer in the facility is the spray dryer absorber which uses recycled wastewater as dilution water for the lime slurry. The first year of operation showed that attaining zero discharge was easier than was anticipated due to lower wastewater generation than predicted, and higher water consumption by the spray dryer. Wastewater generation was 35,000 gpd, while water consumption was 126,000 gpd.

B.5.4 Ash Residue

The ash residue from an RDF facility is determined by the degree of processing, and is typically 8 to 20% by dry weight of the infeed. The more highly processed the fuel is, the less ash will be produced, since more non-combustibles will have been removed from the fuel. During the first year of operation, the total weight of ash produced by the SEMASS facility was 19.4% of the incoming waste (522).

Appendix A, Section A.5.3, Ash Residue, contains a description of the ash disposal options currently available and being considered for muncipal waste combustors.

B.6 RDF CONSIDERATIONS

The failures of the early RDF facilities led to the general opinion that RDF systems did not work. This did not mean, however, that they could not work. Some were simply not designed to achieve customer specifications and thus abandoned; others, after being made to work, were not economically competitive with alternative landfilling and were subsequently closed. Early estimates of RDF system costs and reliability were often optimistic and thus results were far worse than expectations.

While the performance record for RDF technology has been spotty and its state of the art viewed as somewhat risky, many communities continued to believe in its potential to be more efficient and more compatible with materials recovery. In fact, a preference for RDF is probably more driven by residue disposal costs, the public demand for recycling, and new air emission regulations rather than any inherently higher combustion efficiency or cost savings for RDF.

Within the last few years, RDF systems have been demonstrated to work reliably without excessive downtime. RDF systems now work at high capacity with high availability of materials handling and processing systems.

Another phenomenon of RDF development in the 1990s is the fact that the differences between RDF and mass burn are blurring. Now that mass burn operators are installing front-end processing and materials recovery systems to enhance recycling and reduce ash, the differences between the two technologies are becoming less distinctive and the less robust and smaller furnaces for RDF may now begin to offer a comparative advantage.

Commercial experience with RDF production/combustion technologies suggest the following:

- Preprocessing of MSW for resource recovery has a positive impact on boiler efficiency, ash generation, and air emissions (23, 67, 271, 484).
- Secondary processing of primary processing line materials can recover combustibles and reduce landfill disposal requirements (67, 524).
- In addition to technological and operating improvements, process line redundancy can prevent downtime (67, 522).
- Explosion risks in processing operations are manageable through improved process and procedural modifications (255).

- o Attributable to the availability of floor space and processing equipment, RDF technologies provide the flexibility and opportunity to integrate more intensive material recovery (67, 387, 402, 477).

- o Early problems of boiler corrosion and erosion have been corrected by ceramic coatings on linings (402, 524), improved fuel-air mixing techniques (67), and lower furnace temperatures (67).

Limited success has been achieved cofiring RDF in suspension boilers, substituting up to 10 percent by weight of a primary pulverized coal fuel. Commercial operation depends on considerable commitment and flexibility by the fuel use and its equipment (21, 138, 255, 276, 474, 484, 501, 590). Typical modifications that are essential include installation of dump grates, overfire air systems, RDF handling systems, and special ash handling equipment (402, 590).

Commercial experience with RDF production, combustion, and energy recovery has identified several application problems which may be either inherent or developmental limitations of the technology:

- o Despite the degree or means of processing, RDF still is a heterogeneous fuel that varies with respect to ash content (i.e., quantity of inert materials), moisture, and chemical composition, requiring considerable quality control of fuel preparation to manage.

- o The irregular nature of MSW presents a challenge to reliable, cost effective, and safe materials handling. Consequently, RDF plants can offer more operating problems than mass bum facilities (402).

- o Excessive moisture in RDF causes handling and boiler feed problems, reduces boiler efficiency, and adversely affects the efficiency of control devices (due to higher flue gas levels required to optimize combustion) (67).

