RESOURCE RECOVERY TECHNOLOGY APPLICATION DOCUMENT

June 1982

An Investigation Conducted by
SCS ENGINEERS
4014 Long Beach Boulevard
Long Beach, California

N68305-80-C-0055

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*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 288, Units of Weights and Measures, Price $2.25, BD Catalog No. C13:10:286.
This document is intended to provide guidance to Naval shore facilities in planning and selecting solid waste management and resource recovery technology. The document consists of a state-of-the-art review of technology available for materials and energy recovery based on information and data from latest published research and documented practical experience.
The technologies presented include both Navy scale (40 TPD) and municipal scale (up to 2,000 TPD) systems. The document is arranged to provide a large amount of data in a concise format and, therefore, makes liberal use of tables and charts. Systems are grouped into three categories: material recovery systems, fuel recovery systems, and combustion systems. The unit operation making up systems in each of these areas are fully described in the appendixes to the document. The document is presented in loose leaf format to allow updating as new information is developed.
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vii
herein include both Navy-scale systems (10 to 40 tons per day) and municipal-scale systems (up to 2,000 tons per day) with which Navy facilities may become involved as part of a regional project.

Subsequent updates of the document will include the findings of other aspects of this overall Navy RDT&E effort. One such ongoing aspect is a legal/regulatory trend assessment. Another aspect is an assessment of future changes in Navy activities which may impact the generation (types and quantity) of solid waste. This assessment is being supplemented by waste characterization programs, a review of current Navy solid waste management practices, and the development of an energy consumption data base. When combined, the results of these program elements will permit the identification of the most appropriate technologies for Navy application. Cost and reliability data will also be obtained through special test and evaluation operating facilities and at the Navy's solid waste T&E site at NAS, Jacksonville, Florida.

Following the acquisition of needed supportive data from the larger RDT&E program, a section summarizing recommended energy and material recovery concepts will be added to this document. The recommendations will be based on systems that have been demonstrated to be both the most technically feasible and economically viable at a scale suitable for implementation at Navy shore facilities.

USE OF THIS DOCUMENT

The Resource Recovery Technology application document is designed to serve as a central source of information on generic resource recovery systems and unit operations.

This document is arranged to provide a large quantity of data in a format which enables the user to readily access the information. For this reason each system description is limited to four or less pages, making liberal use of graphs and tables where appropriate. The systems are grouped into three general categories: Material Recovery Systems, Fuel Recovery Systems, and Combustion Systems.

Material Recovery Systems (Section II) comprise those technologies where a specific component of the waste (i.e., ferrous metals, aluminum) is separated and prepared for market. Composting systems are also included as a process which produces a saleable commodity rather than a fuel or energy product. Most mechanical recovery systems for a single material cannot be justified alone, but instead depend on another system, such as refuse-derived fuel production, to prepare the material for the recovery stage. The material recovery systems described in Section II are therefore best defined as a combination of (1) the unit operation suitable for recovering a specific material, and (2) a fuel recovery or combustion system which is compatible with that unit operation. For example, a ferrous recovery system consists of a magnet integrated into a fuel recovery processing line.
SECTION I
INTRODUCTION

PURPOSE

This document is intended to assist Engineering Field Division (EFD) and Public Works (PW) personnel at Naval facilities with solid waste management programs, specifically those program elements pertaining to materials and energy recovery from solid waste. The information contained herein reflects the present state-of-the-art in solid waste resource recovery technology.

This document constitutes part of a larger Navy program to identify and develop solid waste management systems for future use. The results of the program will allow the Navy to comply with changing environmental regulations and policies, in both a cost-effective and energy-efficient manner. Most of the program effort is being devoted to field assessments of the more promising technologies, the results of which will be incorporated in subsequent updates of this document.

BACKGROUND AND SCOPE

The recovery of energy and materials from solid waste has been of interest to the Navy for many years. Numerous research programs have been conducted to develop and/or evaluate certain technologies, and most Navy facilities have formally assessed the feasibility of on-site energy recovery at some time in the last 15 years. Several facilities have implemented energy and materials recovery systems as a result.

For those facilities which chose not to implement such a program, recent dramatic changes in both environmental regulations and energy costs have renewed interest in resource recovery. The number of commercially available technologies has increased concurrently. Those EFD and PW personnel tasked with updating their original feasibility assessments are confronted with a more complicated and more important task than in years past. Current information on the technology, cost, and environmental impact of resource recovery is essential to a proper feasibility assessment.

To this end, the Naval Civil Engineering Laboratory (NCEL) Environmental Protection Division, Port Hueneme, California, contracted with SCS Engineers, Long Beach, California, in September, 1980, to prepare this document.

Its contents reflect the current state-of-the-art in materials and energy recovery, and are based on information and data from the latest published research and documented practical experience. The technologies reviewed
Each material recovery system description concentrates on market specifications and demand, leaving the processing support systems to other chapters. Information provided for each material recovery system typically includes the following items:

- Sources of the material.
- Industrial users.
- Use specifications.
- Historical demand.
- Factors influencing demand/price.
- Costs.
- Factors favoring centralized recovery.
- Alternative approaches to recovery, including supporting unit operations.
- Complementary systems and their impact.

The actual recovery unit operations are fully described in the "Materials Handling Equipment" (MH) appendix.

Fuel Recovery Systems (Section III) are defined as those systems producing a solid, liquid, and/or gaseous fuel as their principal output. Systems falling under this heading are generally the most complex, and usually involved three or more processing and handling stages. Because the product characteristics vary substantially within and between systems, the descriptions concentrate more on the technology options than on product characteristics/market specifications.

Each fuel recovery system description includes the following information:

- Fuel markets/uses.
- System applications.
- System characteristics.
- Demand considerations.
- Recovery alternatives.
- Applicable technology and unit operations (reference to appendices).
- Costs.
- Selected implementation and operating considerations.
- Complimentary systems and their impact.

Much of this information is not available for fuel recovery systems with limited operating experience. Systems falling into the latter category instead include a statement regarding their current stage of development.
Combustion Systems, Section IV includes all technologies where the resultant product is an energy product intended for immediate use. All systems reviewed produce one or more of the following energy products:

- Hot water.
- Steam.
- Hot gas.
- Electricity.

Specifications for each product and the method, equipment, and procedures necessary to produce each product are given for each combustion technology.

The typical combustion system description contains both detailed product market and technology information, as contrasted with the necessarily singular focus of the material recovery (product-oriented) and fuel recovery (technology-oriented) sections. Information presented for each combustion system includes the following:

- Product markets (characteristics and use specifications).
- Applicable technology.
- System costs.
- System efficiency.
- Complimentary systems and their impact.

Institutional considerations EFD and PW personnel are likely to encounter when planning or evaluating recovery systems are given in Section V, Institutional Considerations.

Specific considerations are briefly addressed, including:

- Planning and scheduling.
- Energy and materials markets.
- Project financing.
- Risk analysis and procurement.
- Use of outside assistance.

Additional references are provided for a more thorough discussion of each subject.

Generic unit operations summaries for most major system components appear as appendices. Information provided for each unit operation includes the following, where available:

- Types available.
- Types used commercially.
- Physical characteristics.
- General description.
- Principle of operation.
- Materials of construction.
- Advantages over other types.
- Sizing criteria.
- Accessory components.
- Support requirements (i.e., personnel training).
- Operational considerations (i.e., maintenance, controls).
• Safety and environmental considerations.
• Cost analysis.
• State-of-the-art evaluation.
• History.
• Successes.
• Failures.
• Key Problems.

Data were not available to determine all of the above information for each unit operation. Where the published information was insufficient or not available, the words "no data available" are inserted.

The equipment is divided into three general categories: Materials Handling Equipment, Air Pollution Control Equipment, and Combustion Equipment.

Items classified under materials handling include, size reduction unit operation, separation unit operations; as well as conveying, compacting, and storage operations.

Air pollution equipment includes all commonly used equipment associated with either combustion gas cleaning or process gas cleaning.

The combustion equipment section includes those unit operations or pieces of equipment directly associated with the actual combustion process. Included are waste-burning incinerators, as well as equipment to burn solid, liquid, and gaseous derived fuels.

Throughout Sections II, III, and IV references are made to selected appendices. The reference system employed is based on the three basic appendix divisions as described above. The three divisions and their reference code letters are: Materials Handling, code = MH; Air Pollution Control, code = APC; and Combustion Equipment, code = CE. Within each division, each separate unit operation appendix is identified by a single letter code. Thus, the Air Classifier appendix is coded as MH-I, corresponding to its position as the I item in the MH (materials handling) section. Unit operations with each appendix are grouped according to function (e.g., shredders and hammermills, vibrating and trommel screens, etc.). Page numbers are provided both for the entire report and for each unit operation appendix.

This cross reference system should enable the reader to quickly identify the unit operation and locate it within the appropriate appendix.
## MATERIALS MARKET

Forms found in or produced from solid waste

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<td>Aluminum cans (beverage), light and rigid foils such as frozen dinner trays, packaging, furniture.</td>
<td>Aluminum is approximately one percent of post consumer food waste stream. Data for Navy facilities are not available.</td>
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### Industrial Users

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<tr>
<td>Scrap dealers</td>
<td>Once scrap identified as aluminum, it is cleaned, dried, shredded, crushed, screened, separated from other scrap (magnetic) and then baled or bignetted for shipment.</td>
<td>All aluminum cans, frozen food trays, foil, lawn furniture (with webbing removed) and aluminum no greater than 1/16 in in thickness and 1 ft square.</td>
</tr>
<tr>
<td>Secondary smelters</td>
<td>Charging scrap into a reverberatory furnace, sampling molten metal to determine its composition, introducing any necessary additional compounds and aluminum to bring the melt to specification</td>
<td>Same as above.</td>
</tr>
<tr>
<td>Non-integrated foundries and fabrications</td>
<td>Die casting; permanent mold casting, and sand casting</td>
<td>Same as above.</td>
</tr>
<tr>
<td>Primary producers</td>
<td>Recycled into can stock</td>
<td>Same as above.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Form</th>
<th>End Use</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density - is not specified and shall be agreed upon between the purchaser and the seller.</td>
<td>Secondary aluminum smelters, Primary aluminum producers, Aluminum scrap dealers, Iron and Steel Industry Foundries, Non-integrated aluminum producers, Independent aluminum fabricators</td>
<td>ASTM E753-80</td>
</tr>
<tr>
<td>Fines - Shall contain not more than the amount of miners 12 Mesh (U.S. Standard Sieve) material, described in following action:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class A material shall contain not more than 1% by weight of fines.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class B material shall contain not more than 3% by weight of fines.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SECTION II
MATERIAL RECOVERY SYSTEMS

The general category of material recovery includes those systems which separate any saleable component from solid waste, other than a fuel or energy product. Material recovery (MR) systems range from simple source separation programs to elaborate processing systems that mechanically separate several materials from mixed solid waste. In actual practice, economical large volume material recovery occurs where a recovery component is included as part of a full recovery system, and takes advantage of the processing system already in place.

Materials for which commercial recovery is most often considered include the following (codes for subsections in this report are shown in parentheses):

- Aluminum (AL).
- Compost (CM).
- Ferrous Metal (FE).
- Glass (GL).
- Paper (PA).
- Plastics (PL).

Separate subsections for recovery of each material are presented on the following pages. The information is organized under the following headings:

- Material Markets: high concentration sources, industrial users, demand and related considerations, and standard specifications (where available).
- Alternative approaches to recovery.
- Applicable Technology: basic system(s), unit operations, and system characteristics.
- Complimentary systems and their impact.

The actual format of each material recovery subsection varies due to differences between materials and the nature of recovery. References are also made to the appendices, where the recovery equipment/unit operations are presented as a detailed supplement to the general system description.
Factors Favoring Centralized Recovery

- Effective mechanical/electromagnetic separation in concert with front-end processing is many times more efficient than manual separation.
- Market specifications can be met by state-of-the-art separation equipment.

Factors Favoring Source Separation

- Cleaner product.
- Lower capital investment.
- Flexible in case of container legislation or other interruption of flow.

Alternative Approaches

<table>
<thead>
<tr>
<th>System</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separate vehicle for collection</td>
<td>Residents/workers separate metals from waste stream prior to placing waste in collection containers. A vehicle allocated expressly for collection of sorted metals then collects the metal. (Typical vehicles - pick-up truck, trailer, refuse collection vehicle which is no longer in use, other vehicles.)</td>
</tr>
<tr>
<td>Refuse vehicle collection</td>
<td>Separated metals are collected in a separate compartment of the normal refuse collection vehicle.</td>
</tr>
<tr>
<td>Materials recovery facility</td>
<td>Solid waste is shredded and classified. Process heavyes are separated from ferrous, and aluminum is uncovered using eddy current separator.</td>
</tr>
</tbody>
</table>

APPLICABLE TECHNOLOGY

![Diagram of waste processing flowchart]

Unit Operations

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Commonly Used Equipment</th>
<th>Reference No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gross sorting of materials, removal of hazardous, bulky, or oversized items</td>
<td>Handsorting, front-end loader</td>
<td>Not included</td>
</tr>
<tr>
<td>2</td>
<td>Size reduction of refuse to more uniform pieces, liberate composite materials</td>
<td>Hammermills, shredders</td>
<td>MH-E, MH-F</td>
</tr>
</tbody>
</table>
MATERIALS RECOVERY

Aluminum (MR-AL)

Loose Combustibles - Shall contain not more than 2.0% by weight of loose combustible material.

Moisture - Shall contain not more than 0.5% by weight of moisture.

Metal Recovery - A minimum metal recovery of 85% is required.

Magnetics - Presence of free magnetic material is not specified and shall be as agreed upon between the purchaser and seller as part of the purchase contract.

Historical Demand

Factors Which Influence Price

- Relatively high transportation costs from point of origin to point of use.
- Contamination of aluminum scrap with trace elements such as lead, tin, iron, etc.
- Scrap inventory levels.
- Cost and availability of raw materials.

Comments on Future Market Demand

Demand for aluminum scrap is expected to continue increasing similar to that experienced to date. Further development and refinement of aluminum separators should increase the efficiency of aluminum recovery from raw solid waste which will increase the total quantity of aluminum scrap recovered.

At present there are no municipal central recovery operations obtaining aluminum through mechanical separation. Hand sorting or source separation programs are prevalent throughout the United States. The technology for mechanical separation of the aluminum fraction has not been proved successful in full-scale operation.
<table>
<thead>
<tr>
<th>MATERIALS RECOVERY</th>
<th>Aluminum</th>
<th>MR-AL</th>
<th>P. 4 of 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Separate refuse into two concentrate streams</td>
<td>Air classifier, trommel screens</td>
<td>MH-I, MH-D</td>
</tr>
<tr>
<td>4</td>
<td>Separate ferrous metals from refuse stream</td>
<td>Magnetic drum separator, belt magnet separator (overhead)</td>
<td>MH-J, MH-K</td>
</tr>
<tr>
<td>5</td>
<td>Separate aluminum from air classifier heavies</td>
<td>Dense media separator, Eddy current separator</td>
<td>MH-L, MH-M</td>
</tr>
</tbody>
</table>

**System Characteristics**
- Requires iron-free feed from air classifier.
- Eddy current separator most common unit in use for aluminum.

**COMPLIMENTARY SYSTEMS AND THEIR IMPACT**
- Source separation and aluminum separation technology are not compatible.
- Air knife or additional classification step can help clean aluminum fraction.
- Trommel screen will provide system with whole-can feed, which can be separated efficiently by eddy current device.
MATERIAL RECOVERY
Composting
MR-CM
P. 1 of 3

MATERIAL MARKETS/USES

The primary use of composted solid waste has been its application to land as a soil amendment to increase crop production; limit erosion rates or other improvements in soil characteristics. Other uses such as animal feed, or fuel have been suggested but have not been demonstrated. Most solid waste derived composts do not contain adequate amounts of nitrogen or phosphates to be strictly classified as a fertilizer, hence the use as an amendment.

Compost is supplied loose, bagged, or it can be pelletedized for ease of transport and distribution, or slurried for ease of application.

Use Specifications

Exact specifications for compost have not been established. Experience has shown that carbon to nitrogen ratios of below 20 are preferred to ratios above 20. Other critical factors for crop use include: soluble salt levels (should be low), potassium and phosphorus levels (desired levels vary with use), and heavy metal content (particularly important if consumption crops are being produced).

Type of compost, type of soil, climate and specific use all effect the potential usage of compost.

Historical Demand

Composted refuse has been proved technically feasible for many years, particularly in Europe. The lack of successful U.S. based composting operations is primarily a result of limited markets for the compost. When the compost could not be sold and plants continued producing, large stockpiles were created. The stockpiles had to be disposed at an unanticipated cost to the operator.

There is currently no established market for composted refuse. Land reclamation or crop production acres must be identified and secured by the compost producer.

Factors which influence price:

- Proximity to market.
- Absence of competitive products.
- Governmental cooperation.
- Guaranteed product quality.
- Demonstrated success.
- Availability of land needing reclamation.

APPLICABLE TECHNOLOGY

![Diagram of composting process]
COMPLIMENTORY SYSTEMS

At least two manufacturers produce equipment which is specifically designed for windrow-type composting systems. These units are designed to be driven over a refuse pile where the machine shreds, mixes, and places the refuse back into the windrow. Subsequent passes of the unit over the composting refuse, as the composting process is ongoing, maintains the optimum aeration rates and homogeneity of the windrow. The units and their manufacturers or agents are: Cobey Composter®, Division of Eagle Crusher Co., Inc., Galion, Ohio, and SCARAB®, Resource Recovery Systems of Nebraska, Sterling, Colorado.

Capital costs for the windrowing units range between $100,000 and $185,000. Operating and maintenance costs are approximately $40 per hour of operation.

The addition of sewage sludge to refuse is a viable alternative employed in a majority of existing composting operations. The sludge can be mixed with the refuse or it can be applied as a separate layer above the refuse. Both systems have been used.

The heavy metals content of sewage sludge has been a major problem in applying sludge derived composts to crop producing soils.

Refuse/sludge codisposal through composting should be investigated if either refuse or sludge composting appears feasible alone.
MATERIAL RECOVERY

Composting

Unit Operations

<table>
<thead>
<tr>
<th>Operation</th>
<th>Function</th>
<th>Commonly Used Equipment</th>
<th>Reference No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiving</td>
<td>Collect refuse</td>
<td>Tipping floor, pit</td>
<td>Not included</td>
</tr>
<tr>
<td>Sort</td>
<td>Remove uncompostable items</td>
<td>Manual labor</td>
<td>N/A</td>
</tr>
<tr>
<td>Shred</td>
<td>Size reduction, mixing</td>
<td>Shredders</td>
<td>MH-E, MH-I, MH-L</td>
</tr>
<tr>
<td>Magnetic</td>
<td>Remove ferrous</td>
<td>Drum or belt separators</td>
<td>MH-F, MH-G</td>
</tr>
<tr>
<td>separator</td>
<td></td>
<td>Windrows, tanks, bins</td>
<td>Not included, CE-B</td>
</tr>
<tr>
<td>Composting</td>
<td>Digestion of refuse</td>
<td>Shredders</td>
<td>MH-H, MH-K</td>
</tr>
<tr>
<td>Grinding</td>
<td>Size reduction, mixing</td>
<td>Bagging machines</td>
<td>Not included</td>
</tr>
<tr>
<td>Preparation</td>
<td>Final preparation</td>
<td>dryers</td>
<td></td>
</tr>
<tr>
<td>for use</td>
<td>bagging</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

System Characteristics

Composting is the aerobic decomposition of organic materials. The processing steps illustrated above are intended to enhance the decomposition process. Composting systems can be divided into two basic types: mechanical high-rate digestion, and open-windrow methods. In high-rate digestion the decomposition is performed in specifically designed structures using controlled temperatures and air flow rates. Manufacturers have claimed composting times of as little as a few hours. The efficiency of such short time digestion is questioned. The destruction of pathogenic organisms, such as occurs in windrow-type composting, is also questioned.

Open windrow-type composting is typically accomplished by spreading the prepared refuse out on the ground in mounds or in trenches (windrows). The windrows can vary in dimensions, dependent on the equipment used, the amount of refuse to be processed, and the land area available.

Other digestion alternatives have been successfully employed. Some systems combine windrowing with forced air circulation by placing the windrows inside an environmentally controlled building. Still other systems use rotating cylinders to constantly mix the prepared refuse thus promoting more complete and rapid destruction.

Limitations

Composting has the potential to reduce the quantity of solid waste for landfilling. Existing systems have experienced a 60-70 percent volume reduction and a 20-30 percent reduction in weight.

Removal of glass, plastics, and non-ferrous metals presents problems for composting operations. No mechanical means have been developed which remove these materials with high efficiency.

Composting refuse can be malodorous if not properly managed. Flies and rodents can also become problems in a composting plant. Proper housekeeping and operation can reduce these problems.
### MATERIAL RECOVERY

#### Ferrous Metals

#### MR-FE

#### P. 1 of 4

### MATERIAL MARKETS

**Forms Found In or Produced From Military Solid Waste**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Weight Per Cent (Note 1)</th>
<th>Material Form</th>
<th>Weight Per Cent Material Form (Note 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laundry</td>
<td>3</td>
<td>Tin cans</td>
<td>61.0</td>
</tr>
<tr>
<td>Exchanges, commissaries</td>
<td>2</td>
<td>Bimetal tin cans</td>
<td>11.1</td>
</tr>
<tr>
<td>Ordinance</td>
<td>&lt;1</td>
<td>Bimetal tin-free cans</td>
<td>3.3</td>
</tr>
<tr>
<td>Offices, training</td>
<td>5</td>
<td>Bottle caps-paper with</td>
<td>3.9</td>
</tr>
<tr>
<td>Food service</td>
<td>5</td>
<td>metal ends</td>
<td></td>
</tr>
<tr>
<td>Shops, berthing piers</td>
<td>7</td>
<td>Misc. iron, other</td>
<td>20.7</td>
</tr>
<tr>
<td>Warehouses</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Housing</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: 1) Figures listed are for total metals; ferrous fraction is typically 90% of total metal portion, SCS Engineers, 1972
2) Ferrous fraction only; from DeCesare, R.S.

### Industrial Users

<table>
<thead>
<tr>
<th>Name</th>
<th>Specific Process</th>
<th>Material Form Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper Industry</td>
<td>Precipitation</td>
<td>Loose, shredded as agreed upon between purchaser and supplier. Bulk density: 30 (lb/cu-ft)</td>
</tr>
<tr>
<td>Iron and Steel Foundries</td>
<td>Continuous or ingot casting, rolling, and shaping</td>
<td>Loose, balled, or baled (industry practice is to specify a maximum bale size that may vary among users) as agreed upon between purchasers and suppliers. Bulk density: 50 (lb/cu-ft)</td>
</tr>
<tr>
<td>Iron and Steel Production</td>
<td>Furnaces - blast, open hearth basic oxygen, electric arc, cupola</td>
<td>Loose or baled as agreed upon between purchaser and supplier. Bulk density: 75 (lb/cu-ft)</td>
</tr>
<tr>
<td>Detinning Industry</td>
<td>Detinning</td>
<td>Shredded, 95 weight % shall be -6, +1/2 in. (-152, +12.5mm); shall not be baled, burned, incinerated, or pyrolyzed. Bulk density: 25 (lb/cu-ft)</td>
</tr>
<tr>
<td>Ferroalloy</td>
<td>Blast furnace</td>
<td>Loose as agreed upon between purchaser and supplier. Bulk density: 50 (lb/cu-ft)</td>
</tr>
</tbody>
</table>

### Use Specifications

<table>
<thead>
<tr>
<th>Element</th>
<th>Copper Industry (Precipitation Process)</th>
<th>Iron and Steel Foundries</th>
<th>Iron and Steel Production</th>
<th>Detinning Industry</th>
<th>Ferroalloy Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorus, max</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td></td>
<td>0.03</td>
</tr>
<tr>
<td>Sulfur, max</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
<td></td>
<td>0.04</td>
</tr>
<tr>
<td>Nickel, max</td>
<td>0.12</td>
<td>0.8</td>
<td></td>
<td></td>
<td>0.8</td>
</tr>
<tr>
<td>Chromium, max</td>
<td>0.15</td>
<td>0.10</td>
<td></td>
<td></td>
<td>0.15</td>
</tr>
</tbody>
</table>
Experience has shown that material which has been incinerated probably will not meet these requirements.

A minimum of 95 weight % of the material delivered shall be magnetic. Nonmagnetic material attached to the original magnetic article may be included in the minimum requirement.

The scrap shall be appropriately processed (for example, by burning, chemical detinning, etc.) to be virtually free of combustibles.

For steel castings, the requirement for tin content is 0.10 max %.

Not based on melt analyses due to aluminum losses during melting; to be determined by a method mutually agreed upon between the purchaser and supplier.

Refer to sections on magnetic fraction and chemical analysis of tin in Methods E 701. Normal separation of white goods and heavy iron yields tin contents equal to or greater than 0.15 weight %. Lesser tin contents would impact severely the value of the scrap to detinners.

The scrap shall be appropriately processed (for example, by burning, chemical detinning, etc.) to be virtually free of combustibles.

Source: American Society for Testing and Materials
Designation: E 702-79
Comments on future market demand

- May increase if freight rates and tax policies become more favorable for recovered metals.
- May increase if companies are willing to enter into long-term contracts for scrap.
- Ability to remove contaminants improves.
- Supply of raw materials diminishes or prices escalate rapidly.
- Furnaces technology is developed to accept larger scrap portions.
- An expanded scrap market must develop to handle expected increases in scrap from resource recovery plants.

Factors favoring centralized recovery

- Shredding metal may be more economical at a centralized facility.
- Willing market.
- Efficient for large amounts of waste.
- Source for salvage market is centralized.
- No public participation necessary.
- Handles waste from any facility.

Source separation

- Willing market.
- Flexibility in adjusting to different flows of wastes.
- Contamination levels are likely to be low.
- Shredded product would be cleaner if presorted.
- Initial capital and operating costs are low.

ALTERNATIVE APPROACHES

Source separation

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residents/workers separate metals from waste stream prior to placing waste in collection containers. A vehicle allocated expressly for collection of sorted metals then collects the metal. (Typical vehicles - pick-up truck, trailer, refuse collection vehicle which is no longer in use, other vehicles.)</td>
</tr>
</tbody>
</table>

Refuse Vehicle Collection

- Separated metals are collected in a separate compartment of the normal refuse collection vehicle.

Materials Recovery Facility

- Handles unprocessed wastes. A magnetic separator would be the key component. See applicable technology section.

**APPLICABLE TECHNOLOGY**

```
Raw refuse → Presort → Primary shredder → Magnetic separator
| Air classifier (Optional) |
↓                      ↓
| Non-ferrous metals refuse |
```

II-11
Unit Operations

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Commonly Used Equipment</th>
<th>Reference No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gross sorting of materials, removal of hazardous, bulky, or oversized items</td>
<td>Handsorting, front-end loader</td>
<td>Not included</td>
</tr>
<tr>
<td>2</td>
<td>Size reduction of refuse to more uniform pieces, liberate composite materials</td>
<td>Hammermills, shredders</td>
<td>MH-E, MH-F</td>
</tr>
<tr>
<td>3</td>
<td>Separate refuse into two concentrate streams</td>
<td>Air classifier, trommel screens</td>
<td>MH-I, MH-D</td>
</tr>
<tr>
<td>4</td>
<td>Separate ferrous metals from refuse stream</td>
<td>Magnetic drum separator, belt magnet separator (overhead)</td>
<td>MH-J, MH-K</td>
</tr>
</tbody>
</table>

System Characteristics

- Separates ferrous metals from waste stream to produce a clean marketable product.
- Magnetic drum is scalping device and will not pick up small magnetic particles beneath conveyed waste.
- Drawback to belt separators - magnetics are abrasive and result in accelerated belt wear.

Complementary Systems and Their Impact

- Additional air classifiers to remove more of the light fraction.
- Ferrous metals concentrate to clean and separate ferrous metals into two fractions - cans and other light gauge metals and castings, forgings, and rolled stock.
- Can compactor to increase density of the light ferrous metals product.
- Balers to bundle material into uniform sizes.
## MATERIAL MARKETS

Forms found or produced from Military Solid Waste Activity

<table>
<thead>
<tr>
<th>Activity</th>
<th>Material Form</th>
<th>Concentration in Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food Service, Housing</td>
<td>Bottles, Jars</td>
<td>5-10 percent by weight, including flint (clear), amber, and green glass colors.</td>
</tr>
</tbody>
</table>

### Industrial Users

<table>
<thead>
<tr>
<th>Name</th>
<th>Specific Process</th>
<th>Material Form Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass Container manufacturers (Large Volume)</td>
<td>Sort, Magnetic separation, washing, crushing, screening</td>
<td>Whole or broken glass (&quot;cullet&quot;); relatively low contamination.</td>
</tr>
<tr>
<td>Glass bottle users</td>
<td>Sort, wash</td>
<td>Whole bottles (wine, beverage).</td>
</tr>
<tr>
<td>Intermediate glass Processing (small volume)</td>
<td>Magnetic separation, color sort (manual), separate crushing</td>
<td>Whole bottles; mixed bottles and cans.</td>
</tr>
</tbody>
</table>

### Specifications

<table>
<thead>
<tr>
<th>Form</th>
<th>End Use</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole bottles or mixed material</td>
<td>Refining</td>
<td>Whole, relatively clear but mixing metal cans is acceptable.</td>
</tr>
</tbody>
</table>
| Cullet source separated, or otherwise hand sorted. | Glass container manufacture (per GCMI) | - <0.5% H₂O  
- 100% <30mm, 5% <11mm  
- <0.2% organics  
- <0.5% magnetics; <6mm  
- <1.0% inorganics; <6mm  
- 95-100% flint  
- <5% amber  
- <1% green  
- 90-100% amber  
- <10% flint  
- <10% green  
- 50-100% green  
- <35% amber  
- <15% flint  |
| Cullet (froth flotation product) | Glass container manufacture (per GCMI) | Same as sorted product, except:                                                              |
|                                |                                  | - <0.14% magnetic metals.                                                                     |
Historical Demand

Glass has commonly been recycled for many years, and the technology for reuse in commercial process is well developed. Most glass produces already use 10 to 15 percent glass cullet in their furnace feed, with some using as much as 50 percent (in-plant cullet waste).

Post-consumer glass of good quality is welcomed in the industry as an energy saving step. Most glass recycling includes an Intermediate Glass Processor (IGP), who sorts the glass and processes it for delivery to the plant. IGP's are the logical broker for a large-volume resource recovery program, as they are familiar with the quality of most post-consumer products, can except a larger volume of material, and will generally pay a higher price as the only "middleman". The glass container industry as a whole has actively promoted it's interest in post-consumer glass by developing and publicizing standard specifications (listed above).

Factors which influence price

- Energy prices
- Contamination
  - color
  - ceramics
  - metals, other inorganics.
- Transportation.
- Beverage container legislation.
- Whether sale is to recycling center, IGP, or direct to manufacturer/user.

Comments on Future Market Demand

- Glass container industry should continue to promote use of post-consumer glass.
- Several major plants are planned almost exclusively for recycled glass, and recycling bills in several states will provide the necessary capacity demand for expansion of the market.

RECOVERY ALTERNATIVES:

Recycling/Buy Back Center

- Closer control of product quality, but limited to small volume operations.

Mechanical Separator

- Both optical sorting and froth floatation are potentially less expensive per ton than manual separation. Poor reliability and product quality have been the two greatest drawbacks to date. Continued research and experience could result in more extensive commercial acceptance. Even then, the economics of mechanical glass recovery will be poor for Navy scale waste flow.

Source Separation

- Similar to buy-back centers, except curbside collection more conducive to medium scale recovery. Source separation could conceivably serve any size of facility but must include materials other than glass if system is to pay for itself.
<table>
<thead>
<tr>
<th>COMPLIMENTARY SYSTEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Common collection of cans and paper.</td>
</tr>
<tr>
<td>- Recycling center designed to accept other materials.</td>
</tr>
</tbody>
</table>
ALTERNATIVE APPROACHES

Centralized Recovery

- Buy-back center on base, which pays for clear recycled glass (whole and/or broken) on a per pound basis (based on the prevailing price/transportation costs).

Separate Collection

- Glass is collected both at residences (curbside) and at major generation point (mess, supply) in a separate truck. Glass is then brought to central storage area and dumped, either in a tipping area or into a buyer-supplied bin. It is then loaded and handed to the buyer for processing. In order to be economical, the system should; (a) include other separated materials; and (b) be justified based on an F.O.B. facility price.

- Glass is collected mixed with cans and newsprint. Material is hauled to buyer, or separated by hand at Navy facility. Separated, material is then hauled to the respective markets. On-base separation is not normally economical, and intermediate glass processors are not too common. The viability of this approach therefore depends on location.