- o With regard to RDF cofiring with conventional fossil fuels, variability in the RDF, even at fine grades, typically reduces boiler efficiency as well as electrostatic precipitator efficiency, and requires considerable process and equipment modifications (21, 58, 253, 274, 402, 416, 590). Thus, RDF cofiring may not be attractive to a utility because it introduces unknown elements into a heretofore well-understood operation (271).

- o High levels of inert materials increase the incidence of slagging, clinkering, fouling, and over-taxing of ash handling systems (67, 255, 484). This is particularly important in cofiring applications (58, 590). Better separation by additional trommeling, upgraded air classification, and steadier feed rates may improve this condition (67). High inert levels increase processing equipment wear, adversely affecting machine reliability and maintenance costs.

Technology trends as indicated by the literature reviewed include:

- o Simplicity and durability in processing design (21).

- o Processing design incorporating the following features (21, 129, 524).

- Initial rough sizing to reduce downstream abrasive wear
- Preliminary and intermediate particle size classification to eliminate oversized items (larger fractions recirculated)
- Two-stage trommeling
- Secondary shredding of larger fraction(s)
- Intermediate recirculation of larger fractions to capture more fuel content
- Magnetic separation of ferrous metals
- Microprocessor-controlled fuel metering to boiler

o Greater use of dedicated combustion units (21)

The appeal of RDF systems as an alternative to mass bum may be based on (21, 67, 253, 477):

o The promise of cofiring with fossil fuels in existing boilers (modified accordingly)

o Inherent compatibility with materials recovery

o Reduction of ash quantities

o The promise of favorable air emission performance

o Public and political acceptance relative to MWC options

REFERENCES

021 Russell, S. H., "Solid Waste Preprocessing: The Return of an Alternative to Mass Burn," Proceedings of ASME National Waste Processing Conference, Philadelphia, PA, May 1988, pp. 73-76.

023 Sommer, E.J. Jr., G.R. Kenny et al, "Mass Burn Incineration with a Presorted MSW Fuel," J. Air & Waste Management Assoc. vol. 39, no. 4, April 1989, pp. 511-516.

024 Sommerlad, R.E., W.R. Seeker et al, "Environmental Characterization of Refuse Derived Fuel Incinerator Technology," Proceedings of ASME Waste Processing Conference, Philadelphia, PA, May 1988, pp. 302-314.

028 Brna, T.G.and J.D. Kilgroe, "The Impact of Particulate Emissions Control on the Control of Other MWC Air Emissions," J. Air & Waste Management Association, September 1990, pp. 1324-1330.

056 Mayberry, J.L., "Energy from Municipal Solid Waste: Status of Mechanical Equipment," Energy from Municipal Waste: State-of-the-Art and Emerging Technologies -- Workshop Proceedings. Chicago, IL, Nov 1983. Argonne National Lab ANL/CNSV-TM-137, February 1984.

057 Hasselriis, F., "Firing Refuse-Derived Fuel," Energy from Municipal Waste: State-of-the-Art and Emerging Technologies -- Workshop Proceedings. Chicago, IL, Nov 1983. Argonne National Lab ANL/CNSV-TM-137, February 1984.

058 Fiscus, D.E., R.D. Petersen et al, "Results of RDF Cofiring by the Electric Utility Industry," Energy from Municipal Waste: State-of-the-Art and Emerging Technologies -- Workshop Proceedings. Chicago, IL, Nov 1983. Argonne National Lab ANL/CNSV-TM-137, February 1984.

059 Savage, G.M., "Modeling Techniques for Characterizing the Performance of Waste Conversion Facilities," Energy from Municipal Waste: State-of-the-Art and Emerging Technologies -- Workshop Proceedings. Chicago, IL, Nov 1983. Argonne National Lab ANL/CNSV-TM-137, February 1984.