APPLICABLE TECHNOLOGY

- For source separation, a variety of compartmentalized trucks/trailers are available.

- Buy-back/recycling center designs can vary widely, and typically consist of no more than a concrete slab and some retaining walls to serve as bins. Some buyer-supplied bins may also be used.

System Characteristics (Source Separation/Recycling)

- Labor intensive.

- Low capital cost, typically limited to construction of recycling center and purchase of truck and/or trailers.

- 20-50 percent recovery for curbside system, lower for buy-back system or volunteers recycling center.

- Strong markets throughout U.S.

- Personnel sorting or handling glass should be required to wear protective clothing identical to solid waste handlers.
### MATERIAL MARKETS

**Forms found or produced in Military Solid Waste**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Material Form</th>
<th>Concentration in Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>• Newsprint</td>
<td>5-10%</td>
</tr>
<tr>
<td></td>
<td>• Corrugated</td>
<td>0-20%</td>
</tr>
<tr>
<td></td>
<td>• White Ledger</td>
<td>0-10%</td>
</tr>
<tr>
<td></td>
<td>• Computer Printout (CPO)</td>
<td>0-50%</td>
</tr>
<tr>
<td></td>
<td>• Tab Cards</td>
<td>0-10%</td>
</tr>
</tbody>
</table>

#### Industrial Users

<table>
<thead>
<tr>
<th>Name</th>
<th>Specific Process</th>
<th>Material Form Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper Mills</td>
<td>Pulping and reprocessing</td>
<td>Newprint</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Corrugated</td>
</tr>
<tr>
<td></td>
<td></td>
<td>White Ledger</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CPO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tab Cards</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Kraft Paper (Combination of above)</td>
</tr>
<tr>
<td>Insulation Manufacturer</td>
<td>Grinding and fireproof coating</td>
<td>Newspaper</td>
</tr>
</tbody>
</table>

#### Specifications

<table>
<thead>
<tr>
<th>Form</th>
<th>End Use</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newsprint</td>
<td>Pulping</td>
<td>• Usually Baled is preferred; contamination should be &lt;10%, particularly free of coated (magazines) or long fiber papers.</td>
</tr>
<tr>
<td></td>
<td>Boxboard, Insulation</td>
<td>Unknown</td>
</tr>
<tr>
<td>White Ledger, CPO</td>
<td>Pulping</td>
<td>• Baled or stacked; any level of contamination should be avoided, as most buyers will not specify a contamination limit.</td>
</tr>
<tr>
<td>Corrugated</td>
<td>Pulping</td>
<td>• Baled.</td>
</tr>
<tr>
<td>Tab Cards</td>
<td>Pulping</td>
<td>• Boxed or Baled.</td>
</tr>
</tbody>
</table>

#### Historical Demand

Paper recovery has been practiced for many years, but only within the past decade has the market expanded to accept post-consumer paper. Prior to 1970, paper recycling concentrated on industrial scrap and other inherently pure waste streams. Since that time, the market has expanded due to: (a) increased exports; (b) increased industry acceptance of recycled paper; and (c) expansion of the industry's capacity to accept recycled paper due to growth in the volume of recycled paper available.
The paper market is quite volatile; newspaper prices, for example, have varied from as low as $5/ton to as high as $70/ton in some locations; all over a period of 6 to 7 years. Price stability is guaranteed by many buyers through "floor prices", regardless of how the market performs.

Factors Which Influence Price

- Contamination (although contamination more often results in rejection of a load rather than price reduction).
- Transportation costs.
- Market conditions
  - export level
  - competition from other (sporadic) markets, such as insulation
  - availability of recycled paper from other major sources

Comment on Future Market Demand

- Expansion of markets for all recycled paper as supply expands.
- Several companies are rapidly expanding their capacity, with mills devoted to recycled paper.

RECOVERY ALTERNATIVES

- Source Separation via Separate Collection (Residential Newsprint).
- Source Separation of pure streams at Source (office paper, corrugated, CPO, tab cards).
- Hand sorting of paper from mixed trash (newsprint, corrugated).

ALTERNATIVE APPROACHES

- Source Separation via Separate Collection Newsprint is collected from homes in bundles or bags; using either separate vehicles (see MRS-GLS) or compartments/racks built onto the regular collection vehicles. The paper is off loaded at the storage yard and sorted to remove bags and other contaminants. Paper is then stored loose or stacked, and shipped when a full load is justified.

- Source Separation of pure waste streams at the source.
  High grade office paper (white ledger, CPO) is separated at the point of generation rather than mixed with regular refuse. The paper is stored flat in a desktop container or separate trash can. Custodians collect the paper each evening and take it to collection/storage area (bin) in each building or complex. The bins are later transferred to central depository on base, for either loose storage or baling. Under a full service contract, the buyer will pick-up the paper on call, with other cost of transport factored into the contract price. Otherwise, Navy personnel transport it to market.

  Corrugated and tab cards are handled in much the same manner, except that storage, boxing, and/or baling typically takes place at the point of generation.
Hand sorting of paper from mixed trash.

Separated mixed material is collected at curbside and transported to a central location for sorting. Once the cans and glass are removed, the newsprint is baled or stored loose. Poor quality is common, as removing wet garbage from the glass and cans will contaminate paper. The material is often accepted, but at a lower price than pre-sorted newprint.

**APPLICABLE TECHNOLOGY**

- Truck newspaper racks.
- Compartmentalized vehicles or trailers.
- Balers.
- Sorting conveyors.
- Bins.

**References**

- Not included
- MH-H
- MH-B
- Not included

**System Characteristics**

- Labor intensive.
- Market is typically strong, but marked geographic distribution of demand will influence economic feasibility.
- Both curbside newsprint collection and desktop separation of high grade paper are proven systems; common sense usually dictates the most efficient approach at a given base or building.
- High degree of recovery is possible for white ledger, CPO, tab cards, and corrugated. Newsprint recovery is usually the most successful of curbside components, and may range from 20-75 percent. Strong market contracts are a must, due to market volatility and storage space required.

**COMPLIMENTARY SYSTEMS**

- Curbside collection of glass and/or metal cans, whether mixed or separated.
- Recycling/buy-back centers for other materials.
- Energy recovery from mixed solid wastes.
<table>
<thead>
<tr>
<th>Activity</th>
<th>Material Form</th>
<th>Concentration in Waste*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food Service, housing, recreation areas, medical, ships, storage area</td>
<td>Bottles (largest percentage by volume), packaging, foam trays, bags, cups, and other discarded consumer goods</td>
<td>Thermoplastics - 89% high and low density polyethylenes, polypropylene, polystryene, PVC (polyvinyl chloride), thermosets Plastics - 2%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Industrial Users</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Specific Process</td>
</tr>
<tr>
<td>P.E.T. bottle recyclers (Polyethylene terephthalate polyester bottles)</td>
<td>Separating, cleaning, washing and grinding</td>
</tr>
<tr>
<td></td>
<td>Production to key components, then repolymerized into fiber grade P.E.T. polyester</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specifications</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Form</td>
<td>End Use</td>
</tr>
<tr>
<td>Ground or baled; if ground P.E.T./ packaging may be preferred (material has gone through 1/2&quot; screen and is contained in box weighing 600-1,000 lbs)</td>
<td>Polyester products (non-food contact)</td>
</tr>
</tbody>
</table>

Historical Demand

P.E.T. bottles are the only post-consumer plastics recycled at this time. The number of P.E.T. beverage bottles being produced is steadily increasing.

* Note -
- Thermoplastics can be melted and reformed numerous times.
- P.E.T. Bottles (polyethylene terephthalate) are the only consumer plastics being recycled in any appreciable quantity.
- Thermosets can not be melted and reformed.
Factors which influence price

- Amount of contaminants.
- Availability of P.E.T. bottles.
- Transportation costs
  - recycler picks up bottles
  - bottles shipped to recycler
  - location of recycling plants.
- Whether deposit law for P.E.T. bottles is in effect.
- Price of virgin resin.

Comments on future market demand

- Expanded use of recycled P.E.T. for unsaturated polyester resins for non-food contact containers and other applications.
- May become more desirable as a fuel supplement in RDF systems. The fuel value of P.E.T. is 10,000 Btu/lb.
- Expanded use of P.E.T. bottles in container field.

RECOVERY ALTERNATIVES

Centralized Recovery

- Recycling center for P.E.T. bottles and other recycled materials.
- If volume high enough, P.E.T. bottles can be separated by machinery rather than by hand.

Source Separation

- Cleaner scrap (caps loose or removed before shipping).
- Reduces volume of material going to landfill.
- Does not rely on large volume to operate.

Material collected at collection points. Brought to central point where P.E.T. bottles are sorted by hand. Bottles are stored in bins until quantity reached is economically feasible to transport to bottle manufacturers, off-base recycling center, or directly to the recycler. At this central place, the base may operate a baler or grinder.

Base personnel are informed of source separation and know it is to be accomplished. Bottles are put in an appropriate container for collection on same day as other refuse or on alternate days. Bottles are taken to central locations to be containerized for shipping. At this central place, the base may operate a baler or grinder, depending on the specifications of the recycler.
System Characteristics

- Labor intensive.
- Does not require large capital outlay even if a baler or grinder has to be purchased.
- 100% recovery P.E.T. bottles.
- System would retrieve 2 liter and 1 liter soda bottles.
- Ready market for recycled bottles.
- P.E.T. bottles would be set aside by base personnel at each collection point or waste is taken to central place where bottles can be separated by hand.
- As more P.E.T. bottles of different sizes appear in the waste stream, no difficulty in sorting new bottles should occur.
- Personnel sorting bottles should be required to wear protective clothing identical to solid waste handlers.

Complementary Systems

- Slow moving conveyor system to pick bottles from waste stream.
- Storage bin system.
- If source separation system, separate or piggy-back system for collection of P.E.T. bottles from collection points.
SECTION III
FUEL RECOVERY SYSTEMS

Fuel recovery (FR) systems process and segregate a portion of mixed solid waste for use as a fuel. Most fuel products are intended as partial substitutes for conventional fossil fuels, and take the form of that fuel (i.e., solid, liquid, or gas) for ease of handling and combustion.

It is difficult to categorize fuel recovery systems into a small number of distinct groups, particularly by fuel form alone. To produce each fuel form, there are often several commercial-scale processing systems available. Slight variations within system categories and solid waste composition also produce variations in fuel composition. For simplicity, the following generic system categories are presented in this section (system codes are shown in parentheses):

- **Solid fuel (SF)**
  - Raw MSW (RW)
  - Chemically powdered RDF (CP)
  - Coarse fluff RDF (CF)
  - Densified RDF (DN)
  - Physically powdered RDF (PP).

- **Gaseous fuel (GF)**
  - Low-Btu gas (pyrolysis) (LB)
  - Medium-Btu gas (pyrolysis) (MBP)
  - Medium-Btu gas (anaerobic digestion) (MBA)
  - High-Btu gas (anaerobic digestion) (HR).

- **Liquid fuel (LF)**
  - Pyrolysis oil (PO)
  - Gasoline (GS).

The format of all subsections is similar, emphasizing the technological variations rather than the site-specific marketing considerations (note the contrast with Section II).

Each subsection contains information under the following major headings:

- **Fuel Characteristics**: general information, recommended applications, system and output specifications, and demand restrictions.
Recovery Alternative: comments on Navy applicability, and alternatives to central processing.

Applicable Technology: generic system description, unit operations, operating experience, and cost.

Complimentary systems and their impact.

Much of the discussion is general in nature, as specific descriptions might tend to favor one system variation over another. Extensive reference to the appendices is used for additional detail.

Typical fuel characteristics for liquid and gaseous fuel products are presented in the appropriate subsections. Solid fuel characteristics are presented below for ease of comparison.

<table>
<thead>
<tr>
<th>PROCESSING ALTERNATIVE</th>
<th>Raw MSW</th>
<th>Coarse Fluff RDF</th>
<th>Fine Fluff RDF</th>
<th>Densified RDF</th>
<th>Physically Powdered RDF</th>
<th>Chemically Powdered RDF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heating valve (Btu/lb)</td>
<td>4,000-6,000</td>
<td>6,000-7,000</td>
<td>6,000-7,000</td>
<td>6,000-7,000</td>
<td>7,500-8,500</td>
<td>7,500-8,500</td>
</tr>
<tr>
<td>Moisture 20-40 content (%)</td>
<td>20-35</td>
<td>20-35</td>
<td>20-35</td>
<td>0-10</td>
<td>0-10</td>
<td></td>
</tr>
<tr>
<td>Total volatile (%)</td>
<td>40-60</td>
<td>65-80</td>
<td>65-80</td>
<td>65-80</td>
<td>65-80</td>
<td>65-80</td>
</tr>
<tr>
<td>Fixed carbon (%)</td>
<td>4-8</td>
<td>5-9</td>
<td>5-9</td>
<td>5-9</td>
<td>5-9</td>
<td>5-9</td>
</tr>
<tr>
<td>Carbon (%)</td>
<td>25-35</td>
<td>30-40</td>
<td>30-40</td>
<td>30-40</td>
<td>30-40</td>
<td>30-40</td>
</tr>
<tr>
<td>Hydrogen (%)</td>
<td>3-6</td>
<td>3-6</td>
<td>3-6</td>
<td>3-6</td>
<td>3-6</td>
<td>3-6</td>
</tr>
<tr>
<td>Nitrogen (%)</td>
<td>0.5-1.0</td>
<td>0.5-1.0</td>
<td>0.5-1.0</td>
<td>0.5-1.0</td>
<td>0.5-1.0</td>
<td>0.5-1.0</td>
</tr>
<tr>
<td>Sulfur (%)</td>
<td>0.1-0.5</td>
<td>0.1-0.5</td>
<td>0.1-0.5</td>
<td>0.1-0.5</td>
<td>0.1-0.5</td>
<td>0.1-0.5</td>
</tr>
<tr>
<td>Chlorine (%)</td>
<td>0.4-0.7</td>
<td>0.4-0.7</td>
<td>0.4-0.7</td>
<td>0.4-0.7</td>
<td>0.4-0.7</td>
<td>0.4-0.7</td>
</tr>
<tr>
<td>Bulk density (lb/ft)</td>
<td>2-4</td>
<td>3-5</td>
<td>3-5</td>
<td>30-35</td>
<td>25-30</td>
<td>25-30</td>
</tr>
<tr>
<td>Particle size</td>
<td>10-15*</td>
<td>4-7</td>
<td>2-3</td>
<td>2-4</td>
<td>100 mesh</td>
<td>150 mesh</td>
</tr>
<tr>
<td>distribution, largest (in)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Excludes oversize and bulky items.
FUEL MARKETS/USES

Fuel Characteristics

Unprocessed solid waste has only limited value as a saleable fuel. Only combustion systems designed specifically for solid waste are suitable.

Potential Uses

- **Combustion**
  - Modular incineration
  - Water wall incineration

- **Refinement**
  - RDF production

System Specifications

<table>
<thead>
<tr>
<th>System Characteristic</th>
<th>Specification</th>
<th>Typical Range</th>
<th>Important to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>Tons/hour</td>
<td>7 - 125</td>
<td>Handle expected waste flow</td>
</tr>
<tr>
<td>Capital cost</td>
<td>Dollars/ton</td>
<td>1,000 - 10,000</td>
<td>Evaluate cost effectiveness</td>
</tr>
<tr>
<td>Facility size</td>
<td>Area</td>
<td>1 acre - 10 acres</td>
<td>Fit into available space</td>
</tr>
</tbody>
</table>

Restriction/Limitations

Raw MSW fuel
Combination with municipal partner necessary due to size constraints.
Market for fuel

Demand

Price is a function of:

- Displaced fuel cost and availability.
- RDF quality, quantity, and deliverability (guaranteed/non-guaranteed).
- Future conventional and alternate fuel price trends.
- Technical compatibility of combustion equipment.
- Air pollution control requirements.
- Residue disposal requirements.

There is virtually no demand for raw solid waste among industrial or military coal users.

APPLICABLE TECHNOLOGY

1. Receive
2. Sort
3. Feed
FUEL RECOVERY
Solid Waste

Unit Operations

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Commonly Used Equipment</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Receive</td>
<td>Concrete tipping floor</td>
<td>Organize and store incoming refuse</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Concrete pit</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Sort</td>
<td>Clamshell crane</td>
<td>Remove oversize and bulky items</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Front-end loader</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Feed</td>
<td>Clamshell crane</td>
<td>Control material throughput</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Front-end loader</td>
<td></td>
</tr>
</tbody>
</table>

Personnel Requirements: 0-100 tpd, 1-2 operators.

Marketability of product: 0-150 tpd, modular incineration only.
150-250 tpd, modular or field erected incinerator.
250-2,000 tpd, field erected incinerator only.

Operating example: Numerous heat recovery incinerators on line

Applicability: Military only - modular incineration
             Regional - modular incineration or field erected incinerator.

Cost: Excluding combustion system, cost is limited to transfer and transportation.

COMPLIMENTARY SYSTEMS

Source separation
- Removal of aluminum cans, tin-coated steel cans, glass containers, and any other non-combustible material will improve waste fuel characteristics.
- Removal of office paper, newspaper, corrugated cardboard, or any other combustible material will degrade waste fuel characteristics.

Selective waste acceptance
- Waste of commercial origin has more desirable fuel characteristics than waste of residential origin.
### Fuel Characteristics

Chemically powdered RDF is the most refined form of solid RDF available. The principal difference between physical and chemical powdering is the addition of an embrittling agent to the latter, improving the final stage of production. Use restrictions and advantages are similar to those of physically powdered RDF (FR-SF-PP).

### Potential Uses

<table>
<thead>
<tr>
<th>System Type</th>
<th>Restriction/Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion</td>
<td>RDF blended with pulverized coal</td>
</tr>
<tr>
<td>Suspension-fired coal boiler or heater</td>
<td></td>
</tr>
</tbody>
</table>

### System Specifications

<table>
<thead>
<tr>
<th>System Characteristic</th>
<th>Specification</th>
<th>Typical Range</th>
<th>Important to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>Tons/hour</td>
<td>Data are not available to determine typical ranges</td>
<td>Handle expected waste flow</td>
</tr>
<tr>
<td>Capital cost</td>
<td>$/ton</td>
<td></td>
<td>Evaluate cost effectiveness</td>
</tr>
<tr>
<td>Facility size</td>
<td>Area</td>
<td></td>
<td>Fit into available space</td>
</tr>
<tr>
<td>Particulate emissions</td>
<td>gr/dSCF</td>
<td></td>
<td>Obtain air pollution operating permits</td>
</tr>
<tr>
<td>Product output</td>
<td></td>
<td></td>
<td>Evaluate operating economies</td>
</tr>
<tr>
<td>RDF</td>
<td>Ton RDF/ton MSW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ferrous scrap</td>
<td>Ton scrap/ton MSW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Consumption</td>
<td>KWH/ton</td>
<td></td>
<td>Compatible with existing system</td>
</tr>
</tbody>
</table>

### Demand

Price is a function of the same variables as physically powered RDF. The cost may be slightly higher due to chemical additives, which could be offset by reduced operating and maintenance cost for final grinding stage.

### Recovery Alternatives

Same as for physically powdered RDF (FR-SF-PP).
FUEL RECOVERY  Chemically Powdered RDF  FR-SF-CP  P. 2 of 3

APPLICABLE TECHNOLOGY

Unit Operations

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Commonly Used Equipment (Reference)</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Receive</td>
<td>Concrete tipping floor</td>
<td>Organize and store incoming refuse</td>
</tr>
<tr>
<td>2</td>
<td>Sort</td>
<td>Concrete pit (not included)</td>
<td>Protect equipment from unprocessibles</td>
</tr>
<tr>
<td>3</td>
<td>Primary shred</td>
<td>Clamshell crane, front-end loader (not included)</td>
<td>Protect equipment from unprocessibles</td>
</tr>
<tr>
<td>4</td>
<td>Classify</td>
<td>Horizontal/vertical hammermill (MH-E, MH-F)</td>
<td>Size reduction - homogenization</td>
</tr>
<tr>
<td>5</td>
<td>Secondary shred</td>
<td>Vertical/rotary air classifier, ballistic classifier, trommel</td>
<td>Separation of organics/inorganics</td>
</tr>
<tr>
<td>6</td>
<td>Magnetic separation</td>
<td>Horizontal/vertical hammermill</td>
<td>Size reduction</td>
</tr>
<tr>
<td>7</td>
<td>Shredder feed</td>
<td>Overhead, electromagnetic, belt magnetic separator (MH-J, MH-K)</td>
<td>Separation of ferrous scrap/inorganics</td>
</tr>
<tr>
<td>8</td>
<td>Materials conveyance</td>
<td>Primary conveyor (MH-B)</td>
<td>Conveyance/control</td>
</tr>
<tr>
<td>9</td>
<td>Chemical feed</td>
<td>Secondary conveyor (MH-B)</td>
<td>Transport of waste</td>
</tr>
<tr>
<td>10</td>
<td>Mixing chamber</td>
<td>Spray chamber (Not included)</td>
<td>Meter embrittling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rotary drum, agitation arms agent into intimate contact with</td>
<td>Bring embrittling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>waste (Not included)</td>
<td></td>
</tr>
</tbody>
</table>

Personnel Requirements

- 0-250 tpd, one operator, two assistants, one mechanic.
- 250-750 tpd, one operator, three assistants, one mechanic.

Marketability of Product

- Same as for FR-SF-PP.

Operating Example

- No operating systems.
Applicability

- Military only - not feasible in 0-40 tpd range
  Regional - minimum of 200-250 tpd for economic feasibility.

Cost

- No data available for commercial systems.

COMPLEMENTARY SYSTEMS AND THEIR IMPACT

Source Separation

- Removal of aluminum cans, tin-coated steel cans, glass containers will enhance fuel processing characteristics.

- Removal of office paper, newspaper, corrugated cardboard will enhance fuel processing operations but degrade fuel heat content and reduce fuel quantity.

- Removal of tin-coated steel cans will reduce ferrous scrap recovered.
**FUEL MARKETS/USES**

**Fuel Characteristics**

Coarse fluff RDF represents the least refined form of processed solid waste commercially used as a solid fuel substitute. The principal difference between coarse fluff and other RDF forms is the degree of processing applied. The resulting product typically has a larger size distribution (4 to 7 in nominal) and may contain a higher percentage of inorganic matter due to limited classification (air, screens).

The principal users of coarse fluff RDF are limited to grate fired incinerators and boilers. Industry concerns over boiler slagging and corrosion from entrained inorganics has limited the market growth of coarse fluff RDF.

**Potential Uses**

<table>
<thead>
<tr>
<th>System Type</th>
<th>Restriction/Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion</td>
<td>Alone or mixed with raw MSW.</td>
</tr>
<tr>
<td>Modular incineration</td>
<td></td>
</tr>
<tr>
<td>Solid fuel (boiler)</td>
<td>Alone or mixed with original fuel.</td>
</tr>
<tr>
<td>Solid fuel (heater)</td>
<td>Alone or mixed with original fuel.</td>
</tr>
<tr>
<td>Solid fuel (boiler/heater)</td>
<td>Unless equipped with automatic ash handling, technical feasibility is doubtful.</td>
</tr>
</tbody>
</table>

**System Specifications**

- **System Characteristic**: Typical Specification, Range, Important to:

  - **Capacity**: Ton/hr, 60-150, Handle expected waste flow.
  - **Capital cost**: Dollars/ton/day, $6,000-$20,000, Evaluate cost effectiveness.
  - **Facility size**: Height (ft) x length (ft) x width (ft), 1 acre - 25 acres, Fit into available space.
  - **Product output**: RDF, Ton RDF/ton MSW, .75-.85, Evaluate operating economies.
  - **Ferrous scrap**: Ton scrap/ton MSW, .03-.06
  - **Power consumption**: KWH/ton, 29-50, Compatible with existing distribution system.
Demand

Price is a function of:

- Displaced fuel cost and availability.
- RDF quality, quantity, and deliverability (guaranteed/non-guaranteed).
- Future conventional and alternate fuel price trends.
- Air pollution control requirements.
- Residue disposal requirements.

Demand is most often controlled by the questionable combustion characteristics and compatibility of the fuel with most coal-fired combustion systems. Significant improvements in the fuel characteristics (particularly inorganic content) can be made by retrofitting a trommel screen ahead of the first shredder. Other improvements involve a substantial modification of system and equipment design, and are too costly to retrofit. Based on current knowledge, a fine fluff RDF system is usually preferred, with or without a dedicated boiler system.

RECOVERY ALTERNATIVES

Production Considerations

- Coarse fluff RDF systems are the simplest of the RDF systems in design. Operation and maintenance of requirements are therefore lower and system reliability is higher.

- Some system components currently in use, particularly shredders and air classifiers, are considered most efficient at 50 tons/hr or above. Even small RDF systems often include some large capacity components for this reason. Significant economies of scale exist where this design philosophy prevails.

- All commercial-scale RDF systems on line or planned, have larger design capacities than most Navy installations need.

Sale/Use Considerations

- Effective sale of RDF usually required large volume production (>500 tpd) to interest large volume users.

- Regional RDF systems are common, in part because of the need to attract large buyers.

- RDF buyers are unpredictable, because most industries are not familiar with RDF. They may agree to buy it but later decide against it for technical reasons. Test burns and corrosion tests are recommended before negotiations begin.
FUEL RECOVERY

Coarse Fluff RDF

FR-SF-CF

P. 3 of 4

APPLICABLE TECHNOLOGY

![Diagram]

System Costs

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Commonly Used Equipment</th>
<th>Reference No</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Receive</td>
<td>Concrete tipping floor</td>
<td>Not included</td>
</tr>
<tr>
<td>2</td>
<td>Sort</td>
<td>Concrete pit</td>
<td>Not included</td>
</tr>
<tr>
<td>3</td>
<td>Primary shred</td>
<td>Clamshell crane, front-end loader</td>
<td>Not included</td>
</tr>
<tr>
<td>4</td>
<td>Classify</td>
<td>Horizontal/vertical hammermill</td>
<td>MH-E, MH-F</td>
</tr>
<tr>
<td>5</td>
<td>Magnetic separation</td>
<td>Vertical/rotary air classifier, ballistic classifier, trommel screen</td>
<td>MH-I, MH-N</td>
</tr>
<tr>
<td>6</td>
<td>Shredder feed</td>
<td>Overhead, electromagnetic, belt magnetic separator</td>
<td>MH-J, MH-K</td>
</tr>
<tr>
<td>7</td>
<td>Materials conveyance</td>
<td>Primary conveyor</td>
<td>MH-B</td>
</tr>
<tr>
<td>8</td>
<td>Storage</td>
<td>Surge bin, silo</td>
<td>MH-A</td>
</tr>
</tbody>
</table>

Personnel Requirements

- 0-250 tpd: one operator, two assistants, one mechanic.
- 250-750 tpd: one operator, three assistants, one mechanic.

Marketability of Product

Coarse fluff RDF has traditionally been difficult to market due to its relatively unrefined condition and the associated high inorganic content. Test burns of coarse fluff RDF at the St. Louis test facility proved successful enough to the local utility for consideration of commercial scale production.

On the other hand, the Tacoma, Washington system does not presently operate at capacity due exclusively to a lack of markets.
Operating Example

- Tacoma, Washington (500 tpd).

Applicability

Military - not feasible in 0-40 tpd range regional - minimum of 200-250 tpd for economic feasibility.

COMPLEMENTARY SYSTEMS

Source separation

- Removal of aluminum cans, tin-coated steel cans, glass containers will enhance fuel processing characteristics (decreased inorganics)
- Removal of office paper, newspaper, corrugated cardboard will enhance fuel processing operations but degrade fuel heat content and reduce fuel quantity.
- Removal of tin-coated steel cans will reduce ferrous scrap recovered.

Incinerators/Boilers

- Suspension firing alone of coarse fluff RDF is not recommended in industrial boilers.
- Proper combustion requires a fixed or moving grate for proper burnout of the larger particles.
FUEL MARKETS/USES

Fuel Characteristics

Densified refuse-derived fuel (dRDF) is the extruded form of coarse fluff or fine fluff RDF. It most often takes the form of cylindrical pellets ranging from 1/4 in to 1 in in diameter and up to 3 in in diameter. Because moisture usually serves as the binding agent, the chemical composition is the same as the input RDF.

The dRDF pellets are intended to serve as a fuel substitute for coal in solid fuel-fired combustion systems. Various tests have been performed using dRDF in conventional coal-fired boilers, with mixed results. Violatization is typically slower for the dRDF, and the coal and ash handling systems do not always adapt well to dRDF.

Potential Uses

<table>
<thead>
<tr>
<th>Potential Uses</th>
<th>System Type</th>
<th>Restriction/Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion</td>
<td>Modular incineration</td>
<td>Alone or mixed with raw MSW</td>
</tr>
<tr>
<td></td>
<td>Solid fuel boiler</td>
<td>Alone or mixed with original fuel</td>
</tr>
<tr>
<td>Refinement</td>
<td>Coal-fired boilers and heaters</td>
<td>d-RDF may have to be re-shredded prior to use</td>
</tr>
<tr>
<td></td>
<td>All</td>
<td>Ash handling system may have to be oversized</td>
</tr>
</tbody>
</table>

System Characteristic

<table>
<thead>
<tr>
<th>Specification</th>
<th>Typical Range</th>
<th>Important to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>Tons/hr</td>
<td>Handle expected waste flow</td>
</tr>
<tr>
<td>Capital cost</td>
<td>Dollars/ton</td>
<td>Evaluate cost effectiveness</td>
</tr>
<tr>
<td>Facility size</td>
<td>Height (ft)x length (ft)x width (ft)</td>
<td>Fit into available space</td>
</tr>
<tr>
<td></td>
<td>No long-term operating data available</td>
<td>Obtain air pollution operating permits.</td>
</tr>
</tbody>
</table>

Product output

<table>
<thead>
<tr>
<th>Product output</th>
<th>Specification</th>
<th>Important to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDF</td>
<td>Ton RDF/ton MSW</td>
<td>Evaluate operating economics</td>
</tr>
<tr>
<td></td>
<td>Ton scrap/ton MSW</td>
<td></td>
</tr>
<tr>
<td>Ferrous scrap</td>
<td>Ton scrap/ton MSW</td>
<td>Compatible with existing system</td>
</tr>
<tr>
<td>Power consumption</td>
<td>KWH/ton</td>
<td></td>
</tr>
</tbody>
</table>
Demand

Price is a function of:
- Displaced fuel cost and availability.
- RDF quality, quantity, and deliverability (guaranteed/non-guaranteed).
- Future conventional and alternate fuel price trends.
- Technical compatibility of combustion equipment.
- Air pollution control requirements.
- Residue disposal requirements.

As in the case of coarse fluff RDF, dRDF demand is controlled by customer awareness of its composition and combustion characteristics. Densification is considered advantageous for long-term storage (3 to 6 months), but test runs on burn, storage and handling characteristics are recommended for systems with equipment already in place.

RECOVERY ALTERNATIVES

Production considerations
- dRDF production is 2 steps more complex than fine fluff RDF, and as such is that much more susceptible to maintenance downtime.
- The pellet mills are commonly experience rapid die wear, and have been a high maintenance item in pilot scale systems.
- Because pelletizing is an additional stage which does not produce an associated fuel value (revenue) increase, a captive large volume user is crucial to project success.
- Regional systems are favored, again due to significant economy of scale for processing components.

Sale/Use Considerations
- Same as for coarse fluff scale/use.

APPLICABLE TECHNOLOGY
### Unit Operations

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Commonly Used Equipment</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Receive</td>
<td>Concrete tipping floor, Concrete pit (not included)</td>
<td>Organize and store incoming refuse</td>
</tr>
<tr>
<td>2</td>
<td>Sort</td>
<td>Clamshell crane, front-end loader (not included)</td>
<td>Protect equipment from unprocessibles</td>
</tr>
<tr>
<td>3</td>
<td>Primary shred</td>
<td>Horizontal/vertical hammermill (MH-E, MH-F)</td>
<td>Size reduction - homogenization</td>
</tr>
<tr>
<td>4</td>
<td>Classify</td>
<td>Vertical/rotary air classifier, ballistic classifier, trommel screen (MH-D, MH-I)</td>
<td>Separation of organics/inorganics</td>
</tr>
<tr>
<td>5</td>
<td>Secondary shredder</td>
<td>Horizontal/vertical hammermill (MH-E, MH-F)</td>
<td>Size reduction</td>
</tr>
<tr>
<td>6</td>
<td>Magnetic separation</td>
<td>Overhead, electromagnetic, belt magnetic separator (MH-J, MH-K)</td>
<td>Separation of ferrous scrap/inorganics</td>
</tr>
<tr>
<td>7</td>
<td>Shredder feed</td>
<td>Primary conveyor (MH-B)</td>
<td>Conveyance/control raw waste feed</td>
</tr>
<tr>
<td>8</td>
<td>Materials conveyance</td>
<td>Secondary conveyor, (MH-B)</td>
<td>Transport of waste from operation to operation</td>
</tr>
<tr>
<td>9</td>
<td>Condition</td>
<td>Sprinklers, dryers (not included)</td>
<td>Adjust moisture content</td>
</tr>
<tr>
<td>10</td>
<td>Pelletize</td>
<td>Grain press, pellet mill (MH-O)</td>
<td>Reduce bulk density</td>
</tr>
</tbody>
</table>

### Personnel Requirements

- 0-250 tpd, one operator, two assistants, one mechanic.
- 250-750 tpd, one operator, three assistants, one mechanic.

### Marketability of Product

Lack of commercial experience with dRDF sale and use will hinder marketing efforts. Ongoing test burns at Wright-Patterson AFB and elsewhere should confirm combustion and handling properties, permitting more rapid commercial development.

### Operating Examples

- Baltimore County.
- Other pilot scale demonstrations.

### Applicability

- Military - not feasible in 0-40 range.
- Regional - minimum of 200-250 tpd for economic feasibility

### Complementary Systems and Their Impact

**Source Separation**

- Removal of aluminum cans, tin-coated steel cans, glass containers will enhance fuel processing characteristics.
- Removal of office paper, newspaper, corrugated cardboard will enhance fuel processing operations but degrade fuel heat content and reduce fuel quantity.
- Removal of tin-coated steel cans will reduce ferrous scrap recovered.
<table>
<thead>
<tr>
<th>FUEL RECOVERY</th>
<th>Physically Powdered RDF</th>
<th>FR-SF-PP</th>
<th>P. 1 of 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>FUEL MARKETS/USES</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Application</td>
<td>System Type</td>
<td>Restriction/Limitations</td>
<td></td>
</tr>
<tr>
<td>Combustion</td>
<td>Suspension-fired</td>
<td>RDF blended with pulverized coal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>coal boiler or</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>heater</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specifications</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Characteristic</td>
<td>Specification</td>
<td>Typical Range</td>
<td>Important to:</td>
</tr>
<tr>
<td>Capacity</td>
<td>Tons/hour</td>
<td>600-1,400 tpd</td>
<td>Handle expected waste flow</td>
</tr>
<tr>
<td>Capital cost</td>
<td>$ per ton/day</td>
<td>Data not available to determine parameters</td>
<td>Evaluate cost effectiveness</td>
</tr>
<tr>
<td>Size</td>
<td>Height (ft) x length (ft) x width (ft)</td>
<td>Fit into available space</td>
<td></td>
</tr>
<tr>
<td>Particulate emissions</td>
<td>Micro grams/cu meter</td>
<td></td>
<td>Obtain air pollution operating permits</td>
</tr>
<tr>
<td>Product output</td>
<td>RDF</td>
<td></td>
<td>Evaluate operating economics</td>
</tr>
<tr>
<td></td>
<td>Ton RDF/ton MSW</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ferrous scrap</td>
<td>Ton scrap/ton MSW</td>
<td></td>
</tr>
<tr>
<td>Power consumption</td>
<td>KWH/ton</td>
<td></td>
<td>Compatible with existing system</td>
</tr>
</tbody>
</table>

**Demand**

Price is a function of:
- Displaced fuel cost and availability.
- RDF quality, quantity, and deliverability (guaranteed/non-guaranteed).
- Future conventional and alternate fuel price trends.
- Technical compatibility of combustion equipment.
- Air pollution control requirements.
- Residue disposal requirements.
RECOVERY ALTERNATIVES

Production considerations

Centralize Processing
- Larger capacity systems
- Provide capital and operating economies of scale
- Siting and design is simplified

Regional Processing
- Hauling costs are reduced
- Redundancy is provided
- Surge capacity and operating flexibility increased

APPLICABLE TECHNOLOGY

Unit Operations

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Commonly Used Equipment</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>Sort</td>
<td>Clamshell crane, front-end loader (not included)</td>
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<td>3</td>
<td>Primary shred</td>
<td>Horizontal/vertical hammermill (MH-E, MH-F)</td>
<td>Size reduction - homogenization</td>
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<td>4</td>
<td>Classify</td>
<td>Vertical/rotary air classifier, ballistic classifier, trommel screen (MH-D, MH-I)</td>
<td>Separation of organics/inorganics</td>
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<td>5</td>
<td>Secondary shred</td>
<td>Horizontal/vertical hammermill (MH-E, MH-F)</td>
<td>Size reduction</td>
</tr>
<tr>
<td>6</td>
<td>Magnetic separation</td>
<td>Overhead, electromagnetic, belt magnetic separator (MH-J, MH-K)</td>
<td>Separation of ferrous scrap/inorganics</td>
</tr>
<tr>
<td>7</td>
<td>Shredder feed</td>
<td>Primary conveyor (MH-B)</td>
<td>Conveyance/control raw waste feed</td>
</tr>
<tr>
<td>8</td>
<td>Materials conveyance</td>
<td>Secondary conveyor (MH-B)</td>
<td>Transport of waste from operation to opera-</td>
</tr>
<tr>
<td>9</td>
<td>Tertiary grinding</td>
<td>Ball mill, roller mill (not included)</td>
<td>Size reduction</td>
</tr>
</tbody>
</table>
### FUEL RECOVERY

<table>
<thead>
<tr>
<th>Physically Powdered RDF</th>
<th>FR-SF-PP</th>
<th>P. 3 of 3</th>
</tr>
</thead>
</table>

Personnel Requirements: 0-250 tpd, one operator, two assistants, one mechanic. 250-750 tpd, one operator, three assistants, one mechanic.

Marketability of Product: Operators of suspension-fired coal boilers or heaters. Operators of fuel oil-fired boilers or heaters.

Operating Example: Bridgeport, Conn.

ECO - Fuel II (1,800 tpd)

The Bridgeport facility has experienced numerous through-put problems throughout its two-year existence. The facility is currently closed due to financial difficulties and the previous two operators do not expect to reopen. The prepared fuel was utilized as designed with no adverse effects. The future of the plant is uncertain.

Applicability: military only - not feasible in 0-40 tpd range regional - minimum of 200-250 tpd for economic feasibility.

### COMPLEMENTARY SYSTEMS AND THEIR IMPACT

**Source Separation**

- Removal of aluminum cans, tin-coated steel cans, glass containers will enhance fuel processing characteristics.
- Removal of office paper, newspaper, corrugated cardboard will enhance fuel processing operations but degrade fuel heat content and reduce fuel quantity.
- Removal of tin-coated steel cans will reduce ferrous scrap recovered.

**Selective Waste Acceptance**

- Waste of commercial origin has more desireable fuel characteristics than waste of residential origin.
## FUEL RECOVERY

### Low Btu Gas (Pyrolysis)

#### FR-GF-LB

## FUEL MARKETS/USES

### Fuel Characteristics

Low Btu gas produced by pyrolysis consists of a mixture of a wide variety of combustible and non-combustible gases. The exact composition of the gas depends on the composition of the raw material and on the specific process used to convert the raw material to gaseous, liquid, and solid components. In general, a low Btu gas produced by pyrolysis will consist of a mixture of nitrogen, carbon dioxide, carbon monoxide, hydrogen, and methane.

### Fuel Uses

Pyrolysis of solid waste requires that heat energy be added to the pyrolysis reactor. In most of the pyrolysis systems that have been proposed, 100 percent of the low Btu gas that is produced has been recycled back to the reactor for this purpose. Gas from a system designed to produce excess gas could be used on-site for steam production or other heating applications. Because of the low heating value and the presence of toxic carbon monoxide in the gas, transport for use offsite is not practical.

## RECOVERY ALTERNATIVES

Pyrolysis is the process by which complex organic materials are broken down by heat into a combustible gas, a liquid containing long chain hydrocarbons, and a solid char. The quantity and quality of the gas (as well as the other outputs) are highly dependent on the design and operating conditions of the pyrolysis unit. In systems which produce a low Btu gas, the necessary process heat is commonly provided by partially combusting the waste. The carbon dioxide produced, and the nitrogen in the intake air, are noncombustible and therefore reduce the heating value of the gas.

## CURRENT STATE OF DEVELOPMENT

A large-scale (1,000 ton/day) facility for the production and on-site use of pyrolysis gas was constructed in Baltimore, Maryland in 1972-1975. This facility did not operate as designed and was extensively modified in 1976. Additional modifications were performed in 1978, and the system is now shut down for conversion to mass burning incineration. Further development of the pyrolysis technology employed is not anticipated. Significantly more basic research needs to be performed before any full scale facilities are built.

## Cost

No cost estimates for small to medium scale facilities are available. The cost of the 1,000 ton/day facility in Baltimore, after adjusting to discount the one-time costs associated with a first of a kind demonstration, was estimated to be $22 million (1977 dollars).
Fuel Characteristics

Medium Btu gas produced by pyrolysis consists of a mixture of a wide variety of combustible and non-combustible gases. The exact composition of the gas depends on the composition of the raw material and on the specific process used to convert the raw material to gaseous, liquid, and solid components. Estimates of the characteristics of the gas resulting from three different systems are given below:

<table>
<thead>
<tr>
<th>Component</th>
<th>Purox System</th>
<th>Enterprise System</th>
<th>Dual Fluidized Bed</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2</td>
<td>26</td>
<td>1.19 - 4.06</td>
<td>19.58</td>
</tr>
<tr>
<td>C3</td>
<td>40</td>
<td>3.53 - 21.25</td>
<td>35.84</td>
</tr>
<tr>
<td>C4</td>
<td>23</td>
<td>14.00 - 36.36</td>
<td>16.73</td>
</tr>
<tr>
<td>C5</td>
<td>5</td>
<td>2.31 - 13.69</td>
<td>14.35</td>
</tr>
<tr>
<td>Other Hydrocarbons</td>
<td>1</td>
<td>6.07 - 14.18</td>
<td>9.08</td>
</tr>
<tr>
<td>N2 and others</td>
<td>1</td>
<td>17.3 - 72.26</td>
<td>4.08</td>
</tr>
<tr>
<td>Heating Value (Btu/SCF)</td>
<td>370</td>
<td>146 - 502</td>
<td>530</td>
</tr>
</tbody>
</table>

Fuel Uses

Pyrolysis fuel gas can be combusted on-site to produce steam. Transporting the gas off-site is limited by the relatively low heating value (as compared to natural gas) and the quantity of toxic carbon monoxide in the gas stream. Carbon monoxide has a heating value of 323 Btu/cu ft, therefore the removal of this component would adversely affect the energy recovery efficiency of the system.

Recovery Alternatives

Pyrolysis is the process by which complex organic materials are broken down by heat into a combustible gas, a liquid containing longer chain hydrocarbons, and a solid char. The quantity and quality of the gas (as well as the other outputs) is highly dependent on the design and operating conditions of the pyrolysis unit. The heat required for pyrolysis can be applied by partially combusting or by indirectly heating the raw material. If a medium Btu gas is desired systems which partially combust the waste must use pure oxygen as the combustion source rather than air. Indirect heating can be achieved by heating the walls and internal mechanisms of the pyrolysis reactor, or by using an intermediary, such as a preheated fluidized bed. The processes in FR-gF-L8 demonstrate each of these three alternatives.

Current State of Development

Pilot and full-scale pyrolysis units have been constructed in several locations in the United States. These facilities have not been successful in demonstrating that pyrolysis technology is ready for wide-spread application to produce energy. Additional research and development is required if pyrolysis is ever to become a viable technology.

For application to Navy facilities, pyrolysis is particularly unsuitable because it is a high technology, capital intensive process in which small to medium-scale plants are impractical.

Cost

No cost data for small to medium-scale pyrolysis plants are available.
### FUEL RECOVERY

<table>
<thead>
<tr>
<th>Application/Market</th>
<th>System Type</th>
<th>Restrictions/Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-site combustion</td>
<td>Space heating, Steam generation, IC engines</td>
<td>Hydrogen sulfide must be removed. Lack of total system reliability would require that alternate energy sources are available, through storage and/or connection to outside sources.</td>
</tr>
<tr>
<td>Transport offsite</td>
<td>Sale to utility or local industrial user</td>
<td>Purchaser will limit moisture, hydrogen sulfide, and carbon dioxide. The relatively low heating value (compared to natural gas) makes transport over long distances impractical. See Item ID, p. 2.</td>
</tr>
<tr>
<td>Automotive fuel</td>
<td>Motor pools, delivery vehicles</td>
<td>Vehicles converted to methane have limited driving range between refuelings. A range of 25-50 miles can be expected.</td>
</tr>
</tbody>
</table>

### Fuel Specifications

Fuel specifications are divided into specifications for the raw material for the digester, and those for the resulting gas. Specifications for raw material are essential for proper operation of the process, and control of the quality and quantity of gas produced.

<table>
<thead>
<tr>
<th>Raw Material Characteristics</th>
<th>Desirable Level</th>
<th>Important to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation rate</td>
<td>&gt;40 tons/day</td>
<td>System economics (see Section 4).</td>
</tr>
<tr>
<td>Generation rate variability</td>
<td>Uniform generation rate</td>
<td>System performance. Process cannot adjust to rapid increase in input.</td>
</tr>
<tr>
<td>Biodegradability</td>
<td>&gt;75% of input</td>
<td>Non-biodegradable materials do not produce gas, but do require processing and disposal.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Resulting Fuel Characteristics</th>
<th>Desirable Level</th>
<th>Important to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy content</td>
<td>&gt;500 Btu/SCF (maintained by controlling digester pH)</td>
<td>Fuel use. Gas with a low energy content has limited use. Equipment modification is possible within a limited range to accommodate low Btu gas.</td>
</tr>
<tr>
<td>H₂S content</td>
<td>No H₂S</td>
<td>Any H₂S in gas will cause corrosion of equipment.</td>
</tr>
</tbody>
</table>

**Demand**

Medium Btu gas produced by anaerobic digestion can be directly substituted for natural gas, usually with only minor modifications to existing equipment. If the digestion process is properly controlled, the resulting gas is clean burning and highly desirable environmentally. The gas typically will have 1/2 the heating...
value of natural gas, and therefore be sold for approximately half the cost of that fuel. If the quantity of digester gas is very small (less than 5 percent) of the total quantity of gas used locally, it may be possible to inject the gas into the existing gas pipeline network, without processing to increase the Btu content.

RECOVERY ALTERNATIVES

Anaerobic digestion is the process by which complex organic materials are broken down into carbon dioxide and methane by bacteria which live in an oxygen-free environment. This environment can be maintained in an enclosed digestion tank, which also serves as the collection and short-term storage facility for the product gas. The quantity of gas produced is dependent on the amount of organic material fed to the digester temperature. Temperatures of 90-110°F result in a slower, more easily controlled, digestion of materials. Temperatures of 120-140°F result in a faster, more complete, conversion to gas if system stability can be maintained. Operating temperatures between these two ranges are usually unfavorable because of instability and low conversion efficiency. Most digestion systems operate in the lower temperature range.

APPLICABLE TECHNOLOGY

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Commonly Used Equipment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Provide waste on a continuous basis</td>
<td>Compactor vehicles, storage bins, conveyors</td>
<td>MH-B, MH-A</td>
</tr>
<tr>
<td>2</td>
<td>Remove recoverable material and non-biodegradable material, reduce size of particles, remove grit</td>
<td>Magnetic separator, aluminum separator, air classifier, flail mill, shredder, screens</td>
<td>MH-J, MH-K, MH-N, MH-I, MH-G</td>
</tr>
<tr>
<td>3</td>
<td>Digest organics to methane and carbon dioxide</td>
<td>Anaerobic digester, mixer, heat recovery system</td>
<td>CE-J, CE-D</td>
</tr>
<tr>
<td>4</td>
<td>Minimize waste treatment costs, recycle essential nutrients to digester</td>
<td>Filter press, centrifuge, vacuum filter</td>
<td>Not included</td>
</tr>
<tr>
<td>5</td>
<td>Gas processing to permit use</td>
<td>Depends on intended use of gas</td>
<td>Not included</td>
</tr>
</tbody>
</table>
System Alternatives

The type of equipment necessary in Items 2 and 5 above depend on both economic and technical considerations. Inclusion of a magnetic separator may merely be economically desirable. Inclusion of a trommel screen may, however, be essential technically to permit proper operation of the digester without frequent equipment breakdown due to grit.

Other alternatives to be considered would be the inclusion of sewage sludges and municipal refuse from surrounding areas in a larger, regional facility.

Cost

Application of the relatively complex energy recovery system shown above to navy facilities is limited by size constraints. Currently available equipment is not sized for small-scale systems. The operating labor costs also make small-scale systems impractical. The estimated cost for a 100 ton/day facility is $5 million (1981 dollars). Additional costs for disposal of non-biodegradable materials and dewatered solids must be added.

State of Development

A 100 ton/day anaerobic digester for municipal refuse is currently being tested by Waste Management, Inc., at their solid waste disposal facility at Pompano Beach, Florida. After initial start-up problems associated with separation of inorganic fines from the input stream, the system is performing as anticipated. A test program to determine optimum operating temperature, feed rate, retention time, and the requirements for front-end processing is underway. Data are not yet available on the results of this work.

Technology transfer from other processes somewhat reduces the requirements for additional research and development work. The front-end processing of municipal solid waste is common to many resource recovery options. Anaerobic digestion of sewage sludges has been common for many years, as has the dewatering of sludges.

COMPLIMENTARY SYSTEMS

Anaerobic digestion for energy production can be enhanced by an preprocessing which reduces the inorganic content of the feed material. Overall system economics are usually improved by the inclusion of metal recovery, making this option highly advantageous. Removal of other inorganics through the use of screens, air classifiers, hand sorting, source separation, etc., may not provide economically recoverable materials, but decreases both the required size and maintenance for the digester and following units.

Increased digestion efficiency can be obtained by increasing digester temperature. This can be accomplished quite easily if the gas is used on-site by using the waste heat from boilers or the cooling water from IC engines to heat the digester.
### FUEL MARKETS/USES

**Fuel Characteristics and Uses**

**Anaerobic Digester inputs and resulting gas quality/quantities:**

<table>
<thead>
<tr>
<th>Characteristics of feed stock to processing</th>
<th>Typical Base Activity Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approximate generation rate (per day)</td>
<td>Food Service</td>
</tr>
<tr>
<td>% Organic</td>
<td>Exchange or Commissary</td>
</tr>
<tr>
<td>% Biodegradable</td>
<td>Barracks</td>
</tr>
<tr>
<td>Methane content (%)</td>
<td>Offices</td>
</tr>
<tr>
<td>Carbon Dioxide content (%)</td>
<td>Storage/ Warehouse</td>
</tr>
<tr>
<td>Btu value (Btu/scf)</td>
<td>Food Service</td>
</tr>
<tr>
<td>Conversion efficiency (Approximate percentage of organic material converted to gas.)</td>
<td>Exchange or Commissary</td>
</tr>
<tr>
<td>Energy recoverable (per day)</td>
<td>Barracks</td>
</tr>
<tr>
<td>Application/Market</td>
<td>Offices</td>
</tr>
<tr>
<td>System Type</td>
<td>Storage/ Warehouse</td>
</tr>
<tr>
<td>Restrictions/Limitations</td>
<td></td>
</tr>
</tbody>
</table>

**Fuel Specifications**

Fuel specifications are divided into specifications for the raw material for the digester, and those for the resulting gas. Specifications for raw materials are essential for proper operation of the process, and control of the quality and quantity of gas produced.
FUEL RECOVERY

High Btu Gas
(Anaerobic Digestion)

FR-GF-HB

P. 2 of 4

Raw Material Characteristics

<table>
<thead>
<tr>
<th>Generation rate</th>
<th>Desirable Level</th>
<th>Important to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation rate</td>
<td>&gt;100 tons/day</td>
<td>System economics (see Section 4)</td>
</tr>
<tr>
<td>variability</td>
<td>Uniform generation rate</td>
<td>System performance. Process can not adjust to rapid increase in input</td>
</tr>
<tr>
<td>Biodegradability</td>
<td>&gt;75% of input</td>
<td>Non-Biodegradable materials do not produce gas, but do require processing and disposal.</td>
</tr>
</tbody>
</table>

Resulting Fuel Characteristics

<table>
<thead>
<tr>
<th>Energy content</th>
<th>Desirable Level</th>
<th>Important to:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy content</td>
<td>&gt;900 Btu/Scf</td>
<td>Compatibility with existing gas supply</td>
</tr>
<tr>
<td>Pressure</td>
<td>200-1,000 PSI (III)</td>
<td>Match pressure of existing long distance pipelines</td>
</tr>
<tr>
<td>Moisture</td>
<td>Less than saturated</td>
<td>Reduce corrosion and improve heating value</td>
</tr>
<tr>
<td>H₂S content</td>
<td>None present</td>
<td>Reduce corrosion</td>
</tr>
</tbody>
</table>

Demand

If digester gas is processed to increase its heating value, the resulting methane is perhaps the most highly desirable source of energy that can be produced from solid waste. The gas can be directly substituted for existing natural gas supplies, with no modifications to equipment. Existing storage and distribution systems can also be used. Environmentally, methane is virtually an ideal fuel, producing only carbon dioxide and water vapor upon combustion.

RECOVERY ALTERNATIVES

Anaerobic digestion is the process by which complex organic materials are broken down into carbon dioxide and methane by bacteria which live in an oxygen-free environment. This environment can be maintained in an enclosed digestion tank, which also serves as the collection and short-term storage facility for the product gas. The quantity of gas produced is dependent on the amount of organic material fed to the digester, the residence time in the digester, and digester temperature. Temperatures of 90-110°F result in a slower, more easily controlled digestion of materials. Temperatures of 120-140°F result in a faster, more complete conversion to gas if system stability can be maintained. Operating temperatures between these two ranges are usually unfavorable because of instability and low conversion efficiency. Most digestion systems operate in the lower temperature range.

High Btu gas is produced by removing the carbon dioxide from the digester gas. Several technologies for this process have been developed, with large-scale facilities in operation to clean up natural gas supplies.
APPLICABLE TECHNOLOGY

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Commonly Used Equipment</th>
<th>Reference No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Provide waste on a continuous basis</td>
<td>Compactor vehicles, storage bins, conveyors</td>
<td>MH-A, MH-B</td>
</tr>
<tr>
<td>2</td>
<td>Remove recoverable material and non-biodegradable material reduce</td>
<td>Magnetic separator, Air classifier, Aluminum separator, Flail mill, Shredder, Screen</td>
<td>(MH-J, MH-K)</td>
</tr>
<tr>
<td></td>
<td>particle size, remove grit</td>
<td></td>
<td>(MH-I)</td>
</tr>
<tr>
<td>3</td>
<td>Digest organics to methane and carbon dioxide</td>
<td>Anaerobic digester, Heat recovery system</td>
<td>(MH-J)</td>
</tr>
<tr>
<td>4</td>
<td>Minimize waste treatment costs, recycle essential nutrients</td>
<td>Filter press, Centrifuge, Vacuum filter, Acid gas removal system</td>
<td>Not included</td>
</tr>
<tr>
<td>5</td>
<td>Produce pipeline quality gas</td>
<td></td>
<td>Not included</td>
</tr>
</tbody>
</table>

System Alternatives

The type of equipment necessary in Items 2, 4, and 5 above depend on both economic and technical considerations. Extensive sorting and classification will improve digester performance. If sludge is dewatered sufficiently it can be incinerated to produce the required process steam. The type of gas clean-up system selected is highly dependent on the volume of gas processed.

Cost

Application of the complex energy and resource recovery system shown above to navy facilities is impractical due to size constraints. Currently available equipment is not sized for small systems. The operating labor costs also make small system impractical. Larger, regional facilities, processing 1000 tons/day of refuse, can be operated economically. The projected capital expenditure for a system of this size is $14-20 million.
**FUEL MARKETS/USES**

Pyrolysis oil can be processed into a variety of organic chemicals and feed stocks, including benzene, toluene, xylene, naphthalene, resins, and gasoline substitutes. Alternatively, the pyrolytic oil can be burned as a replacement for heavy or light fuel oil without refining. The characteristics of the pyrolytic oil depend on the type of raw waste input to the system and the operating parameters of the pyrolysis unit. A heavy oil resembling No. 6 fuel oil can be produced (the Garrett, or Occidental process) or a lighter oil, similar to No. 2 fuel oil (the Enterprise pyrolysis system). Characteristics of oil from the Enterprise test unit are shown below. The test was performed with selected Navy waste consisting primarily of paper and plastic materials from Port Hueneme, California.

<table>
<thead>
<tr>
<th>Sulfur</th>
<th>0.02%</th>
<th>Viscosity SSU</th>
<th>35.1 @ 100°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat content</td>
<td>18,730 Btu/lb</td>
<td>25.1 @ 210°F</td>
<td></td>
</tr>
<tr>
<td>Gravity API @ 60°F</td>
<td>26.9</td>
<td>Water &amp; Sediment</td>
<td>1.8%</td>
</tr>
<tr>
<td>Flash point</td>
<td>194°F</td>
<td>Water</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

**RECOVERY ALTERNATIVES**

Pyrolysis is the process by which complex organic materials are broken down by heat into a combustible gas, a liquid containing long-chain hydrocarbons, and a solid char. The quantity and quality of the liquid fuel produced by pyrolysis depends on the design and operating conditions of the pyrolysis unit. The longer the residence time in the pyrolysis reactor, and the higher the temperature in the reactor, the heavier the oil produced by pyrolysis.

**CURRENT STATE OF DEVELOPMENT**

The Garrett process, which was developed in cooperation with the Occidental Research Corporation, was used in a 200 tons/day demonstration plant constructed in El Cajon, California. Several major process problems were discovered, but financial support to modify the system was unavailable. Plant operations have been suspended.

A 150 tons/day system by the Enterprise Company was constructed for testing and development at South Gate, California in 1976. Testing and evaluation continued through 1978 when operations were terminated. No further development has occurred.

**Cost**

No detailed cost estimates are available for small to medium-scale installations applicable to Navy facilities. The Garrett process was developed under partial support of the U.S. EPA, with an estimated initial cost of $15 million. The Enterprise system was developed with private funds, with the amount not disclosed.
### FUEL MARKETS/USES

The fuel produced by the purification and polymerization of pyrolysis gas can be refined into a gasoline-like substitute fuel. This fuel can be used directly in gasoline engines or mixed with other supplies. The quantity of gasoline produced by this process has been estimated at approximately 42 gallons per ton of refuse.

### RECOVERY ALTERNATIVES

Pyrolysis systems can be designed and operated in a manner which increases the quantity of olefins (hydrocarbons with double carbon bonds) in the pyrolysis gas, and decreases the quantity of other pyrolysis products. The gas is then separated into components, and the olefins polymerized into gasoline. Alternatively, the synthetic crude oil produced by other pyrolysis systems can be refined into gasoline.

### STATE OF DEVELOPMENT

The bench-scale process for producing olefin-rich pyrolysis gas included the grinding of the refuse to .01-in diameter, injection of steam, and rapid heating to approximately 1300°F. The gas can then be cleaned to remove the char, and the olefins separated out. The olefins can then be converted to a gasoline substitute.

The conversion process described is only in its early development. Short-term bench-scale tests have been carried out, but no pilot or full-scale plans have been developed. More basic research, economic analysis, and testing is required before the process can be considered a viable recovery alternative. Additional data are not available.

### REFERENCES

Combustion systems (CS), the third and final system category presented in this report, is limited to those systems which consume a solid waste-derived fuel to produce an energy product (steam, hot water, hot gas, and/or electric power).

Subsections are presented for each of the following systems (codes are shown in parentheses):

- **Solid fuel (SF)**
  - Modular incinerators (MO)
  - Pulverized (PV)
  - Stokers (SF)
  - Fluidized bed (FB).

- **Liquid fuel (LF)**
  - Light fuel oil (LO)
  - Light fuel oil/solid slurry (LS)
  - Heavy fuel oil (HO)
  - Heavy fuel oil/solid slurry (HS)
  - Internal combustion engine (IC).

- **Gaseous fuel (GF)**
  - Low-Btu gas/natural gas mixture (LB)
  - High-Btu gas/natural gas mixture (HB)
  - Gas turbines (GT).

The content of the combustion system subsections provides equal emphasis on the marketing and technical aspects, under the following major headings:

- **Product markets:** product characteristics, uses, and specifications.
- **Applicable technology:** general description, unit operations, alternative configurations, cost.
- **Complementary systems and their impact.**

Some systems are considered developmental, and the subsection detail is reduced as appropriate. In these instances, a subsection entitled, "Stage of Development," replaces "Applicable Technology."
## PRODUCT MARKETS

### Product Characteristics

<table>
<thead>
<tr>
<th>Product</th>
<th>Range of Characteristics</th>
<th>Output/ton of solid waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam</td>
<td>100-280 psig, saturation</td>
<td>3,700 lb/ton (average)</td>
</tr>
<tr>
<td>Hot water</td>
<td>No use reported</td>
<td>Data not available</td>
</tr>
<tr>
<td>Hot gases</td>
<td>150-500°F expected</td>
<td>Data not available</td>
</tr>
<tr>
<td>Electric power</td>
<td>No use reported up to 1600°F expected</td>
<td>Data not available</td>
</tr>
<tr>
<td></td>
<td>200-1000 KWH expected</td>
<td>30-100 KWH per ton expected</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.008-0.027 KWH/lb steam expected</td>
</tr>
</tbody>
</table>

### Product end uses, specifications

<table>
<thead>
<tr>
<th>End Use</th>
<th>Average Btu/sq ft/yr (000)</th>
<th>Hot water Gal/sq ft/yr</th>
<th>Steam (lb/sq ft/yr)</th>
<th>Electrical (KWH/sq ft/yr)</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offices</td>
<td>55</td>
<td>336.4</td>
<td>39.5</td>
<td>6.1</td>
<td>A B C (all uses) D,E,G</td>
</tr>
<tr>
<td>Hospital</td>
<td>160</td>
<td>974.0</td>
<td>115.1</td>
<td>46.8</td>
<td>D,E,G</td>
</tr>
<tr>
<td>Training Facility</td>
<td>50</td>
<td>304.4</td>
<td>36.0</td>
<td>14.6</td>
<td>D,E,F,H</td>
</tr>
<tr>
<td>Housing Family</td>
<td>82</td>
<td>499.2</td>
<td>59.0</td>
<td>24.0</td>
<td>D,E,I</td>
</tr>
<tr>
<td>BOQ</td>
<td>61</td>
<td>371.3</td>
<td>43.9</td>
<td>17.9</td>
<td>D,E,I</td>
</tr>
<tr>
<td>Storage</td>
<td>50</td>
<td>34.4</td>
<td>36.0</td>
<td>14.6</td>
<td>D,E,J</td>
</tr>
<tr>
<td>Service</td>
<td>95</td>
<td>578.3</td>
<td>68.3</td>
<td>27.8</td>
<td>D,E,K</td>
</tr>
</tbody>
</table>

### Considerations

A. Budgets listed include a 45% energy reduction as mandated by E.0.12003 for new facilities. Existing facilities for which waste derived energy is being considered will have energy demands exceeding the values listed.

B. Hot water system calculations assumes 20°F temperature drop across radiator. 180°F input. For 30°F drop 2/3 the listed quantity would be required, a 10°F drop would require 2 times the listed quantity.

C. Based on metered rate for electrical energy. Generated rate would require approximately 3.4 times listed figure.

D. Demands listed are heating and cooling loads only. No process energy is supplied.

E. Values listed are heating and cooling loads based on national averages and typical building of this type. Local requirements will vary.

F. Nonworking hour loads will be substantially lower in most cases.

G. Noninterruptable supply is critical.

H. Demand will fluctuate widely with facility use patterns.

I. Demand will be 24 hour.

J. Cold storage facilities have approximately 2 times the demand as valves listed.

K. Includes laundry/dry cleaning, and commissary facilities.
### Unit operations

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Commonly Used Equipment</th>
<th>Reference No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Receiving area</td>
<td>Tipping floor, pit, front-end loader</td>
<td>Not included</td>
</tr>
<tr>
<td>2</td>
<td>Presorting area</td>
<td>Front-end loader, crane, manual</td>
<td>Not included</td>
</tr>
<tr>
<td>3</td>
<td>Loading</td>
<td>Manual-batch, hydraulic ram-batch, charging hopper-batch,</td>
<td>MH-B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>conveyor-continuous</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Incineration</td>
<td>Incinerator</td>
<td>CE-A</td>
</tr>
<tr>
<td>6</td>
<td>Steam generation</td>
<td>Waste heat boiler</td>
<td>CE-D</td>
</tr>
<tr>
<td>7</td>
<td>Ash removal</td>
<td>Quench pit, water spray conveyor</td>
<td>Not included</td>
</tr>
</tbody>
</table>

### Alternative Approaches

- **Shredding**: preprocessing by shredding can increase combustion efficiency by reducing particle size and increasing surface area for combustion.
- **Electrical generation**: ease of transport of product (electricity) and universal nature and relatively constant level of demand are plus factors. With extraction type turbine steam is released at approximately 110 psig. High pressure steam, >400 psig, is needed. Higher capital cost for equipment.