067 Hasselriis, F., Thermal Systems for Conversion of Municipal Solid Waste, Vol 4. Burning Refuse-Derived Fuels in Boilers: A Technology Status Report, Argonne National Lab ANL/CNSV-TM-120 vol 4, March 1983.

091 Savage, G.M. and L.F. Diaz, "Key Issues Concerning Waste Processing Design," Proceedings of ASME National Waste Processing Conference, Denver, CO, June 1986, pp. 361-373.

093 Nollet, A.R., D.S. Hedlund and F. Hasselriis, "Test of Rotary Drum Air-Classifier at Albany, NY Solid Waste Energy Recovery System," Proceedings of ASME National Waste Processing Conference, Denver, CO, June 1986, pp. 383-400.

104 Massoudi, M.S., "Feasibility of 100% RDF Firing for Power Generation," Proceedings of ASME National Waste Processing Conference, Orlando, FL, June 1984, pp. 111-118.

129 Gibbs, D.R. and L.A. Kreidler, "From Hamilton to Palm Beach: the Evolution of Dedicated RDF Plants," Processed Fuels & Materials Recovery from MSW Symposium, sponsored by Resource Recovery Report and GBB,Inc. Washington, DC, December 1985.

138 Norton, G.A. and A.D. Levine, "Cocombustion of Refuse-Derived Fuel and Coal," Environmental Science & Technology, 1989, pp. 774-783.

195 Nollet, A.R., "Designing Shredding Plants That Don't Go Up in Smoke," World Wastes, June 1989, pp. 50-51.

196 Nollet, A.R., "How to Prevent Shredding Plant Explosions," World Wastes, July 1989, pp. 56-60.

253 Bretz, E., "Energy from Wastes," Power, March 1989, pp. W1-W26.

255 Reason, J., "Next Step for Waste-to-Energy: Better Availability, Efficiency," Power, July 1986, pp. 17-24.

267 Mallan, G.E., "History and Description of SEMASS Waste-to-Energy Project," Proceedings of APCA Conference: Thermal Treatment of Municipal, Industrial and Hospital Wastes. Pittsburgh, PA, November 1987.

271 Robinson, W.D., ed., The Solid Waste Handbook, A Practical Guide, John Wiley & Sons, Inc., 1986.

272 Popp, P.O., N.L. Hecht and R.E. Melberth, Decision-Making in Local Government: The Resource Recovery Alternative, Technomic Publishing Co., Lancaster, PA, 1985.

274 Rogoff, M.J., How to Implement Waste-to-Energy Projects, Noyes Publications, Park Ridge, NJ, 1987.

276 Alvarez, R.J., "Current Status of Energy Generation from Thermal Processing of Municipal Solid Waste in the U.S.," Proceedings: Energy Recovery Through Waste Combustion. Elsevier Science, 1988.

348 Gershman, Brickner & Bratton, Inc., Small-Scale Municipal Solid Waste Energy Recovery Systems, Van Nostrand Reinhold, 1986.

349 Tchobanoglous, G., H. Theisen and R. Eliassen, Solid Wastes, Engineering Principles and Management Issues. McGraw-Hill, Inc., 1977.

354 U.S. Environmental Protection Agency, Municipal Waste Combustion Study: Emission Data Base for Municipal Waste Combustors. EPA/530-SW-87-021b, June 1987.

387 Berenyi, E. and R. Gould, 1991 Resource Recovery Yearbook, Directory & Guide, Governmental Advisory Associates, Inc., New York, NY, 1991.

402 Barrett, R.E. et al, Municipal Waste-to-Energy Technology Status, Battelle Memorial Institute Report, August 1989.

416 McGowin,C.R., "Impact of RDF Cofiring on Power Plant Operation and Economics," Energy from Biomass and Wastes XII, D.L. Klass, ed., Institute of Gas Technology, Chicago, IL, 1989, pp. 567-590.