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Commonly Used Equipment</th>
<th>Reference No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Size reduction</td>
<td>Shredders</td>
<td>MH-E, MH-F</td>
</tr>
<tr>
<td>8</td>
<td>Electricity</td>
<td>Extraction turbine, backpressure</td>
<td>Not included</td>
</tr>
<tr>
<td></td>
<td>generation</td>
<td>turbine</td>
<td></td>
</tr>
</tbody>
</table>

### System Costs

#### Capital Costs

![Graph showing capital costs vs. capacity (TPD)]

#### Operating and Maintenance Costs

![Graph showing operating and maintenance costs vs. capacity (TPD)]

**Operating and Maintenance Costs**

Based on limited data, the expected shape of the curve is depicted.
Nomograph Use Procedure

1. Locate on line A the heating value (Btu/lb dry solids) of your alternate fuel. Typical heating values of solid waste are given in the graph below.

2. Locate on line B the moisture content of the solid waste fuel.

3. Draw a straight line through the alternate fuel heating value (line A) and moisture content (line B) to line C to determine the net heating value of one ton of alternate fuel.

4. Locate the price of the alternate fuel on line D.

5. Draw a straight line through the net heating value (line C) and price (line D) to line E to determine the net cost of alternate fuel in $/MM Btu.

6. Select your particular energy requirement or a multiple thereof from one of the four lines labeled F.

7. Transfer the energy requirement to line G by following the grid lines. Line G expresses your requirement in terms of MM Btu/hr natural gas equivalent energy.

8. Draw a straight line through the alternate fuel cost (line E) and energy requirement (line G) to line H.

9. Draw a straight line connecting the point on line H to the zero point on the left end of line I. This line intersects line K and the intersection point will be used in Step 13.

10. Locate the price currently being paid for fuel oil or natural gas on one of the lines labeled J.

11. Transfer the fuel price on line J to line E. This number represents your current fuel price expressed in $/MM Btu.

12. Draw a straight line through your current fuel cost (line E) and energy requirement (line G) to line H.

13. Draw a straight line to line I through the point determined in Step 12 and the intersection point previously established on line K (Step 9). The point located on line I by Step 13 gives a direct reading of annual fuel savings only. Multiply savings by scale factor used in Step 6.

This nomograph is based on the following criteria:
- 8,000-hour operating year
- Efficiencies based on 350°F exhaust temperature from heat recovery devices
- One gallon of #2 fuel oil provides 142,000 Btu
- Price of natural gas is based on 1,000 Btu cubic foot
- Savings are expressed as fuel cost differential only

Nomograph supplied by:
Thermal Processes, Inc.
Olympia Fields, IL 60461
Material Separation

- Removal of noncombustible components from the waste stream can benefit the operation of a packaged incinerator facility by increasing the net heating value of the feed on a per pound basis.

- Removal of the glass fraction can aid in preventing slagging of the bottom and ash removal grates, which has been a common problem in systems of this type.

Initial Size Reduction

- Preprocessing by shredding or other means may benefit an incineration system by improving combustion and burnout, and reduce the quantity of residue needing disposal. These economic tradeoffs associated with preprocessing have not been well defined.
**PRODUCT MARKETS**

**Product Characteristics**

<table>
<thead>
<tr>
<th>Product</th>
<th>As Designed</th>
<th>As Experienced</th>
<th>Quantity/Ton of Solid Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam</td>
<td>150-350 psig</td>
<td>100-300 psig</td>
<td>5,700 pounds</td>
</tr>
<tr>
<td>Electricity</td>
<td>500-600 kWh</td>
<td>400-500 kWh</td>
<td>400 kWh</td>
</tr>
<tr>
<td>Hot water</td>
<td>150-300°F</td>
<td>100-300°F</td>
<td>70-150 gpm</td>
</tr>
</tbody>
</table>

**APPLICABLE TECHNOLOGY**

**Unit Operations**

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Typical Equipment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Receive</td>
<td>Live bottom bin</td>
<td>MH-J</td>
</tr>
<tr>
<td>2</td>
<td>Feed</td>
<td>Primary shred (ferrous, AL, and glass free)</td>
<td>MH-E, MH-I, MH-L</td>
</tr>
<tr>
<td>3</td>
<td>Incinerator/boiler</td>
<td>Ram feeder (hydraulic)</td>
<td>Not included</td>
</tr>
<tr>
<td>4</td>
<td>Residue (manual dump)</td>
<td>Ash handling system (batch removal from ash pit)</td>
<td>CE-L, CE-O</td>
</tr>
<tr>
<td>4a</td>
<td>Continuous dumping</td>
<td>Ash handling system (drag chain conveyor in quench pit)</td>
<td>Not included</td>
</tr>
<tr>
<td>5</td>
<td>Pollution control</td>
<td>Baghouse, cyclone, or ESP</td>
<td>APC-A, APC-R, APC-C</td>
</tr>
<tr>
<td>6</td>
<td>Steam users</td>
<td>Load centers, as buildings, etc.</td>
<td>N/A</td>
</tr>
<tr>
<td>7</td>
<td>FW return</td>
<td>Feed water (FW) return or supply system (pumps, water treatment, generator, feed water heater, etc.)</td>
<td>N/A</td>
</tr>
</tbody>
</table>
### Alternative System Unit Operations

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Typical Equipment (Alternative System)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1'</td>
<td>Receive</td>
<td>Live bottom bin (fine shred material) RDF storage and retrieval.</td>
</tr>
<tr>
<td>2'</td>
<td>Feed</td>
<td>Pneumatic blowing of fine shredded RDF</td>
</tr>
<tr>
<td>3'</td>
<td>Incinerator/boiler</td>
<td>Dedicated boiler; semi-suspension firing (or) co-firing with coal, spreader-stoker firing</td>
</tr>
<tr>
<td>4'</td>
<td>Residue</td>
<td>Continuous ash dump, quench and drag chain ash removal, straining and hauling</td>
</tr>
<tr>
<td>5'</td>
<td>Pollution control</td>
<td>Baghouse, or ESP</td>
</tr>
<tr>
<td>6'</td>
<td>Steam user</td>
<td>Heating steam to building, etc.</td>
</tr>
<tr>
<td>7'</td>
<td>F.W. return</td>
<td>100% condensate return, water make-up or 100% treated water make-up</td>
</tr>
<tr>
<td>8'</td>
<td>Steam drive</td>
<td>Steam turbine (solar, Terry)</td>
</tr>
<tr>
<td>9'</td>
<td>Elec. generator</td>
<td>Electrical generator system</td>
</tr>
</tbody>
</table>

### Capital Costs - One Time Items

<table>
<thead>
<tr>
<th>Equipment</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site: Preparation, fence, landscaping</td>
<td>1.3</td>
</tr>
<tr>
<td>Building, foundation, steel, concrete</td>
<td>9.4</td>
</tr>
<tr>
<td>Incinerator/boiler, ID fan, pollution control, ash system</td>
<td>68.2</td>
</tr>
<tr>
<td>Pumps and drive</td>
<td>0.4</td>
</tr>
<tr>
<td>Water treatment</td>
<td>1.0</td>
</tr>
<tr>
<td>Process control panel</td>
<td>0.8</td>
</tr>
<tr>
<td>Stack and support</td>
<td>7.2</td>
</tr>
<tr>
<td>Construction and installation of equipment</td>
<td>1.7</td>
</tr>
<tr>
<td>Utilities (water, electrical, fuel, steam)</td>
<td>9.6</td>
</tr>
<tr>
<td>Engineering</td>
<td>100.0</td>
</tr>
</tbody>
</table>

### Capital Costs - (Maximum Value)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Tpd - $ \times 10^3$ (1980)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Prep &amp; Landscaping</td>
<td>20 30 50</td>
</tr>
<tr>
<td>Building, foundation, concrete</td>
<td>9.4 13.0 19.6</td>
</tr>
<tr>
<td>Incinerator/boiler, ID fan, pollution control, ash sys.</td>
<td>68.0 94.1 141.6</td>
</tr>
<tr>
<td>ID fan, pollution control, ash sys.</td>
<td>493.7 682.9 1,027.7</td>
</tr>
<tr>
<td>Pumps &amp; drives</td>
<td>3.0 4.0 6.0</td>
</tr>
<tr>
<td>Water treatment</td>
<td>7.2 10.0 15.1</td>
</tr>
</tbody>
</table>
COMBUSTION SYSTEMS

<table>
<thead>
<tr>
<th>Process control panel</th>
<th>Pulverized Refuse Incinerator</th>
<th>CS-SF-PV</th>
<th>P. 3 of 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack &amp; support</td>
<td>3.0</td>
<td>4.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Construction, etc.</td>
<td>5.8</td>
<td>81.021</td>
<td>108.5</td>
</tr>
<tr>
<td>Utilities</td>
<td>12.3</td>
<td>17.0</td>
<td>25.6</td>
</tr>
<tr>
<td>Engineering</td>
<td>69.5</td>
<td>96.1</td>
<td>144.7</td>
</tr>
<tr>
<td>Total Plant Facilities Invest. (PFI)</td>
<td>724.0</td>
<td>1,001.2</td>
<td>1,506.9</td>
</tr>
<tr>
<td>Startup &amp; organ. (5% of PFI)</td>
<td>36.2</td>
<td>50.0</td>
<td>75.3</td>
</tr>
<tr>
<td>Total Capital Inv.</td>
<td>760.2</td>
<td>1,051.2</td>
<td>1,582.2</td>
</tr>
</tbody>
</table>

Costs - Recurring (Annual) ($ x 10³ - 1980 $)

<table>
<thead>
<tr>
<th>Item</th>
<th>20</th>
<th>30</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>90.1</td>
<td>13.1</td>
<td>90.1</td>
</tr>
<tr>
<td>Residue</td>
<td>8.8</td>
<td>13.1</td>
<td>21.9</td>
</tr>
<tr>
<td>Electricity</td>
<td>3.5</td>
<td>5.3</td>
<td>8.8</td>
</tr>
<tr>
<td>Oil (trucks &amp; startup)</td>
<td>13.7</td>
<td>20.6</td>
<td>34.3</td>
</tr>
<tr>
<td>Water</td>
<td>1.8</td>
<td>3.2</td>
<td>5.0</td>
</tr>
<tr>
<td>Maintenance supplies (2% PFI)</td>
<td>14.5</td>
<td>20.0</td>
<td>30.1</td>
</tr>
<tr>
<td>Maintenance labor (2% PFI)</td>
<td>14.5</td>
<td>20.0</td>
<td>30.1</td>
</tr>
<tr>
<td>Chemical/water treatment</td>
<td>1.6</td>
<td>3.8</td>
<td>5.2</td>
</tr>
<tr>
<td>Admin Overhead (15% labor)</td>
<td>13.5</td>
<td>13.5</td>
<td>13.5</td>
</tr>
<tr>
<td>Total Operating Cost</td>
<td>162.0</td>
<td>189.6</td>
<td>290.0</td>
</tr>
</tbody>
</table>

Basis of Operating Cost Calculations

- Labor: 2 men/1st shift; 1 man/2nd shift, 16 hr/day (0.75 x 365) days/year $20,800/year cost of labor - including benefits.
- Equivalent of 4-1/3 people's cost.
- Elec. $0.04/kWh; 1.0 kw/tpd
- Oil: 40 gpd at $1.25/gallon
- Water: Assume 100% make-up, 10% blow down plus 8 gal/ton for ash quench and clean up.
- Labor cost includes substitute people needed to meet leave and emergency. Capital costs not included
- Net Operating Cost = Total operating cost minus credit as tipping fee, salvage of ferrous, aluminum, and glass and energy cost credit for steam or electricity.
- Residue = .4 x tpd x $4/ton

NOTE: For plants of 1 to 2 tph capacity, the labor and administration costs are approximately constant. Operating costs/ton decrease when plant is operating 3 shifts/day, 365 days/year. The realistic hours of operation are calculated here.

COMPLIMENTARY SYSTEMS - OPTION #2

The Option #2 consists of (1) pneumatic feeding of fine shredded refuse (2 stage shredding vs. single stage shredding of Option #1) and, (2) electricity generation instead of using the steam for process and building heating.
## COMBUSTION SYSTEMS

### Pulverized Refuse Incinerator

#### Cost Factors (Option #2)

1. Pneumatic feeder
2. Pneumatic fan
3. Pneumatic transport line
4. Installations

<table>
<thead>
<tr>
<th>Plant Facilities Investment (PFI)</th>
<th>20 TPD</th>
<th>30 TPD</th>
<th>50 TPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option #2A ($1980)</td>
<td>$749 \times 10^3</td>
<td>$1,033.7 \times 10^3</td>
<td>$1,554.4 \times 10^4</td>
</tr>
</tbody>
</table>

#### Option #2B - Electrical Generation

1. Steam turbine (non-condensing)
2. Generator
3. Controls, switchgear, and transformer
4. Pipeline, installation, and bldg.

<table>
<thead>
<tr>
<th>Plant Facilities Investment (PFI)</th>
<th>20 TPD</th>
<th>30 TPD</th>
<th>50 TPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option #2B ($1980)</td>
<td>$759 \times 10^3</td>
<td>$1,042 \times 10^3</td>
<td>$1,042 \times 10^3</td>
</tr>
</tbody>
</table>

#### Operating Costs ($1980)

<table>
<thead>
<tr>
<th>Option #2A - Same as Option #1</th>
<th>20 TPD</th>
<th>30 TPD</th>
<th>50 TPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option #2B (Additional over Option #1)</td>
<td>$72.8 \times 10^3</td>
<td>$72.8 \times 10^3</td>
<td>$72.8 \times 10^3</td>
</tr>
<tr>
<td>Labor/1 man extra shift x 2 shift/day + relief = 3/12 m</td>
<td>$0.7 \times 10^3</td>
<td>$0.8 \times 10^3</td>
<td>$1.2 \times 10^3</td>
</tr>
<tr>
<td>Maintenance supplies (2% PFI)</td>
<td>$85.1 \times 10^3</td>
<td>$85.3 \times 10^3</td>
<td>$86.1 \times 10^3</td>
</tr>
<tr>
<td>Admin. or Head (15% labor)</td>
<td>$10.9 \times 10^3</td>
<td>$10.9 \times 10^3</td>
<td>$10.9 \times 10^3</td>
</tr>
</tbody>
</table>

#### Comments

For small solid waste plant (1 to 2 tph), a modular solid waste boiler (type Basic Env. Eng. Co's unit or equivalent) is adequate. For such an incinerator/boiler single stage shredding with ram feeding of the primary shredded refuse is the best option. Generation of electricity is not recommended with saturated steam. For small boilers, superheated steam, although possible to generate, is not very common.

16 hours/day of operation is quite adequate. The boiler can be banked for the night and started again in the morning. The manpower estimated is minimum.

#### REFERENCES

### COMBUSTION SYSTEMS

<table>
<thead>
<tr>
<th>Stoker Boiler</th>
<th>CS-SF-SF</th>
<th>P. 1 of 4</th>
</tr>
</thead>
</table>

## PRODUCT MARKETS

### Product Characteristics

<table>
<thead>
<tr>
<th>Product</th>
<th>As Designed</th>
<th>As Experienced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output</td>
<td>Quantity/Ton of Solid Waste</td>
<td></td>
</tr>
<tr>
<td>Hot water</td>
<td>150-300°F</td>
<td>100-300°F</td>
</tr>
<tr>
<td></td>
<td>5,400 lb sat at 300 psig</td>
<td></td>
</tr>
<tr>
<td>Steam</td>
<td>150-300 psig</td>
<td>100-300 psig and saturated</td>
</tr>
<tr>
<td></td>
<td>5,400 lb sat at 300 psig</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>500 kW</td>
<td>400 kW</td>
</tr>
<tr>
<td></td>
<td>385 kW</td>
<td></td>
</tr>
</tbody>
</table>

### Product end uses, specifications

<table>
<thead>
<tr>
<th>End Use</th>
<th>Average Btu/sq ft/yr (000)</th>
<th>Hot water Gal/sq ft/yr</th>
<th>Steam lb/sq ft/yr</th>
<th>Electrical KWH/sq ft/yr</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offices:</td>
<td>55</td>
<td>336.4</td>
<td>39.5</td>
<td>16.1</td>
<td>ABC (all uses)</td>
</tr>
<tr>
<td>Hospital</td>
<td>160</td>
<td>974.0</td>
<td>115.1</td>
<td>46.8</td>
<td>D,E,G</td>
</tr>
<tr>
<td>Training</td>
<td>50</td>
<td>304.4</td>
<td>36.0</td>
<td>14.6</td>
<td>D,E,F,H</td>
</tr>
<tr>
<td>Housing Facility</td>
<td>82</td>
<td>499.2</td>
<td>59.0</td>
<td>24.0</td>
<td>D,E,I</td>
</tr>
<tr>
<td>BOQ</td>
<td>61</td>
<td>371.3</td>
<td>43.9</td>
<td>17.9</td>
<td>D,E,I</td>
</tr>
<tr>
<td>Storage</td>
<td>50</td>
<td>34.4</td>
<td>36.0</td>
<td>14.6</td>
<td>D,E,J</td>
</tr>
<tr>
<td>Service</td>
<td>95</td>
<td>578.3</td>
<td>68.3</td>
<td>27.8</td>
<td>D,E,K</td>
</tr>
</tbody>
</table>

**Considerations**

A. Budgets listed include a 45% energy reduction as mandated by E.O.12003 for new facilities. Existing facilities for which waste derived energy is being considered will have energy demands exceeding the values listed.

B. Hot water system calculations assumes 20°F temperature drop across radiator. 180°F input. For 30°F drop 2/3 the listed quantity would be required, a 10°F drop would require 2 times the listed quantity.

C. Based on metered rate for electrical energy. Generated rate would require approximately 3.4 times listed figure.

D. Demands listed are heating and cooling loads only. No process energy is supplied.

E. Values listed are heating and cooling loads based on national averages and typical building of this type. Local requirements will vary.

F. Nonworking hour loads will be substantially lower in most cases.

G. Noninterruptable supply is critical.

H. Demand will fluctuate widely with facility use patterns.

I. Demand will be 24 hour.

J. Cold storage facilities have approximately 2 times the demand as values listed.

K. Includes laundry/dry cleaning, and commissary facilities.
### COMBUSTION SYSTEMS

<table>
<thead>
<tr>
<th>Item</th>
<th>20</th>
<th>30</th>
<th>50</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>114.4</td>
<td>114.4</td>
<td>114.4</td>
<td>Equivalent of 5 1/2 people</td>
</tr>
<tr>
<td>Residue haul</td>
<td>9.9</td>
<td>14.8</td>
<td>24.6</td>
<td>Residue = 0.45 (wet) refuse and $4/ton for hauling cost</td>
</tr>
<tr>
<td>Electricity</td>
<td>3.5</td>
<td>5.3</td>
<td>8.8</td>
<td>Elec.: $0.04/kWh; 1.0 kW/Tpd</td>
</tr>
<tr>
<td>Water</td>
<td>1.8</td>
<td>3.2</td>
<td>5.0</td>
<td>(20 x 16 H/D x 365 x .75 D/Y x .04)</td>
</tr>
<tr>
<td>Chemical</td>
<td>1.6</td>
<td>3.8</td>
<td>5.2</td>
<td>Water: Assume 100% makeup, 10% blow down plus 8 gal/ton for ash quench and clean up.</td>
</tr>
<tr>
<td>Oil</td>
<td>6.8</td>
<td>10.2</td>
<td>17.0</td>
<td></td>
</tr>
<tr>
<td>Maintenance supplies (2% PFI)</td>
<td>12.8</td>
<td>18.0</td>
<td>27.5</td>
<td>Labor cost includes substitute people to meet summers, leave, and emergency.</td>
</tr>
<tr>
<td>Maintenance labor (2% PFI)</td>
<td>12.8</td>
<td>18.0</td>
<td>27.5</td>
<td></td>
</tr>
<tr>
<td>Admin. overhead (15% labor)</td>
<td>17.2</td>
<td>17.2</td>
<td>17.2</td>
<td></td>
</tr>
<tr>
<td>Total operating cost</td>
<td>168.0</td>
<td>204.9</td>
<td>247.2</td>
<td>Net operating cost = actual operating cost. (Credit tipping fee, salvage of ferrous, alum., glass) and energy cost credit for steam or electricity.)</td>
</tr>
<tr>
<td>Operating cost/ton/yr ($ x 10^3)</td>
<td>$8.4</td>
<td>$6.83</td>
<td>$4.94</td>
<td></td>
</tr>
</tbody>
</table>

### Capital Cost - Complementary System
- Steam turbine.
- Generator.
- Controls, switchgear, and transformers.
- Piping and installations.
### Unit Operations

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Typical Equipment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Receive</td>
<td>Live bottom sorted raw refuse</td>
<td>MG-H</td>
</tr>
<tr>
<td>2</td>
<td>Ram feed</td>
<td>Ram feeder (hydraulic)</td>
<td>Not included</td>
</tr>
<tr>
<td>3</td>
<td>Incinerator/boiler</td>
<td>Solid waste incinerator/boiler unit (steam or hot water, travelling grate)</td>
<td>CE-G</td>
</tr>
<tr>
<td>4</td>
<td>Pollution control</td>
<td>Baghouse or cyclone</td>
<td>APC-A, APC-B</td>
</tr>
<tr>
<td>5</td>
<td>Residue</td>
<td>Manual dump ash bin and removal system</td>
<td>Not included</td>
</tr>
<tr>
<td>6</td>
<td>Steam user</td>
<td>Heating and/or process steam or hot water user points</td>
<td>N/A</td>
</tr>
<tr>
<td>7</td>
<td>Boiler feed</td>
<td>Feed water supply (return) system including pump, heatup, and treatment</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### Alternative System

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Receive</td>
<td>Primary shred; Fe, aluminum and glass free MSW</td>
</tr>
<tr>
<td>2</td>
<td>Ram feed</td>
<td>Ram feeder (hydraulic)</td>
</tr>
<tr>
<td>3</td>
<td>Incinerator/boiler</td>
<td>Solid waste incinerator/boiler unit (steam or hot water, travelling grate)</td>
</tr>
<tr>
<td>4</td>
<td>Pollution control</td>
<td>Baghouse or cyclone</td>
</tr>
<tr>
<td>5</td>
<td>Residue</td>
<td>Manual dump ash bin and removal system</td>
</tr>
<tr>
<td>5A</td>
<td>Residue - Alt.</td>
<td>Continuous discharging ash dumping, quenching and handling system</td>
</tr>
<tr>
<td>6</td>
<td>Steam user</td>
<td>Heating and/or process steam or hot water user points</td>
</tr>
<tr>
<td>7</td>
<td>Boiler feed</td>
<td>Feed water supply (return) system including pump, heatup, and treatment</td>
</tr>
<tr>
<td>8</td>
<td>Steam drive</td>
<td>Steam turbine (non-condensing)</td>
</tr>
<tr>
<td>9</td>
<td>Electrical energy</td>
<td>Turbine-driven electrical generator system</td>
</tr>
<tr>
<td>COMBUSTION SYSTEMS</td>
<td>Stoker Boiler</td>
<td>CS-SF-SF</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------</td>
<td>----------</td>
</tr>
<tr>
<td>Estimated cost</td>
<td>20 Tpd</td>
<td>30 Tpd</td>
</tr>
<tr>
<td>(Plant facilities investment)</td>
<td>$675 \times 10^3$</td>
<td>$940.8 \times 10^3$</td>
</tr>
<tr>
<td>Operating cost (additional)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor 1 man/shift x 2 shifts</td>
<td>$72.8 \times 10^3$</td>
<td>$72.8 \times 10^3$</td>
</tr>
<tr>
<td>x factor for relief men</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance supplies (2% PFI)</td>
<td>0.7 \times 10^3</td>
<td>0.8 \times 10^3</td>
</tr>
<tr>
<td>Maintenance labor (2% PFI)</td>
<td>0.7 \times 10^3</td>
<td>0.8 \times 10^3</td>
</tr>
<tr>
<td>Admin. overhead (15% labor)</td>
<td>10.9 \times 10^3</td>
<td>10.9 \times 10^3</td>
</tr>
<tr>
<td>Total additional cost</td>
<td>$85.1 \times 10^3$</td>
<td>$85.3 \times 10^3$</td>
</tr>
</tbody>
</table>

Comments

Several different types of mechanical stokers are commonly used in processing solid wastes as shown and described below. However, for solid waste processing plants of 1 to 2 TPH capacity, a travelling grate type system is generally adopted. For 200 to 400 TPD plants, both reciprocating and rocking grate type stokers have been extensively used.

Stoker-fired units can handle both processed and unprocessed solid wastes. Normally, for spreader-stoker firing, processed solid waste fuel is fed onto the traveling grate and incinerated as it travels through the furnace. The stoker typically consists of a large grate occupying 100% of the cross-sectional area of the furnace. Forced draft and overfire air are supplied through the grates and walls over the solid waste bed. At the end of the grate, a conveyor is used to remove the ash.

REFERENCES

## COMBUSTION SYSTEMS
### Fluidized Bed

#### CS-SF-FB

## PRODUCT MARKETS

**Product Characteristics**

<table>
<thead>
<tr>
<th>Product</th>
<th>As Designed</th>
<th>As Experienced</th>
<th>Output Quantity/Ton of Solid Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water</td>
<td>150-300°F 1-5 atm</td>
<td>100-300°F 1-3 atm</td>
<td>200-100 gpm</td>
</tr>
<tr>
<td>Hot gases</td>
<td>100-200°F</td>
<td>N/A</td>
<td>400-2,000 SCFM</td>
</tr>
<tr>
<td>Steam</td>
<td>250 and 350 psig and saturated</td>
<td>150 and 300 psig and saturated</td>
<td>6,250 lb</td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td></td>
<td>638 kW</td>
</tr>
</tbody>
</table>

**Product end uses, specifications**

<table>
<thead>
<tr>
<th>End Use</th>
<th>Average Btu/sq ft/yr (000)</th>
<th>Hot water Gal/sq ft/yr</th>
<th>Steam lb/sq ft/yr</th>
<th>Electrical KWH/sq ft/yr</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offices</td>
<td>55</td>
<td>336.4</td>
<td>39.5</td>
<td>16.1</td>
<td>ABC (all uses) D,E,G, D,E,F,G H</td>
</tr>
<tr>
<td>Hospital</td>
<td>160</td>
<td>974.0</td>
<td>115.1</td>
<td>46.8</td>
<td>D,E,F,G</td>
</tr>
<tr>
<td>Training</td>
<td>50</td>
<td>304.4</td>
<td>36.0</td>
<td>14.6</td>
<td>D,E,F</td>
</tr>
<tr>
<td>Housing</td>
<td>82</td>
<td>499.2</td>
<td>59.0</td>
<td>24.0</td>
<td>D,E</td>
</tr>
<tr>
<td>Bachelor</td>
<td>61</td>
<td>371.3</td>
<td>43.9</td>
<td>17.9</td>
<td>D,E,I</td>
</tr>
<tr>
<td>Storage</td>
<td>50</td>
<td>34.4</td>
<td>36.0</td>
<td>14.6</td>
<td>D,E,J</td>
</tr>
<tr>
<td>Service</td>
<td>95</td>
<td>578.3</td>
<td>68.3</td>
<td>27.8</td>
<td>D,E,K</td>
</tr>
</tbody>
</table>

**Considerations**

A. Budgets listed include a 45% energy reduction as mandated by E.O.12003 for new facilities. Existing facilities for which waste derived energy is being considered will have energy demands exceeding the values listed.

B. Hot water system calculations assumes 20°F temperature drop across radiator. 180°F input. For 30°F drop 2/3 the listed quantity would be required, a 10°F drop would require 2 times the listed quantity.

C. Based on metered rate for electrical energy. Generated rate would require approximately 3.4 times listed figure.

D. Demands listed are heating and cooling loads only. No process energy is supplied.

E. Values listed are heating and cooling loads based on national averages and typical building of this type. Local requirements will vary.

F. Nonworking hour loads will be substantially lower in most cases.

G. Noninterruptable supply is critical.

H. Demand will fluctuate widely with facility use patterns.

I. Demand will be 24 hour.

J. Cold storage facilities have approximately 2 times the demand as valves listed.

K. Includes laundry/dry cleaning, and commissary facilities.
**APPLICABLE TECHNOLOGY**

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Typical Equipment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Receiving</td>
<td>Processed RDF receiving bin</td>
<td>Not included</td>
</tr>
<tr>
<td>2</td>
<td>Feeder</td>
<td>Hydraulic or equivalent ram</td>
<td>Not included</td>
</tr>
<tr>
<td>3</td>
<td>Air handling</td>
<td>Fluidizing air handling system</td>
<td>Not included</td>
</tr>
<tr>
<td>4</td>
<td>Combustor</td>
<td>Atmos/pressurized fluidized bed combustor</td>
<td>CE-C, CE-D</td>
</tr>
<tr>
<td>5</td>
<td>Residue</td>
<td>Residue removal system</td>
<td>Not included</td>
</tr>
<tr>
<td>6</td>
<td>Waste heat recovery</td>
<td>Waste heat boiler</td>
<td>CE-G</td>
</tr>
<tr>
<td>7</td>
<td>Pollution control</td>
<td>Baghouse or electrostatic precipitator</td>
<td>APC-A, APC-C</td>
</tr>
<tr>
<td>8</td>
<td>Heating steam users</td>
<td>Buildings and process heat users</td>
<td>N/A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number</th>
<th>Operation</th>
<th>Description</th>
<th>Reference No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Air heating</td>
<td>Air heating system</td>
<td>Not included</td>
</tr>
<tr>
<td>2</td>
<td>Steam drive</td>
<td>Steam turbine</td>
<td>CE-F</td>
</tr>
<tr>
<td>3</td>
<td>Electrical generation</td>
<td>Steam turbine-driven generator</td>
<td>CE-F</td>
</tr>
</tbody>
</table>

**Unit Operations**

1. Receiving
   - Fluidized bed combustor's feed should preferably be inert free (glass, metals, and nonmetals) and shredded. A front-end processing system, consisting of shredding, air classification, trommel operations, has to be adopted. For continuous operation the prepared receiving bin should have the capacity of 2 days of processing load.

4. Air handling
   - To maintain fluidizing inert bed temperature the air should be preheated.

6. Residue removal
   - Could be made automatic and continuous or intermittent and manual operation.
Option #1

Fuel preparation Fe and AL recovery, FRC, steam generation and heating load supply.

Refuse storage space for 72 hr of operation. Oversize material sorting and landfill disposal, mixed glass cullets and contaminated organics to landfill.

Option #2

Fuel preparation, metal recovery, FRC, steam generation, electric power generation, steam and power supply.

Steam at 150 psig - at saturation for Option 1 Steam at 300 psig and saturation expanding to 100 psig for heating load (Option 2 - co-generation, if selected)

Costs -(See graphs on Page 4.)

- Plant operating manpower
  - 10-50 TPD - 14 (3 shifts)
  - 50-100 TPD - 18 (3 shifts)
  - Over 100 TPD - 21 (3 shifts).
- In view of the fact that no commercial or municipal atmospheric fluidized bed combustors are in operation with MSW as feedstock, reliable operating costs could not be projected. Pilot plant data reveal 10 to 15% less cost when compared to conventional incineration system.

Design & Construction Cost Estimate

<table>
<thead>
<tr>
<th>Plant Investment Cost (Typical 50 TPD)</th>
<th>Thousands of $ (4th Quarter 1980)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Preparation</td>
<td>53.4</td>
<td>Cost of an atmospheric fluidizing bed combustor consisting of front-end processing facilities</td>
</tr>
<tr>
<td>Buildings</td>
<td>340.6</td>
<td></td>
</tr>
<tr>
<td>Front-end processing equipment including shredder, air classifier, magnetic separator, trommel, Al recovery, storage and retrieval</td>
<td>297.4</td>
<td></td>
</tr>
<tr>
<td>Atmos. fluidized bed combustor</td>
<td>120.7</td>
<td></td>
</tr>
<tr>
<td>Waste heat boiler</td>
<td>68.3</td>
<td></td>
</tr>
<tr>
<td>Ash handling equipment</td>
<td>35.8</td>
<td></td>
</tr>
<tr>
<td>Pollution control equipment</td>
<td>107.2</td>
<td></td>
</tr>
<tr>
<td>Material handling system</td>
<td>97.3</td>
<td></td>
</tr>
<tr>
<td>Boiler accessories and treatment</td>
<td>79.7</td>
<td></td>
</tr>
<tr>
<td>Engineering</td>
<td>130.6</td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td>119.3</td>
<td></td>
</tr>
<tr>
<td>Utilities</td>
<td>47.7</td>
<td></td>
</tr>
<tr>
<td>Contingencies</td>
<td>172.0</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>$1.67 x 10^6</td>
<td></td>
</tr>
</tbody>
</table>

- A fluidizing bed combustor and waste heat boiler system can attain:
  - Combustion efficiency greater than 90%
  - Overall thermal efficiency greater than 70%
  - Energy loss to surroundings less than 30%.
COMPLEMENTARY SYSTEMS

Separation of Materials

- Resource recovered (for sale): Ferrous, aluminum.
- Resource utilized: Cellulose stocks as paper and paper products. Organic stocks as food wastes, grass, wood, leather.
- Refuse discarded: Mixed colored glass, stone, dirt, and other inerts.