470 AENCO, Inc., Evaluation of Rotary Drum Air-Classification of Shredded and Unshredded Municipal Solid Waste. Report prepared for New York State Energy Research and Development Authority, NYSERDA Rpt 87-4, January 1987.

471 Rood, M.J., Technological and Economic Evaluation of Municipal Solid Waste Incineration, Commissioned by OTT, U. of Illinois Center for Solid Waste Management and Research, Chicago, IL, September 1988.

472 Hegberg, B.A., W.H. Hallenbeck and G.R. Brenniman, Municipal Solid Waste Incineration with Energy Recovery, OTT, U. of Illinois Center for Solid Waste Management and Research, Chicago, IL, March 1990.

474 Hoguet, R.L., "Financing a Waste to Energy Project: Key Contract and Tax Issues," Energy from Biomass and Waste X. D.L. Klass, ed, Institute of Gas Technology, Chicago, IL, 1987.

477 Ohlsson, O.O., "Refuse Derived Fuels: New Technologies for Successful Operations," Workshop - Energy from Municipal Waste: Resource Recovery for Small Communities, Panama City, FL, Argonne National Laboratory, February 1988.

484 Richards, D. et al, Waste-to-Energy Commercial Facilities Profiles: Technical, Operational and Economic Perspectives, Noyes Data Corp., 1990.

501 SYSTECH Corp., RDF Co-Firing Cost/Benefit Analysis Using the NCEL RDF Cost Model, Vol III - RDF Cost Model Manual, sponsored by Naval Facilities Engineering Command, August 1986.

522 Turner, M.C., G.C. Wilson and D.F. Robinson, "First Year of Operation at the SEMASS WTE Facility," Proceedings of ASME National Waste Processing Conference, Long Beach, CA, June 1990, pp. 1-7.

523 Blakley, R.D., "Fireside Tube Corrosion in an Industrial RDF-Fired Boiler - Kodak's Experience," Proceedings, ASME National Waste Processing Conference, Long Beach, CA, June 1990, pp. 9-19.

524 Boley, G.L., "Startup and Operations of the Mid-Connecticut Resource Recovery Project," Proceedings of ASME National Waste Processing Conference, Long Beach, CA, June 1990, pp. 21-29.

590 Energy and Environmental Research Corp., Refuse-Derived Fuel Co-Firing Technology Assessment, prepared for U.S. EPA, September 1988.

621 Garing, C., "Six Years Experience in Producing RDF and Cofiring RDF in a Pulverized Coal Boiler," Proceedings: 1989 Conference on Municipal Solid Waste as a Utility Fuel, EPRI GS-6994, February 1991.

622 Jacobus, P.L., "Cofiring RDF with Pulverized Coal: Ten Years' Experience in Madison," Proceedings: 1989 Conference on Municipal Solid Waste as a Utility Fuel, EPRI GS-6994, February 1991.

624 McGowin, C.R., "Guidelines for Cofiring Refuse-Derived Fuel in Electric Utility Boilers," Proceedings: 1989 Conference on Municipal Solid Waste as a Utility Fuel, EPRI GS-6994, February 1991.

629 Boley, G.L., "Combustion Engineering's Experience in Co-Firing RDF and Coal in Dedicated Combustors," Proceedings: 1989 Conference on Municipal Solid Waste as a Utility Fuel, EPRI GS-6994, February 1991.

716 Will County, IL, Will County Solid Waste Management Plan, Vol V - Waste to Energy Feasibility Study, January 1991.

753 The BioCycle Guide to In-Vessel Composting, 1986.

756 Glaub, J.C., L.F. Diaz, and G.M. Savage, "Preparing MSW for Composting," The BioCycle Guide to Composting Municipal Wastes, The JG Press, Inc., 1989.

799 HDR Engineering, Inc., Lake County (IL) Solid Waste Management Plan, Vol III, Appendices A1 - A5, prepared for Lake County Joint Action Solid Waste Planning Agency, April 1989.

805 Fiscus, D. E. et al, Guidelines for Cofiring Refuse-Derived Fuel in Electric Utility Boilers, Volume 1: Executive Summary, Electric Power Research Institute, Palo Alto, CA, June 1988.

806 Fiscus, D. E. et al, Guidelines for Cofiring Refuse-Derived Fuel in Electric Utility Boilers, Volume 2: Engineering Evaluation Guidelines, Electric Power Research Institute, Palo Alto, CA, June 1988.

807 Fiscus, D. E. et al, Guidelines for Cofiring Refuse-Derived Fuel in Electric Utility Boilers, Volume 3: Appendixes, Electric Power Research Institute, Palo Alto, CA, June 1988.

861 Alter, H. and J. Dunn, "Solid Waste Conversion to Energy, Current European and U.S. Practice," Pollution Engineering and Technology/11, Marcel Dekker, New York, NY, 1980.

862 Elliott, T.C. and Editors of Power Magazine, Standard Handbook of Powerplant Engineering, McGraw-Hill, Inc., 1989.

863 Singer, J.G. ed, Combustion Fossil Power, Fourth Edition, published by Combustion Engineering, Inc., Windsor, CT, 1991.

864 Babcock & Wilcox Company, Steam, Its Generation and Use, 39th Edition, The Babcock & Wilcox Company, 1978.

865 Spendlove, Max J., Reclamation, Utilization, Disposal, and Stabilization, U.S. Bureau of Mines Information Circular 8750, 1977.

868 Moats, D.F., J. Mathews and K.C. O'Brien, A Performance Update for the Columbus Project, Proceedings of the ASME National Waste Processing Conference, Philadelphia, PA, May 1988, pp. 181-189.

870 Hill, R.H., "Three Types of Low Speed Shredder Design," Proceedings of the ASME National Waste Processing Conference, Denver, CO, June 1986, p. 265.

871 wTe Corporation, Shear Shredder Demonstration, Final Report for New York State Energy Research and Development Authority 87-34, Vols I and II, May 1987.

873 Steverson, E.M, T.T. Semler and J.A. Goldsberry, "An Evaluation of Densification Technologies," EG&G Idaho, Inc. Informal Report EGG-EA-6775, prepared for U.S. DOE under DOE Contract No. DE-AC07-76ID01570, June 1985.

874 Raytheon Service Company, "d-RDF Feasibility Study," Draft Final Report to the New York State Energy Research and Development Authority, 1985.

875 "Producing and Burning d-RDF," Technology Review, January 1981.

876 Barton, J.R., "Byker Plant Operation: Test Report No. 2, December 1984," Warren Spring Laboratory, UK, February 1985.

877 Barton, J.R., "Developments in Centralised Treatment Plant for Materials and Energy Recovery," paper presented at IWM Symposium on Progress in Research and Developments into Re-use and Recycling of Wastes, London, November 1987.

878 Barton, J.R. and A.J. Poll, "Doncaster Plant Operation: Test Report No. 2, October 1985," Warren Spring Laboratory, U.K., November 1985.

880 Dougherty, K.E., "Determining Acid Gases, Trace Metals and Organics From Cofiring dRDF/Coal Blends," U.S. DOE Project Reports, 1988.

881 Muehlberg, P.E., "Assessment of Economic Viability of the d-RDF System Concept," Dow Chemical U.S.A. Draft Report, prepared for the U.S. EPA Under Contract No. 68-03-2568, 1988.

883 Stanczyk, M.H. and R.S. DeCesare, Resource Recovery from Municipal Solid Waste, U.S. Dept. of Interior, Bureau of Mines Bulletin 683, 1985, 31 pp.

884 Gorman, P.G. et al, St. Louis Demonstration Final Report: Power Plant Equipment, Facilities, and Environmental Evaluations, U.S. Environmental Protection Agency Report EPA-600/2-77-155b, December 1977.