Comments, Notes

Atmospheric fluidized bed combustors have been operated to a limited extent with sewage sludges, wood and biomass products. However, many attempts of using MSW as feedstocks have not been very successful. The glass contents of the processed refuse, the high volatile matter content of MSW and other characteristics of MSW are not conducive to AFBC method of conversion process. DOE and EPA may be funding for demonstration projects this year (1981). (With Combustion Power Systems, ERCO, and Argonne National Laboratory.)

REFERENCES

1. L. Pruitt and Wilson, "Atmospheric Fluidized Bed Combustion of Municipal Solid Waste: Test Program Results." Presented at the Sixth International Conference on Fluidized Bed Combustion, Atlanta, Georgia, April 1980.
PRODUCT MARKETS

Product Characteristics

<table>
<thead>
<tr>
<th>Product</th>
<th>Range of Characteristics</th>
<th>Output Quantity/Ton of Solid Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water</td>
<td>150-300°F at 1-5 atm</td>
<td>25-85 gpm*</td>
</tr>
<tr>
<td>Steam</td>
<td>150-275 psig and saturated</td>
<td>3,000 lb/hr*</td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td>320 kW**</td>
</tr>
</tbody>
</table>

* Based on 36 gal of oil/ton of refuse oil - and 4.1 x 10^6 Btu/ton of refuse.
  Efficiency: 78%, effective enthalpy of steam = 1,060 Btu/lb.

** 9.4 lb steam/kW.

APPLICABLE TECHNOLOGY

Unit Operations

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Typical Equipment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Storage</td>
<td>Refuse-derived pyrofuel oil storage with heater</td>
<td>Not included</td>
</tr>
<tr>
<td>2</td>
<td>Storage</td>
<td>Residual fuel oil (optional or dual firing)</td>
<td>Not included</td>
</tr>
<tr>
<td>3</td>
<td>Heat source</td>
<td>Duel-oil burner assembly with controls</td>
<td>CE-J</td>
</tr>
<tr>
<td>4</td>
<td>Steam</td>
<td>Boiler (hot water or steam)</td>
<td>CE-G</td>
</tr>
<tr>
<td>5</td>
<td>Pollution control</td>
<td>Scrubber</td>
<td>APC-D</td>
</tr>
<tr>
<td>6</td>
<td>Supply</td>
<td>Steam to users points (heating)</td>
<td>N/A</td>
</tr>
<tr>
<td>7</td>
<td>Feed</td>
<td>Feed water system for boiler</td>
<td>N/A</td>
</tr>
</tbody>
</table>
### Costs - Capital - One Time Items (4th Quarter 1980)

(See graph on Page 4.)

<table>
<thead>
<tr>
<th>Equipment and Cost Factors</th>
<th>TPD - ($ x 10^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building, foundation &amp; concrete</td>
<td>20**</td>
</tr>
<tr>
<td>Site preparation</td>
<td>3.6</td>
</tr>
<tr>
<td>Boiler, burner, F.D. fan &amp; stack</td>
<td>150.1</td>
</tr>
<tr>
<td>Pumps</td>
<td>1.3</td>
</tr>
<tr>
<td>Water treatment</td>
<td>1.0</td>
</tr>
<tr>
<td>Boiler control</td>
<td>3.3</td>
</tr>
<tr>
<td>Polllution control</td>
<td>19.5</td>
</tr>
<tr>
<td>Construction &amp; supervision</td>
<td>16.4</td>
</tr>
<tr>
<td>Utilities installation</td>
<td>13.9</td>
</tr>
<tr>
<td>Engineering</td>
<td>23.9</td>
</tr>
<tr>
<td>Total plant facilities investment (PFI)</td>
<td>257.1</td>
</tr>
<tr>
<td>Organization &amp; startup (5%)</td>
<td>12.9</td>
</tr>
<tr>
<td>Interest of money Depreciation of equipment</td>
<td>omitted for Fed Project</td>
</tr>
</tbody>
</table>

| Total | 270.0 | 373.5 | 562.1 |

* Boiler cost - $50,000/# steam/hr 3,000 lb steam/ton of refuse/hr.

### Comments

- The capital cost of modular boiler fitted with gas/oil burner is a function of heat release rate or the capacity and the heat content of the fuel being fired.

### Costs - Recurring - (Operating per year)

(See graph on Page 4.)

<table>
<thead>
<tr>
<th>Equipment (Boiler System Only)</th>
<th>20</th>
<th>30</th>
<th>50</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>90.1</td>
<td>90.1</td>
<td>90.1</td>
<td>1, 2, 5</td>
</tr>
<tr>
<td>Electricity</td>
<td>3.5</td>
<td>5.3</td>
<td>8.8</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>1.8</td>
<td>3.2</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>Oil (trucks &amp; startup)</td>
<td>6.8</td>
<td>10.3</td>
<td>17.2</td>
<td></td>
</tr>
<tr>
<td>Chemical waste treatment</td>
<td>1.6</td>
<td>3.8</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>Maintenance supplies</td>
<td>5.2</td>
<td>7.1</td>
<td>10.7</td>
<td></td>
</tr>
<tr>
<td>Maintenance labor</td>
<td>5.2</td>
<td>7.1</td>
<td>10.7</td>
<td></td>
</tr>
<tr>
<td>Admin. overhead</td>
<td>13.5</td>
<td>13.5</td>
<td>13.5</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>127.7</td>
<td>140.4</td>
<td>161.2</td>
<td></td>
</tr>
<tr>
<td>Operating cost ($/ton)</td>
<td>6.38</td>
<td>4.67</td>
<td>3.22</td>
<td></td>
</tr>
</tbody>
</table>
COMBUSTION SYSTEMS

Light Fuel Oil

CS-LF-LO

P. 3 of 4

Note: Cost of "pyrofuel" is not taken into account. Pyrofuel has 10,500 Btu/# heating value and $1.00/gal (delivered).

Basis for Costing

Labor: 2 men/1st shift + 1 man/2nd shift - 16 hr/day; $20,800/yr including benefits.

Fuel: $4.5/10^6 Btu, 75% utilization - 16 hr/day, at 4.1 x 10^6 Btu/ton.

Water: 100% makeup + 10% B.D. $0.60/1,000 gal.

Electricity: 1 kW/TPD and $0.04/kWh.

Maintenance: Supplies 2% of capital cost.

Admin. overhead: 15% of operating labor.

Maintenance: labor 2% of PPI.

COMPLEMENTARY SYSTEMS

High pressure steam (300 psig and above) can be used to drive pumps, fans, etc., or to generate electricity by using steam turbine-driven generator. The cost of turbine generator set with transformer and switch gear installed = $50K. (The turbine is of non-condensing type.)

For condensing turbine the cost of condenser, cooling water and deaerater, etc., will be required.

For small processing applications, the system(s) described are not economically justifiable.

To fire residual fuel to produce 50% of boiler load, the cost of oil has to be included in the operating cost. Residual oil has 135,000 Btu/gal and costs $1.00/gal (delivered).

Comments, Notes

The liquid fuel is assumed to have been produced by an appropriate pyrolysis process using MSW as the feedstock (see III-J). Although several attempts and demonstration projects have been tried, no commercial system is now in operation in the public or private sector. The technology has been demonstrated to be feasible by Tech-Air Systems.

Pyrofuel is highly oxygenated organic liquid and contains a high moisture content. The heating values assumed are published values of Occidental and Tech-Air systems.

REFERENCES

## COMBUSTION SYSTEMS

**Light Fuel Oil/ Solid Slurry**

### CS-LF-LS

**P. 1 of 3**

### PRODUCT MARKETS

**Product Characteristics**

<table>
<thead>
<tr>
<th>Product</th>
<th>As Designed</th>
<th>As Experienced</th>
<th>Output Quantity/Ton of Solid Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water</td>
<td>150-300°F at 1-5 atm</td>
<td>100-250°F at 1-4 atm</td>
<td>20-100 gpm</td>
</tr>
<tr>
<td>Steam</td>
<td>100-300 psig</td>
<td>100-300 psig</td>
<td>4,800 lb/ton</td>
</tr>
<tr>
<td>Electricity</td>
<td>9.4 lbs STM/kW</td>
<td>9.4 lbs STM/kW</td>
<td>510 kW/ton</td>
</tr>
</tbody>
</table>

### APPLICABLE TECHNOLOGY

![Diagram of system operations](image)

**Unit Operations**

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Typical Equipment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Storage</td>
<td>MSW receiving and storage (processed/unprocessed)</td>
<td>MH-J</td>
</tr>
<tr>
<td>2</td>
<td>Storage</td>
<td>Pyrofuel storage and distribution</td>
<td>Not included</td>
</tr>
<tr>
<td>3</td>
<td>Heat source</td>
<td>Fuel oil burner</td>
<td>CE-H</td>
</tr>
<tr>
<td>4</td>
<td>Steam</td>
<td>Solid waste boiler</td>
<td>CE-G</td>
</tr>
<tr>
<td>5</td>
<td>Pollution control</td>
<td>Optional (controlled air unit - none required)</td>
<td>APC-A, APC-C, APC-D</td>
</tr>
<tr>
<td>6</td>
<td>Residue</td>
<td>Ash handling and disposal</td>
<td>Not included</td>
</tr>
<tr>
<td>7</td>
<td>Supply</td>
<td>Heating steam users</td>
<td>N/A</td>
</tr>
<tr>
<td>8</td>
<td>Return</td>
<td>Feed water system for boiler</td>
<td>Not included</td>
</tr>
</tbody>
</table>

### System Alternatives

<table>
<thead>
<tr>
<th>Number</th>
<th>Operation</th>
<th>Description</th>
<th>Option #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Steam drive</td>
<td>Steam turbine (non-condensing)</td>
<td>Produce steam and generate electricity to supply power to process train drives.</td>
</tr>
<tr>
<td>10</td>
<td>Electrical power</td>
<td>Turbine-driven electrical generator</td>
<td></td>
</tr>
</tbody>
</table>

**IV-22**
COMBUSTION SYSTEMS

<table>
<thead>
<tr>
<th></th>
<th>Light Fuel Oil/Solid Slurry</th>
<th>CS-LF-LS</th>
<th>P. 2 of 3</th>
</tr>
</thead>
</table>

Costs - Capital - One Time Items (4th Quarter 1980) Option #1 (See graph on Page 3.)

<table>
<thead>
<tr>
<th>TPD - ($ x 10^3)</th>
<th>Cost Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Site preparation</td>
<td>8.6</td>
</tr>
<tr>
<td>Building, foundation and concrete</td>
<td>57.8</td>
</tr>
<tr>
<td>Incinerator/boiler burner, fans steam</td>
<td>359.1</td>
</tr>
<tr>
<td>Pumps &amp; drives</td>
<td>3.1</td>
</tr>
<tr>
<td>Combustion controls</td>
<td>8.0</td>
</tr>
<tr>
<td>Water treatment</td>
<td>2.5</td>
</tr>
<tr>
<td>Pollution control</td>
<td>46.7</td>
</tr>
<tr>
<td>Construction</td>
<td>38.7</td>
</tr>
<tr>
<td>Utilities</td>
<td>33.1</td>
</tr>
<tr>
<td>Engineering and inspection</td>
<td>57.2</td>
</tr>
<tr>
<td>Total plant facilities investment (PSI)</td>
<td>614.4</td>
</tr>
<tr>
<td>Startup &amp; organization (5% PSI)</td>
<td>30.7</td>
</tr>
<tr>
<td>Total</td>
<td>645.1</td>
</tr>
</tbody>
</table>

* This unit is similar to solid waste boiler with ash removal system plus burners for pyrofuel.

(50% Oil & 50% MSW) (See graph on Page 3.)

<table>
<thead>
<tr>
<th></th>
<th>20</th>
<th>30</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>$90.1</td>
<td>$90.1</td>
<td>$90.1</td>
</tr>
<tr>
<td>Residue handling</td>
<td>5.0</td>
<td>8.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Electricity</td>
<td>3.5</td>
<td>5.3</td>
<td>8.8</td>
</tr>
<tr>
<td>Oil</td>
<td>13.7</td>
<td>20.6</td>
<td>34.3</td>
</tr>
<tr>
<td>Water</td>
<td>1.8</td>
<td>3.2</td>
<td>5.0</td>
</tr>
<tr>
<td>Chemical (water treatment)</td>
<td>1.6</td>
<td>3.8</td>
<td>5.2</td>
</tr>
<tr>
<td>Maintenance supplies (2% PFI)</td>
<td>12.3</td>
<td>17.0</td>
<td>25.6</td>
</tr>
<tr>
<td>Admin overhead (15% labor)</td>
<td>13.5</td>
<td>13.5</td>
<td>13.5</td>
</tr>
<tr>
<td>Maintenance labor (2% PFI)</td>
<td>12.3</td>
<td>17.0</td>
<td>25.6</td>
</tr>
<tr>
<td>Total</td>
<td>$153.8</td>
<td>$178.5</td>
<td>$220.1</td>
</tr>
<tr>
<td>Cost ($/ton)</td>
<td>$7.69</td>
<td>$5.95</td>
<td>$4.40</td>
</tr>
</tbody>
</table>

COMPLEMENTARY SYSTEMS (OPTION #2)

High pressure steam above 300 psig can be utilized to generate electricity or to drive process equipment or to generate electrical power. For power generation the estimated installed cost of the turbo-generator set, transformer, switchgear, etc. is $50,000 (1980 dollars).
Comments, Notes

The pyrofuel can be used in conjunction with solid waste by spraying over the waste inside the combustion chamber. An expensive burner may not be required. For a controlled air modular unit the pyrofuel can be used for the secondary combustion chamber to sustain combustion of unburned hydrocarbon gases, as well as, in the primary chamber to keep the combustion chamber hot. The oil heat may be utilized to vaporize the moisture from the solid waste (inside the combustion chamber).

REFERENCES

### Product Markets

#### Product Characteristics

<table>
<thead>
<tr>
<th>Product</th>
<th>Range of Characteristics</th>
<th>Output Quantity/Ton of Solid Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>As Designed</td>
<td>As Experienced</td>
</tr>
<tr>
<td>Hot water</td>
<td>Up to 425°F, normally up to 250°F, 160 psig.</td>
<td>Heavy oil boilers in these ranges do exist, number firing waste fuels unknown.</td>
</tr>
<tr>
<td>Steam</td>
<td>Up to 900°F, 1650 psig, normally limited to 900°F, 1 to 75 psig.</td>
<td></td>
</tr>
<tr>
<td>Cogeneration of electricity</td>
<td>Up to 15 MW</td>
<td></td>
</tr>
</tbody>
</table>

#### Product End Uses, Specifications

<table>
<thead>
<tr>
<th>End Use</th>
<th>Average Btu/sq ft/yr (000)</th>
<th>Hot water Gal/sq ft/yr</th>
<th>Steam (lb/sq ft/yr)</th>
<th>Electrical (KWH/sq ft/yr)</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offices</td>
<td>55</td>
<td>336.4</td>
<td>39.5</td>
<td>16.1</td>
<td>ABC (all uses)</td>
</tr>
<tr>
<td>Hospital</td>
<td>160</td>
<td>974.0</td>
<td>115.1</td>
<td>46.8</td>
<td>D,E,G,H</td>
</tr>
<tr>
<td>Training</td>
<td>50</td>
<td>304.4</td>
<td>36.0</td>
<td>14.6</td>
<td>D,E,F,H</td>
</tr>
<tr>
<td>Facility</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D,E,F,H</td>
</tr>
<tr>
<td>Housing</td>
<td>82</td>
<td>499.2</td>
<td>59.0</td>
<td>24.0</td>
<td>D,E,I</td>
</tr>
<tr>
<td>Family</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>D,E,I</td>
</tr>
<tr>
<td>800</td>
<td>61</td>
<td>371.3</td>
<td>43.9</td>
<td>17.9</td>
<td>D,E,I</td>
</tr>
<tr>
<td>Storage</td>
<td>50</td>
<td>34.4</td>
<td>36.0</td>
<td>14.6</td>
<td>D,E,J</td>
</tr>
<tr>
<td>Service</td>
<td>95</td>
<td>578.3</td>
<td>68.3</td>
<td>27.8</td>
<td>D,E,K</td>
</tr>
</tbody>
</table>

**Considerations**

A. Budgets listed include a 45% energy reduction as mandated by E.O.12003 for new facilities. Existing facilities for which waste derived energy is being considered will have energy demands exceeding the values listed.

B. Hot water system calculations assumes 20°F temperature drop across radiator, 180°F input. For 30°F drop 2/3 the listed quantity would be required, a 10°F drop would require 2 times the listed quantity.

C. Based on metered rate for electrical energy. Generated rate would require approximately 3.4 times listed figure.

D. Demands listed are heating and cooling loads only. No process energy is supplied.

E. Values listed are heating and cooling loads based on national averages and typical building of this type. Local requirements will vary.

F. Nonworking hour loads will be substantially lower in most cases.

G. Noninterruptable supply is critical.
H. Demand will fluctuate widely with facility use patterns.
I. Demand will be 24 hour.
J. Cold storage facilities have approximately 2 times the demand as values listed
K. Includes laundry/dry cleaning, and commissary facilities.

**APPLICABLE TECHNOLOGY**

![Flow diagram of combustion system]

**Unit Operations**

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Typical Equipment</th>
<th>Reference No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oil source</td>
<td>Tanks</td>
<td>Not included</td>
</tr>
<tr>
<td>2</td>
<td>Waste oil source</td>
<td>Tanks</td>
<td>Not included</td>
</tr>
<tr>
<td>3</td>
<td>Mixer</td>
<td>Mixer</td>
<td>Not included</td>
</tr>
<tr>
<td>4</td>
<td>Boiler</td>
<td>Firetube or water tube</td>
<td>CE-G</td>
</tr>
<tr>
<td>5</td>
<td>Economizer</td>
<td>Fired tube</td>
<td>Not included</td>
</tr>
<tr>
<td>6</td>
<td>Air preheater</td>
<td>Regenerative heaters</td>
<td>Non included</td>
</tr>
<tr>
<td>7</td>
<td>Stack</td>
<td>Stack and possible cyclone</td>
<td>Not included</td>
</tr>
<tr>
<td>8</td>
<td>Energy user</td>
<td>Space heater</td>
<td>N/A</td>
</tr>
<tr>
<td>9</td>
<td>Condensate return</td>
<td>Water treatment system</td>
<td>Not included</td>
</tr>
</tbody>
</table>

**System Alternatives**

<table>
<thead>
<tr>
<th>Number</th>
<th>Operation</th>
<th>Description</th>
<th>Reference No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oil source</td>
<td>Drums</td>
<td>Not included</td>
</tr>
<tr>
<td>5</td>
<td>Economizers</td>
<td>Increase overall thermal efficiency.</td>
<td>Not included</td>
</tr>
<tr>
<td>6</td>
<td>Air Preheaters</td>
<td>Increase overall thermal efficiency.</td>
<td>Not included</td>
</tr>
<tr>
<td>7</td>
<td>Cyclone</td>
<td>ESP or air pollution control equipment may be required.</td>
<td>APC-C, APC-B</td>
</tr>
</tbody>
</table>

**Unit Operations**

<table>
<thead>
<tr>
<th>Unit</th>
<th>Operations</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Mixer</td>
<td>Premixed could be bought or separate supply lines could be employed.</td>
</tr>
<tr>
<td>4</td>
<td>Boiler</td>
<td>Firetube below about 15,000 lb steam/hour</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Watertube above this; larger firetube units and smaller watertube are not uncommon.</td>
</tr>
</tbody>
</table>
### PRODUCT MARKETS

#### Product Characteristics

<table>
<thead>
<tr>
<th>Product</th>
<th>Range of Characteristics</th>
<th>Output Quantity/Ton of Solid Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water</td>
<td>Up to 425°F normally up to 250°F, 160 psig.</td>
<td>Heavy fuel oil-coal slurries tested in utility boilers; unknown where heavy fuel oil/solid waste slurries have been used.</td>
</tr>
<tr>
<td>Steam</td>
<td>Up to 900°F, 1,650 psig normally limited to 900°F, 1,075 psig.</td>
<td>Data not available, see Fuel Recovery</td>
</tr>
<tr>
<td>Cogeneration of electricity</td>
<td>Up to 15 MW</td>
<td></td>
</tr>
</tbody>
</table>

#### Product End Uses, Specifications

<table>
<thead>
<tr>
<th>End Use</th>
<th>Average Btu/sq ft/yr (000)</th>
<th>Hot water Gal/sq ft/yr</th>
<th>Steam (lb/sq ft/yr)</th>
<th>Electrical (KWH/sq ft/yr)</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offices:</td>
<td>55</td>
<td>336.4</td>
<td>39.5</td>
<td>16.1</td>
<td>D,E,G,L</td>
</tr>
<tr>
<td>Hospital</td>
<td>160</td>
<td>974.0</td>
<td>115.1</td>
<td>46.8</td>
<td>D,E,G,J,B</td>
</tr>
<tr>
<td>Training Facility</td>
<td>50</td>
<td>304.4</td>
<td>36.0</td>
<td>14.6</td>
<td>D,E,F,H</td>
</tr>
<tr>
<td>Housing Family</td>
<td>82</td>
<td>499.2</td>
<td>59.0</td>
<td>24.0</td>
<td>D,E,I,K</td>
</tr>
<tr>
<td>Storage</td>
<td>61</td>
<td>371.3</td>
<td>43.9</td>
<td>17.9</td>
<td>D,E,I</td>
</tr>
<tr>
<td>Service</td>
<td>95</td>
<td>578.3</td>
<td>68.3</td>
<td>27.8</td>
<td>D,E,J,K</td>
</tr>
</tbody>
</table>

#### Considerations

A. Budgets listed include a 45% energy reduction as mandated by E.O. 12003 for new facilities. Existing facilities for which waste derived energy is being considered will have energy demands exceeding the values listed.

B. Hot water system calculations assumes 20°F temperature drop across radiator. For 30°F drop 2/3 the listed quantity would be required, a 10°F drop would require 2 times the listed quantity.

C. Based on metered rate for electrical energy. Generated rate would require approximately 3.4 times listed figure.

D. Demands listed are heating and cooling loads only. No process energy is supplied.

E. Values listed are heating and cooling loads based on national averages and typical building of this type. Local requirements will vary.

F. Nonworking hour loads will be substantially lower in most cases.

G. Noninterruptable supply is critical.

H. Demand will fluctuate widely with facility use patterns.

I. Demand will be 24 hour.
| Costs - Capital - One Time Items (capacity in $10^3$ lb/hr steam, cost in $\$000$) |
|---|---|---|---|
| **Equipment** | 12 | 25 | 130 |
| **Capacity** | Equipment cost | $103$ | $265$ | $919$ |
| **Reference** | Installation cost | $168$ | $224$ | $388$ |
| **System Efficiency** | Engineering | $27$ | $49$ | $131$ |
| | Construction | $27$ | $49$ | $131$ |
| | Construction expense | $27$ | $49$ | $131$ |
| | Startup | $8$ | $13$ | $30$ |
| | Contingencies | $72$ | $130$ | $346$ |
| | Subtotal | $432$ | $779$ | $2,076$ |
| | Land | $3$ | $3$ | $6$ |
| | Working capital | $70$ | $81$ | $151$ |
| | (fuel excluded) | Total | $505$ | $863$ | $2,233$ |

| Costs - Recurring |
|---|---|---|---|
| **Equipment** | 12 | 25 | 130 |
| **Capacity** | Labor and supervision | $174$ | $174$ | $335$ |
| | Maintenance | $68$ | $75$ | $149$ |
| | Electricity | $16$ | $35$ | $56$ |
| | Steam | $17$ | $35$ | $56$ |
| | Water | $1$ | $1$ | $3$ |
| | Chemicals | $3$ | $3$ | $7$ |
| | (14%) | (4%) | (14%) |
| | Total | $279$ | $323$ | $606$ |
| **Overhead** | Payroll | $52$ | $52$ | $100$ |
| | Plant | $63$ | $65$ | $126$ |
| **Capital charges** | G&A, and insurance | $17$ | $31$ | $83$ |
| | Capital recovery | $60$ | $109$ | $291$ |
| | Total (fuel) | $419$ | $590$ | $1,224$ |

**Comments - Notes**

The system is assumed to be a normal residual oil boiler in which some waste oils may be fired. Any special problems associated with the oil must be decided on a case-by-case basis. The ash content of the waste oil must not be too different from that of normal residual oil. The waste oil should be first treated to remove particulate matter. Luber-finer systems have been used to clean lube oils before mixing. Dirt can plug burner nozzle. Also boiler is not designed to handle large ash levels.
J. Cold storage facilities have approximately 2 times the demand as valves listed K. Includes laundry/dry cleaning, and commissary facilities.

### APPLICABLE TECHNOLOGY

![Combustion System Diagram](image)

#### Unit Operations

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Typical Equipment</th>
<th>Option #1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oil source</td>
<td>Tank</td>
<td>Not included</td>
</tr>
<tr>
<td>2</td>
<td>Solid waste</td>
<td>Solid waste</td>
<td>N/A</td>
</tr>
<tr>
<td>3</td>
<td>Mixer</td>
<td>Pulverized and mixer</td>
<td>Not included</td>
</tr>
<tr>
<td>4</td>
<td>Boiler</td>
<td>Firetube or watertube-tube spacing and furnace size dependent on ash content</td>
<td>CE-G</td>
</tr>
<tr>
<td>5</td>
<td>Economizer</td>
<td>Fired tube if ash content is low</td>
<td>Not included</td>
</tr>
<tr>
<td>6</td>
<td>Air preheater</td>
<td>Regenerative heater</td>
<td>Not included</td>
</tr>
<tr>
<td>7</td>
<td>Stack</td>
<td>Stack and cyclone</td>
<td>Not included</td>
</tr>
<tr>
<td>8</td>
<td>Energy user</td>
<td>Space heater</td>
<td>N/A</td>
</tr>
<tr>
<td>9</td>
<td>Condensate return</td>
<td>Condensate return</td>
<td>Not included</td>
</tr>
</tbody>
</table>

#### System Alternatives

<table>
<thead>
<tr>
<th>Number</th>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Oil source</td>
<td>Drums.</td>
</tr>
<tr>
<td>3</td>
<td>Mixer</td>
<td>Buy ready mixed slurries and thus not needed.</td>
</tr>
<tr>
<td>5</td>
<td>Economizer</td>
<td>Increase overall thermal efficiency.</td>
</tr>
<tr>
<td>6</td>
<td>Air preheater</td>
<td>Increase overall thermal efficiency.</td>
</tr>
<tr>
<td>7</td>
<td>Cyclone</td>
<td>ESP, wet scrubber, possibly baghouse.</td>
</tr>
</tbody>
</table>

#### Unit Operation Comments

<table>
<thead>
<tr>
<th>Unit</th>
<th>Operation</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Boiler</td>
<td>Firetube below about 15,000 lb steam/hr. Ash content of fuel decides type of firetube on or watertube boiler to be used.</td>
</tr>
<tr>
<td>7</td>
<td>Baghouse</td>
<td>Cannot be used on boiler firing oil only; type of ash from solid waste may allow its use.</td>
</tr>
</tbody>
</table>
### COMBUSTION SYSTEMS

<table>
<thead>
<tr>
<th>Equipment</th>
<th>12</th>
<th>25</th>
<th>130</th>
<th>References</th>
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<tbody>
<tr>
<td>Equipment cost</td>
<td>103</td>
<td>265</td>
<td>919</td>
<td>T. Devitt, et al.,</td>
</tr>
<tr>
<td>Engineering</td>
<td>27</td>
<td>49</td>
<td>131</td>
<td></td>
</tr>
<tr>
<td>Construction expense</td>
<td>27</td>
<td>49</td>
<td>131</td>
<td></td>
</tr>
<tr>
<td>Construction fees</td>
<td>27</td>
<td>49</td>
<td>131</td>
<td></td>
</tr>
<tr>
<td>Startup</td>
<td>8</td>
<td>13</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Contingencies</td>
<td>72</td>
<td>130</td>
<td>346</td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td>432</td>
<td>779</td>
<td>2,076</td>
<td></td>
</tr>
<tr>
<td>Land</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Working capital (fuel excluded)</td>
<td>70</td>
<td>80</td>
<td>151</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>505</td>
<td>863</td>
<td>2,233</td>
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</table>

### Costs - Recurring (See graph on Page 4.)

<table>
<thead>
<tr>
<th>Equipment</th>
<th>12</th>
<th>25</th>
<th>130</th>
<th>References</th>
</tr>
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<tbody>
<tr>
<td>Maintenance</td>
<td>68</td>
<td>75</td>
<td>149</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>16</td>
<td>35</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Steam</td>
<td>17</td>
<td>35</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Chemicals</td>
<td>3</td>
<td>3</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td>279</td>
<td>323</td>
<td>606</td>
<td></td>
</tr>
<tr>
<td>Overhead</td>
<td></td>
<td></td>
<td></td>
<td>Oil/solid mixing system as well as fuel costs are not included.</td>
</tr>
<tr>
<td>Payroll</td>
<td>52</td>
<td>52</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Plant</td>
<td>63</td>
<td>65</td>
<td>126</td>
<td></td>
</tr>
<tr>
<td>Capital charges</td>
<td>17</td>
<td>31</td>
<td>84</td>
<td>(4%)</td>
</tr>
<tr>
<td>G&amp;A, and insurance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital recovery</td>
<td>60</td>
<td>109</td>
<td>291</td>
<td>(14%)</td>
</tr>
<tr>
<td>Working capital interest</td>
<td>8</td>
<td>10</td>
<td>18</td>
<td>(12%)</td>
</tr>
<tr>
<td>Total (fuel excluded)</td>
<td>419</td>
<td>590</td>
<td>1,224</td>
<td></td>
</tr>
</tbody>
</table>
## COMBUSTION SYSTEMS

### Internal Combustion Engines

#### CS-LF-IC

## PRODUCT MARKETS

### Product Characteristics

<table>
<thead>
<tr>
<th>Product</th>
<th>As Designed</th>
<th>As Experienced</th>
<th>Output Quantity/Ton of Solid Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot liquids</td>
<td>Not available</td>
<td>Not available</td>
<td>Small</td>
</tr>
<tr>
<td>Hot gases</td>
<td>500-600°F</td>
<td>Not available</td>
<td>10-80,000 CFM</td>
</tr>
<tr>
<td>Electricity</td>
<td>30-35,000 kW</td>
<td>Not available</td>
<td>Not available</td>
</tr>
<tr>
<td>Mechanical power</td>
<td>40-50,000 hp</td>
<td>40-50,000 hp</td>
<td>Not available</td>
</tr>
</tbody>
</table>

### Product end uses, specifications

<table>
<thead>
<tr>
<th>End Use</th>
<th>Average Btu/sq ft/yr (000)</th>
<th>Hot water Gal/sq ft/yr</th>
<th>Steam (lb/sq ft/yr)</th>
<th>Electrical (KWH/sq ft/yr)</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offices</td>
<td>55</td>
<td>336.4</td>
<td>39.5</td>
<td>16.1</td>
<td>ABC (all uses)</td>
</tr>
<tr>
<td>Hospital</td>
<td>160</td>
<td>974.0</td>
<td>115.1</td>
<td>46.8</td>
<td>D,E,F,G</td>
</tr>
<tr>
<td>Training</td>
<td>50</td>
<td>304.4</td>
<td>36.0</td>
<td>14.6</td>
<td>D,E,F,H</td>
</tr>
<tr>
<td>Housing</td>
<td>82</td>
<td>499.2</td>
<td>59.0</td>
<td>24.0</td>
<td>D,E,I</td>
</tr>
<tr>
<td>Family</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BNO</td>
<td>61</td>
<td>371.3</td>
<td>43.9</td>
<td>17.9</td>
<td>D,E,I</td>
</tr>
<tr>
<td>Storage</td>
<td>50</td>
<td>34.4</td>
<td>36.0</td>
<td>14.6</td>
<td>D,E,J</td>
</tr>
<tr>
<td>Service</td>
<td>95</td>
<td>578.3</td>
<td>68.3</td>
<td>27.8</td>
<td>D,E,K</td>
</tr>
</tbody>
</table>

### Considerations

A. Budgets listed include a 45% energy reduction as mandated by E.0.12003 for new facilities. Existing facilities for which waste derived energy is being considered will have energy demands exceeding the values listed.

B. Hot water system calculations assumes 20°F temperature drop across radiator, 180°F input. For 30°F drop 2/3 the listed quantity would be required, a 10°F drop would require 2 times the listed quantity.

C. Based on metered rate for electrical energy. Generated rate would require approximately 3.4 times listed figure.

D. Demands listed are heating and cooling loads only. No process energy is supplied.

E. Values listed are heating and cooling loads based on national averages and typical building of this type. Local requirements will vary.

F. Nonworking hour loads will be substantially lower in most cases.

G. Noninterruptable supply is critical.

H. Demand will fluctuate widely with facility use patterns.

I. Demand will be 24 hour.

J. Cold storage facilities have approximately 2 times the demand as valves listed.

K. Includes laundry/dry cleaning, and commissary facilities.
The actual boiler used depends on the ash content of the fuel. If the ash content is less than about 0.1 wt. percent, a heavy oil boiler could be used except additional cleaning would be required. If the boiler has a bottom ash removal system and furnace wall soot blowers, up to about 5 percent ash oil/solid slurry may be burned. Some derating may be required. Also, new burners may have to be installed. If oil/solid slurries with larger ash content are to be burned, a coal type boiler will be required. A coal type watertube boiler as compared to an oil-fired unit has a smaller heat release rate or larger furnace for some heat input. Also, the tube spacing in the convection section is greater. System efficiency (80 to 80%) depends if there are economizers or air preheaters.
Recovery Considerations

- Additional fuel costs (90% of the burned fuel).
- Cost of waste oil cleaning systems.
- Cost of additives.
- Availability of engines.
- Duty cycle (required operation).
- Pollution control (systems must meet EPA regulations).
- Additional storage handling requirements.
- Blending compatibility.

APPLICABLE TECHNOLOGY

Unit Operations

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Typical Equipment</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Storage</td>
<td>Tank</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>Cleaning</td>
<td>Purifier, strainer, filter, separator, etc.</td>
<td>N/A</td>
</tr>
<tr>
<td>3</td>
<td>Mixing</td>
<td>Pump</td>
<td>N/A</td>
</tr>
<tr>
<td>4</td>
<td>Supplemental fuel</td>
<td>Diesel fuel, gasoline</td>
<td>CE-I</td>
</tr>
<tr>
<td>5</td>
<td>Engine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>End use</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

System Alternatives

Operation       Description                                                                 Reference |
---             --------------------------------------------------                      -------|
Treatment       Waste oil is strained, particulate is removed allowing more to be burned | N/A     |
Precombustion chamber Adds to the flexibility of the engine                           | N/A     |

Unit Operations

<table>
<thead>
<tr>
<th>Number</th>
<th>Operations</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Cleaning</td>
<td>Minimizes adverse effects on engine, increases suitability for burning.</td>
</tr>
<tr>
<td>3</td>
<td>Mixing</td>
<td>In-line blender to emulsify waste oil in the fuel.</td>
</tr>
</tbody>
</table>
## COMBUSTION SYSTEMS
### Internal Combustion Engines

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Costs - Capital - One Time Items</th>
<th>Costs - Recurring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment</td>
<td>Pretreatment</td>
<td>TPD 1980 $/day</td>
</tr>
<tr>
<td></td>
<td>Equipment</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Low level</td>
<td></td>
</tr>
<tr>
<td>Pretreatment</td>
<td>Low level</td>
<td></td>
</tr>
<tr>
<td>Maintenance</td>
<td>Low level</td>
<td>408</td>
</tr>
<tr>
<td>Emission control</td>
<td>Low level</td>
<td>425</td>
</tr>
<tr>
<td></td>
<td>High level</td>
<td>82</td>
</tr>
<tr>
<td></td>
<td>High level</td>
<td>411</td>
</tr>
<tr>
<td></td>
<td>High level</td>
<td>494</td>
</tr>
<tr>
<td></td>
<td>Low level</td>
<td>15K</td>
</tr>
<tr>
<td></td>
<td>High level</td>
<td>180K</td>
</tr>
<tr>
<td></td>
<td>Emission control</td>
<td>310K</td>
</tr>
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<td></td>
<td>Emission control</td>
<td></td>
</tr>
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<td></td>
<td>Emission control</td>
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</tr>
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<td></td>
</tr>
<tr>
<td></td>
<td>Emission control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Emission control</td>
<td></td>
</tr>
</tbody>
</table>

Btu content: Waste oil Btu content = 12,500 to 20,000 Btu/lb.

### COMPLEMENTARY SYSTEMS
- Spectrograph lube oil analysis.
- Fuel metering system.
- Fuel treatment system.

### Effects
- Indicates nature of treatment desired.
- Automatically adjusts waste influent to fuel stream.

### Comments, Notes
IC engines are not very fuel flexible. Waste oil could be mixed if treatment facilities were available. Can burn 1% without degradation of components or emissions. Waste oil is high in non-removable trace metals.

### REFERENCES
PRODUCT MARKETS

Product Characteristics

<table>
<thead>
<tr>
<th>Product</th>
<th>Range of Characteristics</th>
<th>Output Quantity/Ton of Solid Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water</td>
<td>As Designed: 150-300°F at 1-5 atm</td>
<td>As Experienced: 100-300°F at 1-3 atm</td>
</tr>
<tr>
<td>Steam</td>
<td>150-300 psig and sat.</td>
<td>300 psig and sat.</td>
</tr>
</tbody>
</table>

APPLICABLE TECHNOLOGY

Unit Operations

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Typical Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Receive</td>
<td>Low Btu gas storage tank or header</td>
</tr>
<tr>
<td>1A</td>
<td>Supply station</td>
<td>Natural gas supply station (Alternate fuel)</td>
</tr>
<tr>
<td>2</td>
<td>Burner</td>
<td>Scroll-type burner (LBG)</td>
</tr>
<tr>
<td>3</td>
<td>Steam Generation</td>
<td>Boiler system</td>
</tr>
<tr>
<td>4</td>
<td>Users</td>
<td>Heating steam users</td>
</tr>
<tr>
<td>5</td>
<td>F. W. system</td>
<td>F. W. supply system, pumps, water treatment, etc.</td>
</tr>
</tbody>
</table>

System Alternatives - Option 1

<table>
<thead>
<tr>
<th>Number</th>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Supplementary fuel</td>
<td>Low Btu gas + Natural gas burning (5% total heat input)</td>
</tr>
<tr>
<td>2</td>
<td>Burner</td>
<td>Scroll-type LBG burner with natural gas pilot</td>
</tr>
</tbody>
</table>
### Costs - Capital - One Time Items (4th Quarter 1980) Option 1 (See graph on Page IV-37).

<table>
<thead>
<tr>
<th>Equipment and Cost Factors</th>
<th>20</th>
<th>30</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building, foundation and concrete</td>
<td>24.1</td>
<td>33.4</td>
<td>50.3</td>
</tr>
<tr>
<td>Site preparation</td>
<td>3.6</td>
<td>4.9</td>
<td>7.5</td>
</tr>
<tr>
<td>Boiler, burner, F.D. fan and stack</td>
<td>150.1</td>
<td>207.7</td>
<td>312.6</td>
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<tr>
<td>Pumps</td>
<td>1.3</td>
<td>1.8</td>
<td>2.7</td>
</tr>
<tr>
<td>Water treatment</td>
<td>1.0</td>
<td>1.4</td>
<td>2.1</td>
</tr>
<tr>
<td>Boiler control panel</td>
<td>3.3</td>
<td>4.6</td>
<td>6.9</td>
</tr>
<tr>
<td>Pollution control</td>
<td>19.5</td>
<td>27.0</td>
<td>40.7</td>
</tr>
<tr>
<td>Construction and supervision</td>
<td>16.4</td>
<td>22.4</td>
<td>33.7</td>
</tr>
<tr>
<td>Utilities installation</td>
<td>13.9</td>
<td>19.2</td>
<td>28.9</td>
</tr>
<tr>
<td>Engineering</td>
<td>23.9</td>
<td>33.3</td>
<td>49.9</td>
</tr>
<tr>
<td>Total plant facilities investment (PFI)</td>
<td>257.1</td>
<td>355.7</td>
<td>535.3</td>
</tr>
<tr>
<td>Organization and startup (5%)</td>
<td>12.9</td>
<td>17.8</td>
<td>26.8</td>
</tr>
<tr>
<td>Interest and depreciation of equipment</td>
<td>Omitted</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>270.0</td>
<td>373.5</td>
<td>562.1</td>
</tr>
</tbody>
</table>

### Costs - Recurring (See graph on Page 3.)

<table>
<thead>
<tr>
<th>Equipment (Boiler System Only)</th>
<th>20</th>
<th>30</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>90.1</td>
<td>90.1</td>
<td>90.1</td>
</tr>
<tr>
<td>Electricity</td>
<td>3.5</td>
<td>5.3</td>
<td>8.8</td>
</tr>
<tr>
<td>Water</td>
<td>1.8</td>
<td>3.2</td>
<td>5.0</td>
</tr>
<tr>
<td>Oil (truck &amp; startup)</td>
<td>6.8</td>
<td>10.3</td>
<td>17.2</td>
</tr>
<tr>
<td>Chemical water treatment</td>
<td>1.6</td>
<td>3.8</td>
<td>5.2</td>
</tr>
<tr>
<td>Maintenance supplies</td>
<td>5.2</td>
<td>7.1</td>
<td>10.7</td>
</tr>
<tr>
<td>Maintenance labor</td>
<td>5.2</td>
<td>7.1</td>
<td>10.7</td>
</tr>
<tr>
<td>Admin. overhead</td>
<td>13.5</td>
<td>13.5</td>
<td>13.5</td>
</tr>
<tr>
<td>Total</td>
<td>127.7</td>
<td>140.4</td>
<td>161.2</td>
</tr>
<tr>
<td>Operating cost</td>
<td>6.38</td>
<td>4.67</td>
<td>3.22</td>
</tr>
<tr>
<td>$/ton</td>
<td></td>
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</tr>
</tbody>
</table>

### Comments

**Basis for Costs**

- **Labor:** 2 men/1st shift + 1 man/2nd shift - 16 hr/day.
- **Fuel:** $4.5/10^6 Btu, 75% utilization 16 hr/day, at 4.1 x 10^6 Btu/T.
- **Water:** 100% makeup + 10% blow down @ $0.60/1,000 gal.
- **Electricity:** 1 kW/TPD and $0.04/kWh.
- **Maintenance:** Supplies 2% of capital cost.
- **Admin. overhead:** 15% of operating labor.
- **Maintenance:** Labor 2% of PFI.
COMPLEMENTARY SYSTEMS

Low Btu Gas Plus Natural Gas as Fuel

A single burner is capable of burning both the LBG and Natural gas. Thus, the capital cost for Option #2 is approximately the same as for Option #1. The piping and control elements for natural gas line hook-up to the burner is negligible compared to the overall project cost. The operating cost will increase by the amount of natural gas used per year. Assuming $3.50 per million Btu of natural gas, the annual cost of natural gas will be $17,323 for 50 TPD, $10,424 for 30 TPD, and $6,899 for 20 TPD.

Comments, Notes

Air gasification of solid waste could produce low Btu fuel gas having up to 80% of the heating value of the solid waste gasified.

MSW contains an average of $9 \times 10^6$ Btu. Therefore, heating value of the low Btu gas = $7.2 \times 10^6$ Btu having specific fuel heating value of gas 150-200 Btu/ft$^3$. This sort of gas can burn without the help of any auxiliary fuel. Boilers designed to burn only low Btu gas will have different combustion chamber volume than for natural gas-burning boilers.

REFERENCES

### COMBUSTION SYSTEM

#### High Btu Gas/ Natural Gas Mix

<table>
<thead>
<tr>
<th>Product</th>
<th>Range of Characteristics</th>
<th>Output Quantity/Ton of Solid Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water</td>
<td>150-300°F at 1-5 atm</td>
<td>150-250°F at 1-3 atm</td>
</tr>
<tr>
<td>Steam</td>
<td>150-250 psig</td>
<td>150-200 psig</td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Product Characteristics

<table>
<thead>
<tr>
<th>Product</th>
<th>As Designed</th>
<th>As Experienced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot water</td>
<td>150-300°F at 1-5 atm</td>
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<td>150-250 psig</td>
<td>150-200 psig</td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Product end uses, specifications

<table>
<thead>
<tr>
<th>End Use</th>
<th>Average Btu/sq ft/yr (OOO)</th>
<th>Hot water Gal/sq ft/yr</th>
<th>Steam (lb/sq ft/yr)</th>
<th>Electrical (KWH/sq ft/yr)</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offices</td>
<td>55</td>
<td>336.4</td>
<td>39.5</td>
<td>16.1</td>
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<td>160</td>
<td>974.0</td>
<td>115.1</td>
<td>46.8</td>
<td>D,E,G</td>
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<td>304.4</td>
<td>36.0</td>
<td>14.6</td>
<td>D,E,F,H</td>
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<tr>
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<td>499.2</td>
<td>59.0</td>
<td>24.0</td>
<td>D,E,I</td>
</tr>
<tr>
<td>Storage</td>
<td>61</td>
<td>371.3</td>
<td>43.9</td>
<td>17.9</td>
<td>D,E,I</td>
</tr>
<tr>
<td>Service</td>
<td>95</td>
<td>578.3</td>
<td>68.3</td>
<td>27.8</td>
<td>D,E,K</td>
</tr>
</tbody>
</table>

#### Considerations

A. Budgets listed include a 45% energy reduction as mandated by E.O. 12003 for new facilities. Existing facilities for which waste derived energy is being considered will have energy demands exceeding the values listed.

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C. Based on metered rate for electrical energy. Generated rate would require approximately 3.4 times listed figure.

D. Demands listed are heating and cooling loads only. No process energy is supplied.

E. Values listed are heating and cooling loads based on national averages and typical building of this type. Local requirements will vary.

F. Nonworking hour loads will be substantially lower in most cases.

G. Noninterruptable supply is critical.

H. Demand will fluctuate widely with facility use patterns.

I. Demand will be 24 hour.

J. Cold storage facilities have approximately 2 times the demand as values listed.

K. Includes laundry/dry cleaning, and commissary facilities.
COMBUSTION SYSTEM
High Btu Gas/ Natural Gas Mix
CS-GF-HB

APPLICABLE TECHNOLOGY

Unit Operations

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Typical Equipment</th>
<th>Option #1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Storage</td>
<td>Compressed high Btu gas storage tank</td>
<td>Generate steam use steam for building heating and process work</td>
</tr>
<tr>
<td>2</td>
<td>Heat source</td>
<td>High Btu gas burner (cell type)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Steam generation</td>
<td>Boiler fired with high Btu gas</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Steam users</td>
<td>Building, barracks and others</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Feed water return system</td>
<td>Feed water supply systems, pumps, etc.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Conditioned water supply</td>
<td>Make up water supply system</td>
<td></td>
</tr>
</tbody>
</table>

System Alternatives

<table>
<thead>
<tr>
<th>Option</th>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Power generation</td>
<td>Steam turbine (non-condensing)</td>
</tr>
<tr>
<td>2</td>
<td>Electrical generation</td>
<td>Steam-turbine driven generator</td>
</tr>
</tbody>
</table>
### COMBUSTION SYSTEM

**High Btu Gas/Natural Gas Mix**

**CS-GF-HB**

**P. 3 OF 4**

<table>
<thead>
<tr>
<th></th>
<th>20</th>
<th>30</th>
<th>50</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Preparation</td>
<td>0.75</td>
<td>1.03</td>
<td>1.55</td>
<td></td>
</tr>
<tr>
<td>Building, Foundation &amp;</td>
<td>5.05</td>
<td>6.93</td>
<td>10.43</td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boiler, F.D. Fan &amp; Stack</td>
<td>35.44</td>
<td>48.66</td>
<td>73.23</td>
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</tr>
<tr>
<td>Pumps, etc.</td>
<td>0.27</td>
<td>0.37</td>
<td>0.55</td>
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</tr>
<tr>
<td>Control Treatment</td>
<td>0.21</td>
<td>0.29</td>
<td>1.44</td>
<td></td>
</tr>
<tr>
<td>Pollution Control</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Construction</td>
<td>3.38</td>
<td>4.64</td>
<td>7.00</td>
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<tr>
<td>Utilities Construction</td>
<td>2.90</td>
<td>3.98</td>
<td>6.00</td>
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<tr>
<td>Engineering</td>
<td>5.00</td>
<td>6.86</td>
<td>10.32</td>
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<tr>
<td>Total Plant Facilites</td>
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<tr>
<td>Investment</td>
<td>53.7</td>
<td>73.73</td>
<td>110.95</td>
<td></td>
</tr>
<tr>
<td>Organization &amp; Startup (5%)</td>
<td>2.7</td>
<td>3.70</td>
<td>5.54</td>
<td></td>
</tr>
<tr>
<td>Total Capital Investment</td>
<td>56.4</td>
<td>77.43</td>
<td>116.49</td>
<td></td>
</tr>
</tbody>
</table>

**Costs - Capital - One Time Items (4th Quarter 1980) Option #1**

The Capital Cost is for firetube boiler with natural gas burner.

**Costs - Recurring - (Operating per year)**

**System Efficiency**

**Equipment Boiler Systems Only**

<table>
<thead>
<tr>
<th></th>
<th>20</th>
<th>30</th>
<th>50</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>62.4</td>
<td>62.4</td>
<td>62.4</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>3.5</td>
<td>6.4</td>
<td>8.8</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>1.8</td>
<td>3.2</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>Oil (Trucks and Startup)</td>
<td>5.2</td>
<td>7.5</td>
<td>15.3</td>
<td></td>
</tr>
<tr>
<td>Chemical (water treatment)</td>
<td>1.6</td>
<td>3.8</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>Maintenance Supplies</td>
<td>1.1</td>
<td>1.5</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>Maintenance Labor</td>
<td>1.1</td>
<td>1.5</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>Admin. Overhead</td>
<td>9.4</td>
<td>5.4</td>
<td>9.4</td>
<td></td>
</tr>
<tr>
<td>Total Operating Cost</td>
<td>86.1</td>
<td>94.6</td>
<td>110.5</td>
<td></td>
</tr>
</tbody>
</table>

**$/ton**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.31</td>
<td>3.15</td>
</tr>
</tbody>
</table>

**References**

Verbal Quotation from Cleaver.

Installation and delivery factor of 3 used in computing total installation costs.

In most cases 1 man/shift is quite adequate for 2 shift operation. Three men has been taken into consideration. FUEL COST NOT INCLUDED.

**Basis**

- Labor: 2 men/1st shift + 1 man/2 shift - 16 hr/day
- Fuel: $4,5/10^6 Btu 75% utilization - 16 hr/day at 4.1 x 10^6 Btu/ton.
- Water: 100% makeup + 10% B.D. $0.60/1000 gal
### Compressed air

<table>
<thead>
<tr>
<th>Product Characteristics</th>
<th>As Designed</th>
<th>As Experienced</th>
<th>Output Quantity/Ton of Liquid Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressed air</td>
<td>1-10 atm</td>
<td>Same</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

### Hot gases

- **Range of Characteristics**
  - **Product**: Compressed air
  - **As Designed**: 1-10 atm
  - **As Experienced**: Same
  - **Output**: Not applicable

### Electricity

- **Range of Characteristics**
  - **Product**: Hot gases
  - **As Designed**: 500-1,100°F
  - **As Experienced**: Same
  - **Output**: 16,000-500,000 CFM

### Product end uses, specifications

<table>
<thead>
<tr>
<th>End Use</th>
<th>Average Btu/sq ft/yr (000)</th>
<th>Hot Water Gal/sq ft/yr</th>
<th>Steam (lb/sq ft/yr)</th>
<th>Electrical (KWH/sq ft/yr)</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offices</td>
<td>55</td>
<td>336.4</td>
<td>39.5</td>
<td>16.1</td>
<td>ABC (all uses) D,E,G</td>
</tr>
<tr>
<td>Hospital</td>
<td>160</td>
<td>974.0</td>
<td>115.1</td>
<td>46.8</td>
<td>D,E,G</td>
</tr>
<tr>
<td>Training Facility</td>
<td>50</td>
<td>304.4</td>
<td>36.0</td>
<td>14.6</td>
<td>D,E,F,H</td>
</tr>
<tr>
<td>Housing Family</td>
<td>82</td>
<td>499.2</td>
<td>59.0</td>
<td>24.0</td>
<td>D,E,I</td>
</tr>
<tr>
<td>B0Q</td>
<td>61</td>
<td>371.3</td>
<td>43.9</td>
<td>17.9</td>
<td>D,E,I</td>
</tr>
<tr>
<td>Storage</td>
<td>50</td>
<td>34.4</td>
<td>36.0</td>
<td>14.6</td>
<td>D,E,J</td>
</tr>
<tr>
<td>Service</td>
<td>95</td>
<td>578.3</td>
<td>68.3</td>
<td>27.8</td>
<td>D,E,K</td>
</tr>
</tbody>
</table>

### Considerations

- **A.** Budgets listed include a 45% energy reduction as mandated by E.O.12003 for new facilities. Existing facilities for which waste derived energy is being considered will have energy demands exceeding the values listed.
- **B.** Hot water system calculations assumes 20°F temperature drop across radiator. 180°F input. For 30°F drop 2/3 the listed quantity would be required, a 10°F drop would require 2 times the listed quantity.
- **C.** Based on metered rate for electrical energy. Generated rate would require approximately 3.4 times listed figure.
- **D.** Demands listed are heating and cooling loads only. No process energy is supplied.
- **E.** Values listed are heating and cooling loads based on national averages and typical building of this type. Local requirements will vary.
- **F.** Nonworking hour loads will be substantially lower in most cases.
- **G.** Noninterruptable supply is critical.
- **H.** Demand will fluctuate widely with facility use patterns.
- **I.** Demand will be 24 hour.
- **J.** Cold storage facilities have approximately 2 times the demand as valves listed.
- **K.** Includes laundry/dry cleaning, and commissary facilities.
Combustion System | High Btu Gas/Natural Gas Mix | CS-GF-HB | P. 4 OF 4
---|---|---|---
Elec.: 1 kW/tpd and $0.04/kWh
Maint. Supply: 2% of capital cost.
Admin. Overhead: 15% of operating labor.
Maint. Labor: 2% of PFI.

Complementary Systems and Their Impact

High-Btu gas (refuse derived) is equivalent in energy content to natural gas. High pressure steam can be generated to drive steam turbine and generate electricity. The size of the refuse plant is too small for a water tube boiler system. The steam turbine-driven generator, completely installed may cost an additional $50,000. Operating cost will not change significantly.

Comments

Conversion of solid waste to high-Btu gas has not been demonstrated in public sector projects. It involves performing oxygen gasification to produce medium-Btu gas (MBG). The MBG composition will consist of 20 to 25% hydrogen, 35 to 42% carbon monoxide, and 4.5 to 5.8% methane by volume. In order to perform the methanation process and to produce high Btu gas, the initial gas composition should have a H₂ to CO ratio of approximately 3:1.

As the ratio is not present with the initial gas, the MBG has to undergo watergas shift conversion as seen from the relation:

\[ \text{H}_2\text{O} + \text{CO} \rightarrow \text{H}_2 + \text{CO}_2 \]

Then the gas must undergo catalytic methanation process involving reactions as:

\[ 3\text{H}_2 + \text{CO} \rightarrow \text{CH}_4 + \text{H}_2\text{O} \]

The methane-rich gas leaving the combined shift/methanation reactor is then sent to a polish methanation process to reduce the CO level to pipeline gas specifications. CO₂ is removed in bulk by a hot potassium carbonate system and dry SNG is produced. For a small plant of 20 to 50 TPD such an involved process is very seldom recommended. The conversion efficiency ranges from 60 to 63%. In this calculation, it is assumed that an estimated 5.4 million Btu will be realized per ton of refuse processed.
## Costs - Capital - One Time Items

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Tpd (# x 1^{10^3})</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbines (60-240 $/hp)</td>
<td></td>
<td>960K</td>
<td>1.92M</td>
<td>2.86M</td>
<td>3.84M</td>
<td>Precise costing information not available at this time</td>
</tr>
<tr>
<td>Water treatment for NO\textsubscript{x} control ($1.5/kW)</td>
<td></td>
<td>8-25K</td>
<td></td>
<td>100K</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Costs - Recurring

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Tpd 1980</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased maintenance</td>
<td>Data not available</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filter replacement</td>
<td>Data not available</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplementary fuel</td>
<td>$25K/day</td>
<td>$50K/day</td>
<td>$75K/day</td>
<td>$100K/day</td>
<td>$7.3K/yr</td>
<td></td>
</tr>
</tbody>
</table>

Btu Content: Waste oil Btu content = 12,500 to 20,000 Btu/lb

## COMPLIMENTARY SYSTEMS

Fuels treatment - fuel treatment costs are dependent on fuel properties. Analysis of the waste oil to be burned should be performed for assessment of treatment cost.

- Filtering.
- Separation.
- Additions.
- Dual injection nozzles.

Effects

- Filtering removes large particulates, decreases wear in engines, and may allow more waste oil to be burned as a result.
- Separation removes water and particulates, increases performance, and will increase amount of waste oil that can be mixed.
- Additives ease mixing, upgrade performance, reduce wear, corrosion of hot gas parts.
- Dual injection nozzles increase amount of (cleaned) waste oil that can be used.

Comments - Notes

Any use of waste oil should probably be in existing machinery as new equipment is expensive. New equipment should be purchased with its ability to burn waste products in mind, when viewing alternatives.
## Unit Operations

<table>
<thead>
<tr>
<th>Number</th>
<th>Function</th>
<th>Typical Equipment</th>
<th>Reference No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Receive</td>
<td>Storage tank</td>
<td>Not included</td>
</tr>
<tr>
<td>2</td>
<td>Analysis</td>
<td></td>
<td>Not included</td>
</tr>
<tr>
<td>3</td>
<td>Mixing</td>
<td>Pumps, mixers</td>
<td>Not included</td>
</tr>
<tr>
<td>4</td>
<td>Treatment</td>
<td>Purifiers, filters, coalescers</td>
<td>Not included</td>
</tr>
<tr>
<td>5</td>
<td>Turbine</td>
<td>Direct or indirect-fired combustor</td>
<td>CE-F</td>
</tr>
<tr>
<td>6</td>
<td>Cogenerator</td>
<td>Waste heat boiler</td>
<td>CE-G</td>
</tr>
</tbody>
</table>

## System Alternatives

<table>
<thead>
<tr>
<th>Operation</th>
<th>Description</th>
<th>Reference No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomization</td>
<td>Dual orifice injection, allowing waste oil to be supplied when available.</td>
<td>Not included</td>
</tr>
<tr>
<td>Treatment</td>
<td>Purifiers and filters or additives, additives usually have to be approved by manufacturer.</td>
<td>Not included</td>
</tr>
<tr>
<td>Combustor</td>
<td>Designs are being modified to handle increased flexibility in fuels.</td>
<td>Not included</td>
</tr>
</tbody>
</table>

## Unit Operations

<table>
<thead>
<tr>
<th>Unit</th>
<th>Operations</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Analysis</td>
<td>Analysis is important as it determines the amount to be used, the treatment required.</td>
</tr>
<tr>
<td>3</td>
<td>Mixing</td>
<td>May be an alternative to analysis and treatment.</td>
</tr>
<tr>
<td>4</td>
<td>Treatment</td>
<td>Effects system life, usually pays for itself by reduced (normal) fuel costs.</td>
</tr>
<tr>
<td>6</td>
<td>Combustion</td>
<td>Closely monitored for direct fire applications. Improves cycle efficiency up to 20%. (See graph on Page 4.)</td>
</tr>
</tbody>
</table>
REFERENCES

SECTION V

INSTITUTIONAL CONSIDERATIONS FOR NAVY RESOURCE RECOVERY PROJECTS

Technology selection, which is the primary focus of this document, has in recent years proved to be only one of several important facets of a successful project. Industry experts no longer measure the success of a project solely by how well the system works, but also carefully monitor the financial health of the project as well as the success of the contracting mechanism used to procure the project. Federal and state environmental officials are also keeping a close watch on the facility air emissions, liquid effluents, and residue characteristics in an effort to develop formal policies on their proper management.

The following is a summary description of several of the more important institutional considerations in resource recovery implementation. Because most of the energy recovery experience has taken place on the municipal level, practical guidance for implementing a resource recovery project would logically come from the municipal experience. Anyone considering the implementation of a resource recovery project should closely study municipal resource recovery projects in order to gain a better understanding of the implementation process.

PLANNING AND SCHEDULING

The first step in the development of a resource recovery project is an analysis of its feasibility at a given installation. It is important to recognize that the data base developed for a feasibility study is typically inadequate for proper planning and implementation. Several municipalities have made this mistake, and their projects are technical or financial failures as a result.

Typical elements of a proper resource recovery planning and scheduling analysis include an analysis of waste quantity and composition, including laboratory analysis for fuel characteristics; a formal solid waste management plan, which fully describes the refuse collection and disposal strategy for 10 to 20 years; a complete assessment of landfill life and adequacy of current landfill operation, as any resource recovery project requires that landfill capacity be available for residues and overflow; an assessment of waste availability to the resource recovery project; and an analysis of how source separation/recycling can be integrated into the overall resource recovery program. Detailed analysis of these aspects of solid waste management may produce some conflicts or discrepancies with the previous resource recovery feasibility study. Changes to the feasibility study should therefore be made to reflect these differences and to assess the resulting impact on the previous decision.
ENERGY AND MATERIAL MARKETS

Many experts consider market studies and negotiations to be the most important aspects of a successful resource recovery project. Market studies for energy play a more significant role in municipal projects, as most of these projects sell the product to a utility or other industry. A Navy-scale energy recovery project will ordinarily use the steam or electric power product on base. The development of proper specifications and demand profiles for these products to ensure a reliable on-base market is a key factor in Navy resource recovery assessment.

The sale of recovered material is in many ways simpler than for energy products. Source separation activities throughout the country have paved the way for the use of recovered material as secondary material in industry. The consuming industries are familiar with the quality of materials recovered through both source separation and mechanical separation. ASTM has developed standards for most of the commonly recovered materials in resource recovery, which further aid planning and market contracts development for such projects. In addition, DOD and the Navy have established policies promoting material recovery at military installations, and standard procedures exist for the sale of recovered materials through the Defense Property Disposal Office (DPDO).

In most instances, mechanical separation of materials such as ferrous metal and aluminum results in a higher volume and poorer product quality than source separation. Discussion of market potential and contracts should be initiated through DPDO with major consuming industries or major brokers, rather than local recycling organizations which are accustomed to handling a cleaner, low-volume product. Several of the references listed at the end of this section will aid in identifying some of the major local secondary material industries.

PROJECT FINANCING

Most Navy-scale projects for material or energy recovery will cost less than $10 million (1981); as such, they will not usually require any special form of financing. Most Navy public works projects of this type are financed through capital budget allocation, the DD 1391 process. Most municipal projects, on the other hand, are financed through revenue bonds, in which the economic viability of the project is paramount. Case histories of revenue bond financing on the municipal level are readily available through EPA research reports and through other cognizant agencies such as the U.S. Conference of Mayors. Navy personnel must be well acquainted with revenue bond financing, as it is critical to involvement in a regional resource recovery project.

RISK ANALYSIS AND PROCUREMENT

There are three procurement strategies which are commonly used for resource recovery projects:

- Architect/Engineer - An A&E firm designs and constructs a resource recovery plant, the technology for which is specified and selected by the client.
• Turnkey Contract - A vendor or A&E consortium designs, constructs, and starts up a recovery plant. The plant is turned over to the client once the predetermined performance specifications have been met.

• Full-Service Contract - A vendor designs, constructs, starts up, and operates a facility for a client, in essence providing a resource recovery service for a contracted tipping fee and possible operating subsidy. The contractor may also hold an equity position in the project.

The selection of a particular procurement strategy is necessarily a function of the amount of risk that the implementing agency is willing to take on the project. Shedding part of the risk by employing a full-service contractor, for example, will typically reduce the Navy's risk in exchange for a higher disposal cost.

The most common risks encountered in resource recovery planning relate to waste stream quantity and composition, facility construction and operation, by-product marketing, and waste disposal/environmental impact. Waste flow control guarantees, a common problem in municipal resource recovery, should not be of concern at most Navy facilities. However, the risk associated with waste quantity and composition is increased if proper measurement techniques are not used in advance of the design phase.