885 Campbell, J. and M. Renard, Preparation and Properties of Densified Refuse-Derived Fuels, National Center for Resource Recovery Draft Final Report to U.S. Environmental Protection Agency, Grant No. 804150, 1981.

886 Personal Communication With M. Bruner, Solid Waste Authority of Palm Beach, 24 October 1991.

887 Kiser, J.V., "...The Rest of the Story is Good!," Waste Age, November 1989, 5 p.

888 Savage, G.M., J.C. Glaub and L.F. Diaz, "Models of Unit Operations Used for Solid-Waste Processing," Argonne National Laboratory ANL/CNSV-TM-152.

890 Kilgroe, J. D., T. G. Brna, A. Finkelstein, and R. Klicius, "Control of PCDD/PCDF Emissions from Refuse-Derived Fuel Combustors," Chemisphere, Volume 20, Nos. 10-12, 1990, pp. 1809-1815.

891 Kilgroe, J. D., and A. Finkelstein, "Combustion Characterization of RDF Incinerator Technology: A Joint Environment Canada - U. S. EPA Project," First International Municipal Waste Combustion Conference, Hollywood, FL, 1989.

892 Brna, T. G., J. D. Kilgroe, and A. Finkelstein, "The Joint EC/EPA Mid-Connecticut Test Program: A Summary," Second International Municipal Waste Combustion Conference, Tampa, FL, 1991.

893 Personal Communication With Dr. Marc Bruner, Director Of Environmental Programs, West Palm Beach Authority, Fl, 24 October 1991.

894 Massachusetts Industrial Finance Agency, Preliminary Official Statement for Resource Recovery Revenue Bonds (SEMASS Project), 9 August 1991.

895 Connecticut Resources Recovery Authority, Official Statement Supplement for Mid-Connecticut System Bonds, 20 December 1985.

896 Boley, G.L., Startup and Operations of the Mid-Connecticut Resource Recovery Project, Supplement - Discussions, Proceedings of the ASME National Waste Processing Conference, Long Beach, CA, June 1990.

Document Control Page	1. NREL Report No.	2. NTIS Accession No.	3. Recipient's Accession No.
	NREL/TP-431-4988D	DE92016433	

4. Title and Subtitle

Data Summary of Municipal Solid Waste Management Alternatives. Volume IV: Appendix B—RDF Technologies

5. Publication Date
October 1992

6.

7. Author(s)
SRI International

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

SRI International
333 Ravenswood Ave.
Menlo Park, CA 94025-3493

10. Project/Task/Work Unit No.
WM21.1010

11. Contract (C) or Grant (G) No.

(C) RF-1-11003

(G)

12. Sponsoring Organization Name and Address

National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401

13. Type of Report & Period Covered
Subcontract Report

14.

15. Supplementary Notes
NREL Technical Monitor: Bimleshwar Gupta and Philip Shepherd (303) 231-1760

16. Abstract (Limit: 200 words)

The overall objective of the study in this report was to gather data on waste management technologies to allow comparison of various alternatives for managing municipal solid waste (MSW). The specific objectives of the study were to:

1. Compile detailed data for existing waste management technologies on costs, environmental releases, energy requirements and production, and coproducts such as recycled materials and compost.
2. Identify missing information necessary to make energy, economic, and environmental comparisons of various MSW management technologies, and define needed research that could enhance the usefulness of the technology.
3. Develop a data base that can be used to identify the technology that best meets specific criteria defined by a user of the data base.

Volume I contains the report text. Volume II contains supporting exhibits. Volumes III through X are appendices, each addressing a specific MSW management technology. Volumes XI and XII contain project bibliographies.

17. Document Analysis

a. Descriptors
municipal waste; waste to energy; resource recovery; recycling

b. Identifiers/Open-Ended Terms

c. UC Categories
249

18. Availability Statement
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

19. No. of Pages
145

20. Price
A07

Form No. 0069E (6-30-87)