Problems associated with facility construction and operation are numerous, and may include cost overruns during construction, unreliable system performance, or improper operation of the facility. These latter reasons are the primary impetus for increased use of turnkey and full-service contractor procurement among municipalities. The inability of a system to meet its by-product specifications is more prevalent among municipal systems, because the by-product is being sold under contract to industry. In Navy operations, poor performance of this type may still present a problem by impeding the desired public works mission (e.g., steam supply reliability, electric power reliability).

The last area of risk listed above, disposal/environmental impact, may be the most important risk to be considered. Resource recovery plants may be implemented in an effort to lengthen existing base landfill life. Unreliable plant operation results in increased landfill requirements, and would therefore defeat the purpose of these projects. Similarly, improper operation of an energy recovery plant may result in unacceptable air emission levels, thereby replacing perceived long-term environmental impacts from land disposal with an observable problem with air emissions.

Each of the risks listed above is inherent to a resource recovery project. Among the resource recovery projects in our major cities, these risks have been distributed in a variety of fashions. The key to proper risk management is selection of the appropriate procurement strategy, coupled with proper project planning and organization at the facility level.

USE OF OUTSIDE ASSISTANCE

Use of outside engineers to assist in public works project design has been an accepted practice among the military. Implementation of resource
recovery projects brings several added dimensions to the traditional project implementation approach, as it requires expertise in new technology areas. Areas in which resource recovery assistance from an outside engineering firm may be valuable include solid waste management planning, technology selection, and environmental impact assessment. These disciplines go beyond traditional architect/engineer capabilities, and may require a separate procurement for each area in order to obtain the appropriate range of capabilities. Expertise in each of these areas is available from specialty firms throughout the United States. Municipal resource recovery projects have also enlisted assistance from experts in other peripheral areas such as risk assessment, market identification and contract negotiation, and overall project management. Lists of consultants and engineers in each of the specialty areas can be obtained from cognizant federal agencies as well as cities that have already implemented resource recovery projects.

REFERENCES


1. Planning and Overview (SW-157.1).
2. Technologies (SW-157.2).
5. Procurement (SW-157.5).


Solid Wastes Management (Various Issues).


Waste Age (Various Issues).


APPENDIX A

MATERIALS HANDLING EQUIPMENT (MH)
<table>
<thead>
<tr>
<th>COMPONENT DESCRIPTION</th>
<th>Types Available - Competing Components</th>
<th>Types Used Commercially</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage Silo</td>
<td>live bottom</td>
<td>a</td>
</tr>
</tbody>
</table>

**General Description**

Patterned after silos in use for wood chip/sawdust storage. Silos may be as large as 150 ft in diameter and 80 ft high. Diameter increases toward bottom.

**Principle of Operation**

Material is fed from above, and removed from underneath. The continuous revolving arms at the bottom of the unit impart a constant downward motion to prevent bridging and freezing.

**Materials of Construction**

- Walls: wood - concrete.
- Floor: reinforced concrete.
- Traveling arms: steel.

**Advantages Over Other Types**

- Elimination of bridging.

**SIZING CRITERIA**

Daily throughput rates usually designed to store 3 to 5 days of RDF volume to allow downtime surge capacity.

**ACCESSORY COMPONENTS**

- Input/output conveyors (belt or pneumatic).
<table>
<thead>
<tr>
<th>SUPPORT REQUIREMENTS</th>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personnel: Maintenance only, 1/4 man day per day.</td>
<td></td>
</tr>
<tr>
<td>Training: General maintenance, motor repair, welding.</td>
<td></td>
</tr>
<tr>
<td>Skills Required: Welding, motor repair, concrete.</td>
<td></td>
</tr>
<tr>
<td>Inspections: Frequent; high moisture content encourages bridging.</td>
<td></td>
</tr>
<tr>
<td>Access: Sufficient for inspection, maintenance.</td>
<td></td>
</tr>
<tr>
<td>Spare Parts: Traveling arms.</td>
<td></td>
</tr>
<tr>
<td>Permits: None required.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OPERATIONAL CONSIDERATIONS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>General: First material in - first material out.</td>
<td></td>
</tr>
<tr>
<td>Installation: Locate to minimize conveyor reach.</td>
<td></td>
</tr>
<tr>
<td>Maintenance: Traveling arm/floor wear; traveling arm motor.</td>
<td></td>
</tr>
<tr>
<td>Controls: Traveling arm speed; input conveyor speed.</td>
<td></td>
</tr>
<tr>
<td>Scheduling: Based on manufacturer's recommendations.</td>
<td></td>
</tr>
<tr>
<td>Downtime: Can require entire system to shut down if redundancy doesn't exist.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STATE-OF-THE-ART</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>R&amp;D Needs: Storage time as a function of moisture content and other compositional values.</td>
<td></td>
</tr>
<tr>
<td>Operating Systems: Ontario, Canada; Baltimore, Maryland, and Iowa.</td>
<td></td>
</tr>
<tr>
<td>Risks: Bridging, or other bin flow problems will cause flow failures.</td>
<td></td>
</tr>
<tr>
<td>Failures: Baltimore, Maryland; bridging resulted in over spec traveling arm motion causing premature equipment wear.</td>
<td></td>
</tr>
</tbody>
</table>
COMPONENT DESCRIPTION

Conveyors

Types Available - Competing Components
a. Belt
b. Pan
c. Chain

d. Continuous Types Used Commercially
a, b, c

Physical Characteristics

General Description
Continuous conveyor belts are used to move material between receiving areas and processing equipment, between unit operations within the processing line and from final processing to storage or loading areas. The successful conveyance of materials is critical to any resource recovery system. Most conveyors are available in open or closed configurations.

Principle of Operation
Material to be moved is deposited on the conveyor (or into an enclosed trough in chain types) and is carried by the conveyor as it moves along its prescribed tracks. Route may be inclined, horizontal or vertical (enclosed chain types only). Drive mechanisms typically consist of electrical motors with chain or gear drives.

Materials of Construction
- Pans - AISI 1040 steel or other carbon steel - may be reinforced with structural steel bracing.
- Belts - nylon carcass rubber covering, neoprene cleates.
- Supports - structural steel.

Advantages Over Other Types
Pan type conveyor systems offer greater life expectancy and volume handling capability. Belt type offers low initial costs. Enclosed chain type allows for steeper ascent angles than belt or pan conveyors.
### SIZING CRITERIA

<table>
<thead>
<tr>
<th>Capacity (tons/hr)</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width of Conveyor (in)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belt</td>
<td>6 through 36 available</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chain type</td>
<td>5</td>
<td>5-9</td>
<td>7-11</td>
<td>9-25</td>
</tr>
<tr>
<td>Belt type</td>
<td>12 through 120 or greater available</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### ACCESSORY COMPONENTS
- Drive motors.
- Support structures.
- Covers, typically supplied by manufacturer/vendor.

### SUPPORT REQUIREMENTS
Personnel: No individual personnel are required to operate conveyors.
Training: Minimal; maintenance training provided by manufacturer/vendor.
Skills Required: Minimum mechanical for maintenance.
Inspections: Routinely for wear, lubrication.
Access: Adequate, at all points for maintenance.
Spare Parts: Data not available.
Permits: None.

### OPERATIONAL CONSIDERATIONS
General: Conveyors are typically the emergency stopping mechanism for recovery systems. Therefore, adequate observation and control equipment must be installed.
Controls: Automatic shutoff from failure of another unit operation.
Scheduling: 24 hour operation possible.
Downtime: Minimal provided maintenance is carried out.
Other Factors: Refuse, particularly raw refuse, does not turn corners well. Straight line systems are far superior to ones with turns. Shredded refuse is more willing to turn corners.
### SAFETY AND ENVIRONMENTAL CONSIDERATIONS

**General:** Emergency shutoff of conveyors if a processing operation fails.

**Fire Hazard:** Minimal, fires developing elsewhere in plant (shredder) may propagate along conveyors. Fire suppression equipment should be available.

**Explosion:** Minimal.

**Other Safety:** None.

**General Environmental:** Dust control measures should be taken.

### COST ANALYSIS

Manufacturers will quote prices for specific configurations only.

### STATE-OF-THE-ART

**R&D Needs:** Conveyors are proven in many years of use; ability to turn corners needs work. Wet material conveying.

**Operating Systems:** Many.

**Manufacturers:**
- Williams Patent Crusher, MO.
- Mayfram Inc., OH.
- Ruhler-Miag, Inc., MN.
- Many others.

**Risks:** Few.

**History:** Conveyor systems have been used successfully in the resource recovery field as well as many other applications for many years.

**Successes:** Heavy duty construction for refuse applications.

**Failures:** Systems, where conveyor system is inaccessible, have jammed and been difficult to repair.

**Key Problems:** Wire and cables getting caught up in drive mechanisms, belt life with impact loads as experienced in refuse handling systems.
COMPONENT DESCRIPTION

SCREEN

Screen

Type

Vibrating

Types Available - Competing Components

a. Horizontal
b. Vertical

Types Used Commercially

a, b

Physical Characteristics

General Description

Typical units are usually rectangular, with side walls and heavy gauge wire forming the screen. Supported by springs and pneumatically or hydraulically vibrated on top of an undersize collection bin and underneath a dust hood.

Principle of Operation

Waste is deposited at one end of the screen and moved across to the other by directed vibration or gravity (inclined). The material is agitated by the vibration to overcome binding. Undersize material passes thru the screen openings and is collected in a bin. The oversize fraction pass over the screen onto a conveyor.

Materials of Construction

- Screen - heavy gauge wire or expanded metal.
- Other - steel.

Advantages Over Other Types

- Compact.
- Ease of maintenance.

SIZING CRITERIA

- Area - material throughput particle size range.
- Vibrational speed - separation efficiency, material throughput.
- Inclination - material throughput, efficiency.
MATERIALS HANDLING
Separation
MH-C
P. 2 of 3

ACCESSORY COMPONENTS
- Feed and discharge conveyors/collectors.
- Dust collection equipment.

SUPPORT REQUIREMENTS
Personnel: No operator is specifically assigned.
Training: Welding, motor and hydraulic repair.
Skills Required: Maintenance.
Inspections: Stress failures, binding.
Access: Good - no general dismantling required.
Spare Parts: Springs, hydraulic hoses, wire.
Permits: None.

OPERATIONAL CONSIDERATIONS
General: General support base must be rugged.
Installation: Overall equipment balance important.
Maintenance: Heavy; stress loadings high.
Controls: Vibrational (speed) inclination, waste loading.
Scheduling: Due to unpredictable downtime redundancy may be desirable.
Downtime: Excessive and unpredictable.
Other Factors:

SAFETY AND ENVIRONMENTAL CONSIDERATIONS
General: Not particularly hazardous operation.
Fire Hazard: Low - specific preventive measures not usually specified.
Explosion: Low - explosion suppression not usually specified.
Other Safety: Spring supports should be restrained with steel cable in case of failure.
General Environmental: Vacuum dust collection necessary in enclosed applications.

COST ANALYSIS
Cost varies widely based on design and capacity. See manufacturer for quote, particularly custom designs.
STATE-OF-THE-ART

R&D Needs: Optimum opening sizes and spacing.

Manufacturers: Numerous, but not always a stock design or item.

Risks: Without sufficient redundancy, excessive downtime.

History: Extensive use in the rock products industry, not used extensively in solid waste processing except where space is critical.

Key Problems: High-stress factors induced by vibrational motion cause accelerated component failure.
### COMPONENT DESCRIPTION

**Trommel Screens**

**Type**
- Rotary

**Types Available**
- Rotary

**Types Used Commercially**

### Physical Characteristics

A cylindrical barrel, perforated with uniform or various size holes covered by a shroud, inclined to the horizontal in the direction of waste flow, rotated by drive trunions, and supported on an integral base.

### General Description

Waste is fed into the higher barrel end. The tumbling action of rotation exposes all material to the circumferential holes. Undersize material passes through the holes into the shroud. Oversize material travels the length of the barrel and is discharged.

### Principle of Operation

### Materials of Construction

- Shroud - mild steel.
- Barrel - hardened steel.
- Trunions - hardened steel.
- Drive - rubber-tracked steel wheels.

### Advantages Over Other Types

- Low maintenance and operating cost.
- Simplicity of operation.
- High separation efficiency.
### SIZING CRITERIA
- Diameter - expected range of particle size and waste throughput.
- Length - desired separation efficiency and material throughput.
- Inclination - material throughput, residence time, and particle size.
- Rotation speed - desired separation efficiency material throughput rate.

### ACCESSORY COMPONENTS
- Feed and discharge conveyors.

### SUPPORT REQUIREMENTS
Personnel: No special operator is needed.
Training: Motor repair, welding, electrical.
Skills Required: General maintenance; lubrication, motor repair, and general welding.
Inspections: Motor load, blinding of holes, lubrication, barrel trueness, drive wear.
Access: From inside barrel, or outside shroud.
Spare Parts: Rubber drive tracks, motor.
Permits: None.

### OPERATIONAL CONSIDERATIONS
General: Match rotational speed with waste throughput rate.
Installation: Barrel trueness must be exact to control separation.
Maintenance: Regular lubrication.
Controls: Angle of inclination and rotational speed - motorload.
Scheduling: Continuous operation possible.
Downtime: Briefly once/week or more frequently to remove entrapped material.

### SAFETY AND ENVIRONMENTAL CONSIDERATIONS
General: Motor noise attenuation is necessary, but baffling should be adequate.
Fire Hazard: Low - sprinklers optional, not usually specified.
Explosion: Low - explosion suppression usually not specified.
Other Safety: Guards surrounding trunion drive train.
General Environmental: Dust suppression via venting.
COST ANALYSIS

Each unit is custom designed and built, so only limited capital cost data is available. (See graphs below.)

STATE-OF-THE-ART

R&D Needs: Optimum hole(s) size.

Operating Systems: New Orleans, LA (Recovery I), Monroe County, NY

Manufacturers: Numerous; shop-fabricated.

Risks: Low - equipment in service for many years in other industries.

History: Equipment developed primarily in the rock products industry for sizing of crushed ore. Extension into solid waste processing has been generally favorable. Low cost operation gaining in popularity.

Successes: Recovery I in New Orleans most notable. Failures of RDF operations have never been primarily attributable to rotary trommel screen malfunction.

Failures: Collar breakage, barrel out of true, trunion and drive wear, motor overload.

Key Problems: Collar breakage, barrel out of true, trunion and drive wear, motor overload.
Shredder

Types available - competing components
a. Vertical hammermill
d. Ball mill
b. Horizontal hammermill
e. Flail mill
c. Rotary shear

Types used commercially
a, b, c,

Physical Characteristics

General Description

Initially shredders were used to prepare refuse for landfilling. It was anticipated that shredded refuse would not require daily cover and that greater compaction densities would be obtainable. Both of these initial objectives are no longer focal points of shredding.

Shredders are generally the initial processing step in a resource recovery facility. The shredded refuse is more homogeneous in nature, particle size is within known limits, and any containers or bags are opened exposing the contents to subsequent processing steps. Shredding also greatly increases the packing density of recovered materials and promotes more complete combustion if incineration is employed.

Principle of Operation

Raw refuse enters a vertical hammermill through a large infeed opening at the top. Rotating hammers, mounted on a vertical rotor shaft, initially contact the refuse, which through impact break apart many items. The refuse continues falling through the unit impacting subsequent hammers which through shearing action reduce the particle size. The conical cross section of the mill further reduces the particle size distribution as the refuse moves downward.

Final reduction takes place below the main hammer section in a straight cylinder section. Here additional hammers force the material against breaker bars or other solid structures built into the shell of the unit. The final product is discharged horizontally through an opening at the side of the unit.
Materials of Construction

Shell: Hot rolled steel, lined with hot rolled steel or cast manganese attached with countersunk bolts.

Hammers: 11-14% cast manganese steel, other hardened steel.

Rotors: SAE 5155 steel, heat treated.

Advantages Over Other Types:

- Horizontal discharge at any position.
- Reduced maintenance costs due to lack of grates.
- Lower overall height.

SIZING CRITERIA

Unit: Vertical hammermills are typically available for between 50-2300 tpd operations.

Drive Motor: 250-1,000 hp depending on the throughput, particle size, nature of waste stream, etc.

Opening: 42-92 in, depending on model, throughput, nature of waste stream, etc.

Overall Size: Length 15-18 ft, width 13-20 ft, height 16-22 ft.

Weight: 15,700-180,000 lb (includes motor, coupling, infeed, and discharge housing).

Size of Motor (typical).

ACCESSORY COMPONENTS

- Feed conveyors
- Discharge conveyors
- Ejected material collection

SUPPORT REQUIREMENTS

Personnel: No additional personnel are needed to operate the hammermill above that required to run a facility. A welder is usually required weekly.
Other Safety: Maintenance should be routinely scheduled to avoid unnecessary operator adjustments of online units.

General Environmental: Dust suppression may be necessary. No other emissions are generated.

COST ANALYSIS

Capital cost range: $50,000-$750,000 depending on throughput capacity and manufacturer. However, cost is not solely a function of capacity. Reported cost of a 50 TPH shredder ranged from $75,000-$750,000 depending on duty. Most hammermills installed in RDF systems are 40 to 70 ton/hour capacity, and cost from $450,000 to $600,000.

Life Cycle Analysis

High levels of maintenance and energy costs are associated with all shredders. Expected life-span of units is 15-20 years provided adequate maintenance is provided.

STATE-OF-THE-ART

R&D Needs: Shredders have a good overall operating history. Research needs to be done to reduce maintenance requirements and determines the effect of design characteristics on energy requirements, throughput and particle size distribution. Explosion prevention and suppression will always be a problem without waste sorting.

Operating Systems: Greater than 32 operating systems throughout the U.S. and Canada.

Manufacturers:
- The Heil Company.
- Hammermills, Inc.
- Jeffrey Manufacturing
- American Pulverizer

Risks: Proven explosion prevention devices do not exist.

Other Information: None (Problem materials)

History: Shredders have been in use for many years in the scrap auto processing industry. Their introduction into MSW processing occurred in the 1950's. Interest in shredders increased in the 1960's when it was felt that shredding could eliminate the need for daily cover of landfilled waste. The rise of RDF production in the 1970's dramatically increased the use of shredders.

Successes: Shredders have proven themselves in many thousands of hours of operation.

Failures: No major failures have been reported.

Key Problems: Numerous explosions and high maintenance costs.

References:
Training: Training is needed to learn maintenance procedures. No additional training is needed. Hammer resurfacing requires welding skills.

Skills Required: No special skills are needed to operate the unit.

Inspection: Hammermills should be routinely inspected for hammer wear, bearing wear, and lubrication.

Access: Adequate access on all sides and top for maintenance.

Spare parts: Replacement hammers, bearing lubricant, bearings, drive gear/belt (if applicable).

Permits: No special permits are required.

OPERATIONAL CONSIDERATIONS

General: Shredders are usually trouble free but high maintenance units. Pre-sorting of unshreddable or hazardous items such as engine blocks, or gasoline cans is recommended.

Installation: No special installation requirements exist. Units are usually delivered fundamentally intact.

Maintenance: Routine maintenance of hammers, bearings, and drive gears is critical to trouble free operation. Hammers require daily inspection and may require weekly resurfacing depending on wear patterns and material. Hammer replacement is necessary when resurfacing is impossible.

Controls: Automatic with manual override.

Scheduling: 24 hr/day operation is possible provided the unit is off-line at least a portion of one day/wk for hammer maintenance.

Downtime: Shredder history is excellent, maintenance is key to limiting down time.

Other Factors: Oversized items need to be removed or reduced in size prior to entering the shredder. Hammermills do not shred tires well.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Shredders are perhaps the most hazardous single unit operation in a recovery facility.

Fire Hazard: Combustible items entering the shredder or a buildup of dust in the unit can create a fire hazard. Fire suppression equipment should be specified.

Explosion: Explosions in MSW shredders are numerous. The potential exists for explosions to occur within the shredder or along the outfeed conveyors. Internal explosions are usually directed upwards through the infeed opening, while those occurring in the outfeed shoot are directed in all directions. Facility layout and roof design should be specified to reduce potential danger and damage. Explosion suppression equipment should be specified.
COMPONENT DESCRIPTION

SHREDDER

Type

Horizontal Hammermill

Types Available - Competing Components

a. Vertical hammermill
d. Ball mill
b. Horizontal hammermill
e. Flail mill
c. Rotary shear

Types Used Commercially

a, b, c

Physical Characteristics

General Description

Initially shredders were used to prepare refuse for landfilling. It was anticipated that shredded refuse would not require daily cover and that greater compaction densities would be obtainable. Both of these initial objectives are no longer focal points of shredding.

Shredders are generally the initial processing step in a resource recovery facility. The shredded refuse is more homogeneous in nature, particle size is within known limits, and any containers or bags are opened exposing the contents to subsequent processing steps. Shredding also greatly increases the packing density of recovered materials and promotes more complete combustion if incineration is employed.

Principal of Operation

The rotor shaft is mounted in a horizontal position with bearings at both ends. Hammers are free swinging. Waste is fed through the top of the unit and descends by gravity. Stationary breaker bars and a curved grate line the lower portion of the mill. The breaker bars serve as the surface of destruction for large items. The small spacing between the grate and the hammers at their greatest extension serves to continually reduce particle size until the particle is smaller than the opening in the grate. Particle size is therefore determined by the size of the grate openings.
## Materials of Construction

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
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<tbody>
<tr>
<td>Shell</td>
<td>Hot-rolled steel, lined with hot-rolled steel or cast manganese attached with countersunk bolts</td>
</tr>
<tr>
<td>Hammers</td>
<td>11-14% cast manganese steel, other hardened steel</td>
</tr>
<tr>
<td>Rotors</td>
<td>SAE 5155 steel, heat treated</td>
</tr>
</tbody>
</table>

## Advantages over other types:
- Accessibility for inspection and maintenance.
- Particle size consistency.

## Sizing Criteria

**Unit:** Horizontal hammermills are typically available for between 50-2,300 tpd operation.

**Drive Motor:** 250-1,000 hp depending on throughput, particle size, nature of waste stream, etc.

**Opening:** 42-92 in, depending on model, throughput, nature of waste stream, etc.

**Overall Size:** Length 15-18 ft, width 13-20 ft, height 16-22 ft

**Weight:** 15,700-180,000 lb (includes motor, coupling, infeed, and discharge housings)

**Size of Motor (typical):**

![Motor Horsepower/Opening Graph](https://via.placeholder.com/150)

## Accessory Components
- Feed conveyors.
- Discharge conveyors.
- Ejected material collection.
- Explosion suppression.
**SUPPORT REQUIREMENTS**

Personnel: No additional personnel are needed to operate the hammermill above that required to run a facility. A welder is usually required weekly.

Training: Training is needed to learn maintenance procedures. No additional training is needed. Hammer resurfacing requires welding skills.

Skills Required: No special skills are needed to operate the unit. Resurfacing hammers requires welding skills plus moderate mechanical skill.

Inspection: Hammermills should be routinely inspected for hammer wear, bearing wear, and lubrication.

Adequate access on all sides and top for maintenance.

Spare Parts: Replacement hammers, bearing lubricant, bearings, drive gear/belt (if applicable)

Permits: No special permits are required.

**OPERATIONAL CONSIDERATIONS**

General: Pre-sorting of unshreddable or hazardous items such as engine blocks or gasoline cans is recommended.

Installation: No special installation requirements exist. Units are usually delivered fundamentally intact.

Maintenance: Routine maintenance of hammers, bearings, and drive gears is critical to trouble free operation. Hammers require daily inspection and may require weekly resurfacing depending on wear patterns and material. Hammer replacement is necessary when resurfacing is impossible.

Controls: Automatic with manual override.

Scheduling: 24 hr/day operation is possible provided the unit is off-line at least a portion of one day per week for hammer maintenance.

Downtime: Shredder history is excellent, maintenance is the key to limiting down-time.

Other Factors: Oversized items need to be removed or reduced in size prior to entering the shredder. Hammermills do not shred tires well.

**SAFETY AND ENVIRONMENTAL CONSIDERATIONS**

General: Shredders are perhaps the most hazardous single unit operation in a recovery facility.

Fire Hazard: Combustible items entering the shredder or a buildup of dust in the unit can create a fire hazard. Fire suppression equipment should be specified.
Explosions: Explosions in MSW shredders are numerous. The potential exists for explosions to occur within the shredder or along the outfeed conveyors. Internal explosions are usually directed upwards through the infeed opening while those occurring in the outfeed shoot are directed in all directions. Facility layout and roof design should be specified to reduce potential danger and damage. Explosion suppression equipment should be specified.

Other Safety: Maintenance should be routinely scheduled to avoid unnecessary operator adjustments of online units.

General Environmental: Dust suppression may be necessary. No other emissions are generated.

Cost Analysis

Capital cost range: $50,000-$750,000 depending on throughput capacity and manufacturer. However cost is not solely a function of capacity. Reported cost of a 50 TPH shredder ranged from $75,000-$750,000. High levels of maintenance and energy costs are associated with all shredders. Expected life-span of units is 15-20 years provided adequate maintenance is provided. (See graphs on Page 5.)

STATE-OF-THE-ART:

R&D Needs: Shredders have a good overall operating history. Research needs to be done to reduce maintenance requirements and determine the effect of design characteristics on energy requirements, throughput and particle size distribution.

Operating Systems: Greater than 60 operating systems throughout the U.S. and Canada.

Manufacturers: American Pulverizer
Hamermills, Inc.
Williams Patent Crusher, Co.
Traces Marksman
Many others

Risks: Proven explosion prevention devices do not exist.

History: Shredders have been in use for many years in the scrap auto processing industry. Their introduction into MSW processing occurred in the 1950's. Interest in shredders increased in the 1960's when it was felt that shredding could eliminate the need for daily cover of landfilled waste. The rise of RDF production in the 1970's dramatically increased the use of shredders.

Successes: Shredders have proven themselves in many thousands of hours of operation.

Failures: No major failures have been reported.

Key Problems: Numerous explosions and high maintenance costs.

Other Information: None
COMPONENT DESCRIPTION

Shredders

Types Available - Competing Components
a. Vertical hammermill
d. Ball mill
b. Horizontal hammermill
e. Flail mill
c. Rotary shear

Types Used Commercially
a, b, c

Physical Characteristics

TWIN VIEW (Rotors Only)

Refuse In

SIDE VIEW

Refuse Out

General Description

See Vertical Hammermill, MH-F.

Principle of Operation

Twin horizontally-positioned shafts mounted with knife-edged rotors, rotate in opposite directions, directing the incoming refuse towards the center of the two rotors. The knife edges grab the refuse and through shearing action between the rotors reduce the particle size. Units are typically hydraulically-driven and are reversible to prevent jamming.

Materials of Construction

- Shaft: Hardened alloy steel.
- Rotors: Hardened alloy steel.
- Blades: Hardened alloy steel.

Advantages Over Other Types

- Smaller units (<50 tpd) are available.
- Lower power consumption.
- Can shred problem materials i.e., tires, wire, foam rubber.
- No balling up of product.
- Reduced noise level.
- Reduced dust level.
- Reduced explosions.
- Lower costs.
### SIZING CRITERIA
- **Unit:** Shearing type shredders are available for between 5-75 tpd operations.
- **Motor:** 460 volt, 3-phase, 60 hz; horsepower will vary with capacity.
- **Horsepower:** Throughput, nature of material to be processed.
- **Infeed opening:** Throughput, maximum size of material to be processed.

### ACCESSORY COMPONENTS
- **Feed conveyors.**
- **Discharge conveyors.**

### SUPPORT REQUIREMENTS
**Personnel:** One additional personnel is needed full-time to operate the shredder above that required to run a facility. Automatic control is feasible. A welder is periodically required.

**Training:** Training is needed to learn maintenance procedures. No additional training is needed. Blade resurfacing requires welding.

**Skills Required:** No special skills are needed to operate the unit. Resurfacing blades requires welding skills plus moderate mechanical skill.

**Inspection:** Shredders should be routinely inspected for blade wear, bearing wear, and lubrication.

**Access:** Adequate access on all sides and top for maintenance.

**Spare Parts:** Replacement blades, bearing lubricant, bearings, drive gear/belt (if applicable).

**Permits:** No special permits are required.

### OPERATIONAL CONSIDERATIONS
**General:** Shredders are high maintenance units. Pre-sorting of unshreddable or hazardous items such as engine blocks or full gasoline cans is recommended.

**Installation:** No special installation requirements exist. Units are usually delivered fundamentally intact.

**Maintenance:** Routine maintenance of blades, bearings, and drive gears is critical to trouble-free operation. Blades require daily inspection and may require weekly resurfacing depending on wear patterns and material. Blade replacement is necessary when resurfacing is impossible.

**Controls:** Automatic with manual override is preferred. Not all manufacturers have this capability.
Scheduling: 24 hr/day operation is possible, provided the unit is off-line at least a portion of one day per week for blade maintenance.

Downtime: Shredder history is excellent, maintenance is key to limiting downtime.

Other Factors: Oversized items need to be removed or reduced in size prior to entering the shredder.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Shredders are perhaps the most hazardous single unit operation in a recovery facility. Shear-type shredders are less hazardous than impact types.

Fire Hazard: Combustible items entering the shredder or a buildup of dust in the unit can create a fire hazard. Fire suppression equipment should be specified.

Explosions: Explosions in MSW shredders are numerous. The potential exists for explosions to occur within the shredder or along the outfeed conveyors. Internal explosions are usually directed upwards through the infeed opening while those occurring in the outfeed shoot are directed in all directions. Facility layout and roof design should be specified to reduce potential dangers and damage. Explosion suppression equipment should be specified.

Other Safety: Maintenance should be routinely scheduled to avoid unnecessary operator adjustments of on-line units.

General Environment: Dust suppression may be necessary. No other emissions are generated.

COST ANALYSIS

Capital costs range from $35,000-$300,000 depending on capacity and manufacturer. Same considerations apply as to hammermills.

STATE-OF-THE-ART

R&D Needs: Shredders have a good overall operating history. Research needs to be done to reduce maintenance requirements; to determine the effect of design characteristics on energy requirements, throughput and particle size distribution.

Operating Systems: Greater than 100 systems are in operation throughout the United States and Canada. The number processing solid waste exclusively is unknown. Rotary shears are not as common to solid waste processing as hammermills.

Manufacturers:
- Saturn Mfg., Co.
- Montgomery Industries.
- Garbalizer Mfg., Co.

Risks: Unshreddable items need to be removed manually ahead of the shear.

Other Information: Most units are automatically reversing to prevent jamming.
History: Shredders have been in use for many years in the scrap auto processing industry. Their introduction into MSW processing occurred in the 1950's. Interest in shredders increased in the 1960's when it was felt that shredding could eliminate the need for daily cover of landfilled waste. The rise of RDF production in the 1970's dramatically increased the use of shredders.

Successes: Shredders have proven themselves in many thousands of hours of operation.

Failures: No major failures have been reported.

Key Problems: Numerous explosions and high maintenance costs.
### COMPONENT DESCRIPTION

**Baler**

| Type | Hydraulic |

**Types Available**

- Vertical
- Horizontal

**Types Used Commercially**

- a
- b

### Physical Characteristics

**VERTICAL:**

- Piston
- Feed Hopper
- Bale Compartment

**HORIZONTAL:**

- Piston
- Feed Hopper
- Bale Compartment

### General Description

In either vertical or horizontal equipment, loose waste is loaded into a feed hopper. The load door is closed compartmentalizing the waste. A hydraulically-powered ram compresses the waste into about one-third the cubic space. Metal bands can be used to restrain the bale from expansion. The piston is retracted and the finished bale ejected.

### Principle of Operation

Three key elements are: hydraulic power source, piston and ram, and bale compartment. Vertical balers compress up and down, horizontal balers compress side to side. Horizontal units are more common. Automatic bale ejection and metal band bale restraint installers are optional equipment.

### Materials of Construction

- Frame - mild steel.
- Piston - alloy steel.
- Ram - hardened steel.
- Hydraulics - pump and motor, various metals, composite rubber hoses.

### Advantages Over Other Types

Hydraulic balers are faster and generally more cost-effective than mechanical balers.
SIZING CRITERIA

- Bale size - ht x width x length - dependent on bale compartment dimensions.
- Throughput - tons/hr - dependent on bale size, cycle time, and hp.

ACCESSORY COMPONENTS

- Automatic bale ejection.
- Automatic metal tie installation.

SUPPORT REQUIREMENTS

Personnel: One maintenance; one operation.
Training: Loading rate - cycle time, hydraulic repair.
Skills Required: Welding, motor/pump repair, skip loader operation.
Inspections: Piston wear, hose wear, hydraulic fluid level.
Access: Adequate for front-end loader and maintenance.
Spare Parts: Hoses, hydraulic fluid, pump rotor.
Permits: None.

OPERATIONAL CONSIDERATIONS

General: Baler performance dependent on uniform waste flow.
Installation: Insure adequate maintenance clearance.
Maintenance: Periodic and frequent due to harsh operating conditions.
Controls: Automatic or manual bale weight control.
Scheduling: Continuous operation possible.
Downtime: Frequent due to high load/stress conditions.
Other Factors: Minimize vibrations and shock loadings.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Balers are constructed to be safe provided recommended procedures are followed.
Fire Hazard: Moderate - flammable liquids may be extruded during compression, provide sprinklers and fire extinguishers.
Explosion: Low - explosion suppression equipment usually not specified.
Other Safety: Operator training important to reduce risks.
General Environmental: Dust from general handling as opposed to baling per se should be vented.

COST ANALYSIS

Cost varies widely between manufacturers. Baling systems for disposal of solid waste often include a complete facility, much like a transfer station. Balers for recovered materials (metal, corrugated paper, etc.) are much different, and their costs also vary as a fluctuation of material.

See manufacturer for price quotes based on intended use.

STATE-OF-THE-ART


Manufacturers: Numerous.

Risks: Technical risks low.
Air classifiers are used to separate the light combustible organic fraction from the heavy non-combustible inorganic fraction. The separation of material is accomplished aerodynamically using a moving stream of air. Air classification can be preceded by shredding or trommelizing to decrease particle size, but this is not mandatory.

**Principle of Operation**

In a typical configuration air is moved through the classifier by induced draft. Incoming refuse is controlled by an air lock prior to being dropped into the moving air stream where it is turbulently mixed. Rotary type units use the rotating throat section to increase refuse to air contact. Light particles are incorporated into the air flow and carried out of the throat section. Downstream of the throat, a settling chamber is provided where air velocity is greatly reduced and the light materials drop out. Filters are usually provided after the settling chamber to remove incorporated dust and other fines. Heavy materials are not drawn up with the air stream and fall out of the unit by the force of gravity.

**Materials of Construction**

- Throat - heavy steel, abrasion-resistant alloys.
- Fans - heavy duty industrial draft fans.
- Other items - steel construction.
### Advantages Over Other Types

Rotary-type classifiers provide higher levels of refuse to air contact and the rotating action causes dumped items to break apart.

Straight and zig zag-type classifiers have fewer moving parts which contributes to lower overall operating and maintenance costs.

### Sizing Criteria

- **Throat** - dependent on type - drums are between 10-20 ft in diameter, straight and zig zag throats are between 1-15 ft in diameter.
- **Fan Horsepower** - 250-1,000
- **Air Flow (cfm)** - maximum reported is 720,000 for a 200 tph unit.
- **Height** - larger units can approach 50 ft. (See graph on Page 4.)

### Accessory Components

- Infeed conveyors and hoppers; light fraction collection bin or conveyor, heavy fraction collection bin or conveyor. All additional equipment is typically supplied by the manufacturer.

### Support Requirements

- **Personnel**: No additional personnel are required to operate an air classifier.
  - Detailed breakdown of operational manpower needs has not been done for air classifiers.
- **Training**: Operational and maintenance training is required and is usually supplied by the manufacturer.
- **Skills**: No special skills are required.
- **Inspections**: Routine inspection as recommended by the manufacturer. Periodic monitoring of controls required.
- **Access**: Adequate for inspections and maintenance.
- **Spare Parts**: Rotary air lock tip seals, lubricant, redundant fans may be specified, bearings.
- **Permits**: No federal permits required, local air pollution permit may be required in certain areas.

### Operational Considerations

- **General**: Efficiency of separation is dependent on many factors including; air velocity, particle size and moisture content. No configuration has been proved superior.
<table>
<thead>
<tr>
<th>MATERIALS HANDLING</th>
<th>Separation</th>
<th>MH-I</th>
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</tr>
</thead>
</table>

Installation: Crane needed, approximately 3 to 4 week for installation by 3-4 man crew.

Maintenance: Routine greasing and lubrication needed, linings if provided may need periodic replacement.

Controls: Automatic controls for air damper, feed rate. Remote visual monitoring of units has been used successfully.

Scheduling: 24 hr operation possible.

Downtime: Experience has shown that after initial startup problems, downtime is minimal.

Other Factors: Detailed breakdown of yearly costs for air classifier operation is not available.

SAFETY AND ENVIRONMENTAL

General: Little or no safety problems were noted with air classifiers.

Fire Hazard: Minimal.

Explosions: Minimal.

Other Safety: None noted.

General Environmental: Dust control and air clean up equipment is required.

COST ANALYSIS

A cost of $6,000 per ton of design capacity can be assumed. Air pollution control equipment will add an additional $40,000-80,000 per facility. Installation costs are excluded but can range up to $100,000.

STATE-OF-THE-ART


Operating Systems:
- Ames, Iowa - Straight Throat.
- Milwaukee, WI - Zig Zag Throat.
- Chicago, IL - Vibrating Throat.
- Baltimore County, MD - Concentric Tube Throat.
- Monroe County, NY - Rotary Drum.
Manufacturers:

- Straight Throat - Rader Pneumatics, Portland, OR, The Heil Co, Milwaukee, WS.
- Zig Zag Throat - Mac Equipment, Sabetha, KS.
- Vibrating Throat - Triple/S Dynamics, Dallas, TX.
- Concentric Tube Throat - Undetermined.
- Rotary Drum Throat - Iowa Mfg, Cedar Rapids, IA.

Risks: Little risk associated with air classifiers.
**COMPONENT DESCRIPTION**

Magnetic Separator

Types Available - Competing Components
- a. Belt
- b. Rotary drum

Types Used Commercially
- a, b

**Physical Characteristics**

<table>
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<th>Component</th>
<th>Characteristics</th>
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<tr>
<td>Belt</td>
<td></td>
</tr>
<tr>
<td>Rotary drum</td>
<td></td>
</tr>
</tbody>
</table>

**General Description**

Magnetic separators are used primarily to remove ferrous metals from MSW. Removal of the 5-8 percent ferrous fraction has three advantages: 1) production of a highly saleable product 2) reduction of wear on subsequent processing equipment, and 3) an increase in per pound Btu content over raw MSW.

**Principle of Operation**

The separator is positioned over the MSW conveyor. The magnetic attraction of the separator lifts the ferrous metals and holds them as the remaining MSW is deposited into bins or onto conveyors for further processing. The ferrous fraction is carried on the moving belt to a designated point where the magnetic attraction is stopped. The separated material then falls off the belt to be further processed.

**Materials of Construction**

- Belt - stainless steel.
- Other items - machine steel, hardened steel.
- Magnets - electric or permanent type.

**Advantages Over Other Types**

Lifts material off conveyor, thereby reducing wear; focused magnetic field.

**SIZING CRITERIA**

- Belt - width of belt
- Belt speed - throughput, percent separation required.
- Magnetic field penetration (typically 12-24 in).
### ACCESSORY COMPONENTS
- Collection bins.
- Conveyors.

### SUPPORT REQUIREMENTS
**Personnel:** No extra personnel are needed to operate a magnetic separator.

**Training:** No special training is needed, maintenance training supplied by manufacturers.

**Skills Required:** Mechanical for maintenance.

**Inspections:** Belt inspection on a weekly basis.

**Access:** Adequate for maintenance.

**Spare Parts:** Belts wear out regularly, bearings.

**Permits:** No permits required.

### OPERATIONAL CONSIDERATIONS
**Installation:** Optimum installation is necessary for separation efficiency.

**Maintenance:** Belt maintenance should be on a regular basis.

**Controls:** No controls needed.

**Scheduling:** 24 hour operation possible.

**Downtime:** Belt failures is the only expected downtime.

### SAFETY AND ENVIRONMENTAL CONSIDERATIONS
**General:** No major safety or environmental hazards are associated with magnetic separators.

**Explosion:** Dust levels should be controlled.

### COST ANALYSIS
**Capital cost typically includes the separator and power supply but does not include supports or intermediate material handling conveyors.** *(See graph on Page 3.)*

**Life Cycle Cost**
Total cost for 10 years is approximately $100,000 *(assumed 10 years amortization 50 tph throughput, 2,000 hr/yr operation).* *(See graph on Page 3.)*
STATE-OF-THE-ART


History: Magnetic separators have been in use for many years in various industries. Specifically, the scrap automobile industry, iron foundries, and other scrap steel operations.

Successes: Magnetic separators generally pay for themselves within the first year of municipal operation provided ferrous markets exist.

Failures: No failures were noted.

Key Problems: Belt life, no additional problems were noted.
COMPONENT DESCRIPTION

Magnetic Separator

Types Available - Competing Components
  a. Belt
  b. Rotary Drum

Physical Characteristics

General Description

Magnetic separators are used primarily to remove ferrous metals from MSW. Removal of the 5-8 percent ferrous fraction has three advantages: 1) production of a highly saleable product, 2) reduction of wear on subsequent processing equipment, and 3) an increase in per pound Btu content over raw MSW.

Principle of Operation

The separator is positioned over the MSW conveyor. The magnetic attraction of the separator lifts the ferrous metals and holds them as the remaining MSW is deposited into bins or onto conveyors for further processing. The ferrous fraction is carried on the rotating magnetic drum to a designated point where the magnetic attraction is stopped and the separated material then falls off the belt to be further processed.

Materials of Construction

- Drum - stainless steel, hardened steel.
- Other items - machine steel, hardened steel.
- Magnets - electric or permanent type.

Advantages Over Other Types

Lifts material off conveyor thereby reducing wear, no belts to wear out, lower maintenance costs, dual drum systems have been demonstrated.
### SIZING CRITERIA
- Drum - width of belt (see graph on Page 3.)
- Belt speed - throughput, percent separation required.
- Magnetic field penetration (typically 12-24 in).

### ACCESSORY COMPONENTS
- Collection bins.
- Conveyors.

### SUPPORT REQUIREMENTS
Personnel: No extra personnel are needed to operate a magnetic separator.
Training: No special training is needed, maintenance training supplied by manufacturer.
Skills Required: Mechanical for maintenance.
Inspections: Drum inspection on a weekly basis.
Access: Adequate for maintenance.
Spare Parts: Lubrication.
Permits: No permits required.

### OPERATIONAL CONSIDERATIONS
Installation: Optimum installation is necessary for separation efficiency.
Maintenance: Maintenance should be scheduled on a regular basis.
Controls: Minimal controls needed.
Scheduling: 24 hour operation possible.
Downtime: Little downtime is expected.

### SAFETY AND ENVIRONMENTAL CONSIDERATIONS
General: No major safety or environmental hazards are associated with magnetic separators.
Explosion: Dust levels should be controlled.

### COST ANALYSIS
Capital cost typically includes the separator and power supply but does not include supports or intermediate material handling conveyors. (See graph on Page A-38).
Total cost for 10 years is approximately $50,000
(assumes 10 yr amortization, 50 tph throughput, 2,000
hr/yr operation). (See graph on Page 3.)

STATE-OF-THE-ART

R&D Needs: Focus of magnetic field, multiple drum systems.
Operating Systems: Charleston, W.Va; and others.
Risks: Few.

History: Magnetic separators have been in use for many years in various industries.
Specifically, the scrap automobile industry, iron foundries, and other scrap steel
operations.
Successes: Magnetic separators generally pay for themselves within the first year of
municipal operation provided ferrous markets exist.
Failures: No failures were noted.
Key Problems: No major problems were noted.
### COMPONENT DESCRIPTION

**Heavy Medium Separators**

<table>
<thead>
<tr>
<th>Type</th>
<th>MH-L</th>
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<tbody>
<tr>
<td>Cyclone</td>
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</table>

**Competing Components**

<table>
<thead>
<tr>
<th>Types Used Commercially</th>
<th>MH-L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclone, Float-sink</td>
<td></td>
</tr>
</tbody>
</table>

### Physical Characteristics

- **Feed**
- **Overflow**
- **Underflow**

Note: Angle varies to change removal efficiencies and specific gravity of the overflow.

### General Description

A cylindrical tank with a conical bottom. Inflow of the liquid feed is situated to induce the tank contents to spin. Guide tubes or vanes in the center of the tank serve to guide the vortex that is created and maintain the separation of light and heavy fractions around the inlet and overflow outlet.

### Principle of Operation

Separation is accomplished based on the specific gravity of the materials introduced. Heavy materials are removed in the underflow while light materials are removed in the overflow. Depending on the flow velocity, angle of the conical section, and specific gravity of the fluid medium, separation can be accomplished for specific gravities of 1.3 to 3.8 using a heavy medium consisting of fine magnetic or ferrosilicon particles in water.

### Materials of Construction

Mild steel for most components. Wearing surfaces such as the inside of the cone may be coated with a hard ceramic material or made of hardened steel.

### Advantages Over Other Types

Permits separation of aluminum from the heavier ferrous materials. Medium is a mixture of water and fine solid particles, reducing the problem of contamination of the feed materials.
### SIZING CRITERIA

Flow rates through the separator influence the specific gravity of the materials that are separated. The system, therefore, should be carefully sized and matched to the amount of feed material processed.

### STATE-OF-THE-ART

**History:** The separation of coal, ore, and minerals by this technology has been in existence for 25-30 years. Tests to determine the feasibility for use on waste materials have been underway in Europe since 1975.

**Successes:** The recovery of various metals from scrap automobiles is common.

**Key Problems:** In the facility of automobile scrap, oil which adheres to the input material contaminated the heavy medium, requiring the addition of oil/water separation. Wear of the cone of the separator due to abrasion.
**COMPONENT DESCRIPTION**

**Aluminum Separator**

**Type**
- Eddy Current Separator

**Types Available**
- a. Eddy Current Separator
- b. Dense Media Separator
- c. Electrostatic Separator
- d. Air Knife

**Physical Characteristics**

**General Description**

Vibrating pan conveyor feeds belt conveyor, which is stationed between opposing set of electromagnets. Material passes along conveyors into varying magnetic field. Current induced in conductors. Second magnetic field (opposing) induces motion in conducting materials across the belt and off. Conductivity/density is twice as high for aluminum as for other non-ferrous conductors, permitting selective recovery given the proper field strength and position.

**Materials of Construction**

No data available.

**Advantages Over Other Types**
- Essentially dry; no wastewater discharge.
- Available in standard design and capacity; scale-up achieved with redundancy.

**SIZING CRITERIA**
- Design is proprietary; standard size of 4 ton/hours (~200 ton/hour refuse equivalent).
- Recovery efficiency increases as throughput is reduced for a given design capacity.
- Multiple units recommended for larger capacity systems.
### ACCESSORY COMPONENTS
- Vibrating pan feed conveyor.
- Discharge bin/hopper for product.

### SUPPORT REQUIREMENTS
Personnel: System monitoring is required; estimated 0.25 people full time.
Inspections: Belt wear, product quality.
Access: Accessible from all sides.
Spare Parts: Belts; other data not available.
Permits: None.

### OPERATIONAL CONSIDERATIONS
General: Flow metering is critical to good recovery efficiency and quality control.
Installation: System vibration must be accounted for in structural design.
Maintenance: Apparently a low maintenance operation, but regular inspection of feed and conveyance systems is recommended.
Controls: Power only; typically no surge capacity to control flow from front-end processing system.
Downtime: As necessary (infrequent)

### SAFETY AND ENVIRONMENTAL CONSIDERATIONS
General: Vibration control necessary; noise control not a problem.
Fire Hazard: Low.
Explosion: Low.
Other Safety: Shields designed as part of system to deflect moving material.
General Environmental: No problems encountered or anticipated.

### COST ANALYSIS
Limited cost data available. Capital cost of 4 ton/hour separator is approximately $300,000 with supporting components, excluding necessary front end processing.
Specifications and power requirements are listed below:
- Power: 3 phase, 450-volt. 27 kilowatts
- Cooling water: 130 gallons/hours (recirculated).
- Belt: 0.040 in nylon with stainless steel splice (replaceable).

Live cycle: no data available.
STATE-OF-THE-ART

R&D Needs: Extensive research has been conducted on eddy current separation by NCRR and others. The applicability and limitations of this system are well known as a result. Extended operating experience under a variety of feed conditions needed before additional R&D can be identified.


Manufacturers: Combustion Power Company.

Fields: Capital cost is high, so dedication to debugging and process modification may be necessary to guarantee payback. Product market specifications may be difficult to meet in some instances.

History: Eddy current separators have been applied to solid waste on a test scale for many years. First full scale installation was Ames, Iowa, in 1975, but system did not produce a marketable product. Subsequent installation at Recovery I was successful. System is used for research by NCRR and commercial scale testing.

Key Problems: Fine-tuning system to recover acceptable product from a given waste flow and condition.

REFERENCES

1. National Center for Resource Recovery:


## COMPONENT DESCRIPTION

**Pelletizer**

**Type**
Pellet Mill

### Types Available
- Pelletizers
- Briquetters
- Cubetters
- Extruders

### Types Used Commercially
- a

### Physical Characteristics

General Description

Pelletizers are used to form fine fluff or other RDF types into pellets of a specific size and shape. The pellets can be bound together chemically or using the free moisture in the solid waste. A variety of pellet sizes and shapes can be produced, with the intention of generating a product that is similar to coal in its handling and combustion characteristics.

Principle of Operation

Shredded, classified soil waste is first fed into the conditioning chamber. From there the material is introduced into the center of the die using a screw feeder or other device. Two rotating rollers force the material through the die. Blades surrounding the outside of the die cut the pellets to size. On newer units, the die rotates and the rollers remain stationary.

Materials of Construction

Dies: No data available.
**Advantages Over Other Types**
- Capable of continuous operation at a higher capacity than other configurations.

**SIZING CRITERIA**
- Pellet size should be based upon characteristics of existing coal handling systems. Typical RDF pellet thickness is 1/2 to 3/4 inch, and length averages 1 inch.
- Standard designs are available, but typical capacity is much lower than commercial RDF production systems, therefore requiring multiple units.

**ACCESSORY COMPONENTS**
- Feed conveyor.
- Storage bins.

**SUPPORT REQUIREMENTS**
No data are available on routine support requirements for commercial RDF pellet mills. Die wear is known to be a problem, and spare dies would be most expensive spare parts inventory.

**OPERATIONAL CONSIDERATIONS**

**Installation:** Pelletizers are delivered essentially ready for startup. Substantial structural support is necessary (die speeds typically range from 130 to 400 rpm).

**Maintenance:** Limited data are available on equipment maintenance and component life.

**Controls:** Variable speed drives are often used to adjust for variations in feedstock composition.

**Scheduling:** Continuous operation is possible. Visual inspections should be scheduled, as well as routine component replacement.

**Downtime:** Approximately 5 to 10 percent downtime can be expected for inspection and maintenance.

**SAFETY AND ENVIRONMENTAL CONSIDERATIONS**

**General:** No safety or environmental hazards are associated with pellet mills.

**Explosion:** Minimal risk.

**COST ANALYSIS**
No long-term operating data available.
STATE-OF-THE-ART

R&D Needs

- Effect of moisture, die speed, and other operating variables on pellet integrity.
- Combustion characteristics of dRDF relative to other RDF forms.
- Maintenance requirements for commercial dRDF production (>500 tpd).

Operating Systems: Baltimore County, Maryland.

Risks: Technical scaleup of pelletizing systems may encounter maintenance problems impeding continuous operation.

History: The ring type mechanical extrusion mill has nearly universal application, and within relatively broad boundary conditions, has had the highest degree of success in producing pelleted refuse-derived fuel or DRDF.

The first successful pellet mill which used steel dies and rolls was developed in 1931. This unit consisted of a flat steel die with four steel rollers on its surface. Feedstock was fed to the die face, distributed and forced through the die by rollers. The pellet extrusions were cut off or broken off by multiple knives.

The ring-type pellet mill, which uses dies and rollers in a vertical plane, was developed in 1934. Conditioned feedstock is fed and distributed within the working volume by gravity, mechanical deflectors, and centrifugal force. Pressure caused by rotation of the die and rollers compacts the feedstock into a mat on the face of the die and develops the forces which extrude the material through the die holes, forming it into pellets. Adjustable knives shear the extruded material to the desired pellet length. In most modern pellet mills, the die is driven and the rollers are stationary on their axes, but are free to rotate upon contact with the die and the material being pelleted. Two rollers are usually used. Nearly all currently manufactured pellet mills include a feeder, conditioning chamber, die and roller assembly, speed reduction device, prime mover, and a common base.

REFERENCES


APPENDIX B
AIR POLLUTION CONTROL EQUIPMENT (APC)
### COMPONENT DESCRIPTION

#### Dust Collectors

**Types Available:** Competing Components Used Commercially
- a. Fabric filters
- b. Granular bed filters
- c. Fiber bed filters
- d. Viscous filters
- e. Electrostatically augmented filters

**Types Used Commercially:**
- a, b

#### Physical Characteristics

**General Description**

Unit consists of groups of large segmented chambers each equipped with fabric filter bags. The cylindrical or envelope-shaped filters can be constructed in a variety of sizes and arranged so that continuous removal of the collected material is possible. Filter units are cleaned mechanically or by using pressure pulses created by compressed air. Collected dust is removed from hoppers located under the filters.

**Principle of Operation**

Particulate matter is removed by filtering the particulate-laden gas stream through a filter media barrier. The barrier, and more importantly, the collected particulate matter which coats the barrier, acts to prevent particles from passing through. The collection mechanisms are direct interception and inertial impaction for the larger particles and diffusion impact (Brownian motion) for the smaller particulate.

**Materials of Construction**

- Filtering media - granular media (sand, gravel), glass fibers, woven or felted fabrics (Nylon, polypropylene, cotton, wool, Teflon, Nomex, glass, Orlon).
- Shell and structural members - Carbon steel.
- Baffles - Carbon steel, 316 Stainless steel.
- Cleaning mechanism - Carbon steel, 316 Stainless steel.
## Advantages Over Other Types

- High collection efficiency for fine particles.
- Process uses dry collection of dust thus minimal dust treatment is needed.
- Fairly low pressure drop is needed.

## SIZING CRITERIA

- Air to cloth ratio - 6 to 1 or less (use 4)
- Cleaning method - reverse air, pulse jet
- Flue gas temperature - generally between 300-500°F
- Fabric filter type - silicone coated
- Pressure drop - 3-10 in water column

### Size of filter (typical)

Surface area of filter media needed = air to cloth ratio x volume of gas to be cleaned. (See graph on Page 4.)

## ACCESSORY COMPONENTS

- Dust-handling equipment.
- Ducting, dampers, stack, fans.
- Broken bag detector.
- Gas cooling equipment (radiant cooler, spray cooler, dilution air).
- Precleaner (mechanical collector).

## SUPPORT REQUIREMENTS

**Personnel:** operation labor - 2 to 4 man-hr/shift; maintenance labor - 1 to 2 man-hr/shift.

**Training:** Operator training required (usually supplied by manufacturer and/or vendor.

**Skills Required:** General mechanical and electrical.

**Inspections:** General inspection (8 hr of operation); detailed inspection (500-1,000 hr of operation).

**Access:** Access to replace filter units needed.

**Spare Parts:** Filter media (bags).

**Permits:** Air pollution control.
OPERATIONAL CONSIDERATIONS

General: Must keep gas above dew point and below temperature tolerance level of fabric.

Installation: Close as possible to emission source.

Maintenance: Routine maintenance needed for media dust removal system. Must replace bags as needed.

Controls: Bag cleaning can be controlled by pressure drop on system.

Scheduling: Continuous operation.

Downtime: Units are constructed in sections for redundancy, thus total system downtime can be minimized.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS


Explosion: Must consider explosion potential and adjust design to minimize and/or accommodate it.

General Environmental: Must dispose of collected material in an environmentally acceptable manner.

COST ANALYSIS

Cost of filtration system is dependent upon (1) type of fabric and air-to-cloth ratio; (2) intermittent or continuous duty; (3) pressure or suction-type construction; (4) standard or custom design; (5) method of cleaning; (6) materials of construction.

Life Cycle Analysis: Equipment life - low = 5 yr; average = 20 yr; high = 40 yr.
Fabric filter bags - low = 0.3 yr; average = 1.5 yr; high = 5 yr.

Total Capital Cost

Total cost = purchased equipment cost + installation costs. (See graph on Page 4.)
Direction installation costs = 0.56 x purchased equipment costs.
Indirect installation costs = 0.35 x purchased equipment costs.

Operating Costs Components

- Labor - 3 to 5 man-hours/shift.
- Electrical power = 0.5 hp/1,000 ft² of cloth.
- Waste disposal = as needed.

STATE-OF-THE-ART

R&D Needs: Ways to extend life of filter media, electrostatic augmentation.
Manufacturers:
- American Air Filter.
- Standard Havens.
- Western Precipitation.

Risks: Explosion and fire hazard if not properly designed or improper filter media selected.

History: Earliest models of fabric filter units consisted of manually shaken filter sleeves hung in rows and tied together at the bottom. In 1881 a mechanized shaking device was introduced. Improvements in filter media and shaking technique have constantly been made since this device was originally introduced.

Successes: Filtration devices have been installed on numerous industrial processes but their use is primarily limited by temperature and moisture content of the gases or other characteristics of the dust or flue gas. Two fabric filter installations on municipal incinerators exist, however their success has been limited. These are East Bridgewater and Framingham, Massachusetts. A 9000 ACFM has been successful with 99.8% removal when operating at an air-cloth-ratio of 6 to 1 or less.

Failures: The East Bridgewater, Massachusetts facility has had problems of bag and bag house corrosion and periodic high opacity observations have persisted. Since bag-house operation is sensitive to temperature and humidity, municipal incinerators with highly variable input refuse heat and moisture content must have a very tight control system to guarantee proper operation. The problem of fabric deterioration must be controlled by special coatings or pretreating of the input gas stream with neutralizing chemicals.

Key Problems: Filter media problems - fabric life can be shortened by abrasive dusts, sticky dusts, corrosive gases, high temperature gases, and in general, dusts which "bund" the filter media by not being capable of being removed from the media.

REFERENCES
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<th>APC-B</th>
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<tr>
<td>COMPONENT DESCRIPTION</td>
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</tr>
<tr>
<td>Mechanical Collectors</td>
<td></td>
<td>Type</td>
<td></td>
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<tr>
<td>Types Available</td>
<td></td>
<td>Cyclone</td>
<td></td>
</tr>
<tr>
<td>a. Settling chambers</td>
<td></td>
<td>Types Used Commercially</td>
<td>a, b, c</td>
</tr>
<tr>
<td>b. Intertial separators</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c. Reverse flow cyclone</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>d. Multicyclones</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e. Scroll collectors</td>
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</tbody>
</table>

### Physical Characteristics

Cyclone diagram

#### General Description

Cyclones consist of an inlet section, a cylindrical barrel, a conical transition from the barrel to a dust outlet, a gas outlet pipe and a dust container below the dust outlet. High efficiency cyclones are often arranged in parallel in multiple cyclone units with common gas inlets and outlets.

#### Principle of Operation

Mechanical collectors function to remove particles from the gas stream by enhancing the inertia and momentum or gravitational forces which act upon the particles. Settling chambers reduce the velocity of the gas stream to the extent that the particles settle under the force of gravity. Inertial separators cause an increase in gas velocity and rapid changes in flow pattern, thereby causing particles to separate from the gas. Cyclones achieve particle/gas separation by increasing the centrifugal force imparted to the suspended particles which are then forced into the cyclone walls and collected.

#### Materials of Construction

- Cyclone body - mild carbon steel, abrasion-resistant steels.
- Shell for multicyclone units - mild steel.
- Dust hopper - mild steel.
Advantages Over Other Types

- Low cost.
- High tolerance to excessive temperatures and abrasive dust.
- Low space requirements.
- Dry disposal of particulate matter.
- Low maintenance and operational manpower requirements.
- Simple to operate.

SIZING CRITERIA

- Inlet velocity (49-59 ft/s).
- Pressure drop (0.07-0.25 psi).

ACCESSORY COMPONENTS

- Inlet ducting and dampers.
- Dust removal hopper and rotary air lock valves.

SUPPORT REQUIREMENTS

Personnel: No specialized operating personnel. Generally these devices are simple to operate.

Training: No training required.

Skills Required: None.

Inspections: Inspect for excessive wall roughness, dust buildup, air leaks, and unequalized air flow.

Spare Parts: None required.

Permits: Air Pollution Control.

OPERATIONAL CONSIDERATIONS

General: Mechanical collectors generally are not adequate to control incinerator emissions to meet most air quality standards.

Maintenance: Cyclone units generally require minimal maintenance.

Controls: Minimal controls are required.

Scheduling: Continuous operation.

Downtime: Units can be constructed in modules for redundancy, thus total system downtime can be minimized.
SAFETY AND ENVIRONMENTAL CONSIDERATIONS

Fire Hazard: Minimal.

Explosion: Minimal.

General Environmental: Must dispose of collected material in an environmentally acceptable manner.

COST ANALYSIS

Equipment costs not including installation, freight, taxes, etc. = $0.50 to $0.75/ acfm (multicyclone unit with 12" diameter cyclones). Operating costs are equal to the expenses associated with fan power (see Power Requirements).

Life Cycle Analysis - Units generally last 10-15 years.

Power Requirements:

\[ \text{kwh} = \frac{0.746 \times \text{CFM} \times P \times SG \times H}{6,356n} \]

CFM = volumetric flow rate, acfm.

P = pressure.

SG = specific gravity as compared to air @ 70°F, 29.92 in Hg.

H = hours of operation.

n = efficiency, usually 60-70%.

STATE-OF-THE-ART

R&D Needs: These are well established devices and their performance is fairly well understood.

Operating Systems: Should only be used as gas precleaners upstream of scrubbers, ESP's or fabric filters.

Manufacturers:

- American Air Filter.
- Joy Manufacturing Co.
- Air Pollution Industries, Inc.
- Aget Manufacturing Co.
- American Standard.

Risks: Mechanical collectors have low efficiency for fine particles.

History: Because of their simplicity and lack of moving parts, settling chambers, momentum separators and cyclones have a long history of use. However, in recent years because of more stringent air pollution standards, their use as a final control device has been limited.
Successes: There are numerous installations where mechanical collectors and more specifically, settling chambers and multi-cyclone units, have been applied as precleaners prior to fabric filter or electrostatic precipitation units. These units by themselves are not generally sufficient to meet current air quality standards.

Failures: Since mechanical collectors should not be considered as a final control technology, discussion of device failure is referenced to their use as precleaners. Failure can result from improper design (cyclone geometry not appropriate for gas volume and particle size to be collected), or inadequate maintenance.

Key Problems: Cyclones and multicyclones should not be applied to conditions where dust will adhere to the cyclone and dust hopper walls or where the dust is very fine. Specific materials should be used when abrasive or corrosive conditions occur.
COMPONENT DESCRIPTION

Electrostatic Precipitators

Types Available
a. High voltage-single stage
b. Low voltage-two stage
c. Wet wall
d. Dry wall
e. European design
f. American design

Types Used Commercially
a, d, e, f

Physical Characteristics

1. Support insulation
2. Discharge system
3. Rapping mechanism for discharge systems
4. Ground distribution systems
5. Rapping mechanism for collecting systems
6. Collecting electrodes
7. Dust hoppers (either types of discharge arrangements or hoppers attached, etc. between each set of plates)
8. Dust-discharge opening
9. Heat insulation
10. Drive gear for the discharge or collection system
11. Insulated screen door
12. Drive gear for the discharge or collection system
13. Transformer rectifiers with earth current regulation
14. Load cell having (electrically or mechanically) or load cell (in general, mechanical or insulated)

General Description

Consists of a group of large segmented chambers, usually insulated. Suspended in each chamber are flat collecting plates with equal spacing and discharge electrodes (usually wires) between each set of plates. The discharge electrodes and collecting plates are electrically insulated from each other. Transition ducting leads the gas to and from the unit with dust being removed via the bottom.

Principle of Operation

Particles to be collected are electrically charged. This is accomplished by the attachment of negative ions and electrons which have been formed by the electrical ionization of a gas close to a highly charged discharge wire. The electrical field established between the discharge electrode and a grounded plate draws the charged particle to the plate where it is deposited. The collected material is removed as an agglomerated mass from the collecting plates by mechanical rapping.

Materials of Construction

Temperature and corrosion resistance are the two most important factors in the selection of materials.

- Collecting surfaces - carbon steel, special high alloy steel, lead.
- Discharge electrodes - carbon steel, alloy steel.
- Shell - carbon steel, alloy steel, tile, fiberglass.
- Support members - carbon steel, alloy steel.
Advantages Over Other Types
- Low pressure drop.
- High removal efficiency for small particle size.
- Handles high temperature gases.
- Used for both solid and liquid particulate matter.

SIZING CRITERIA
- Plate spacing: 8-12 in.
- Velocity through precipitation: 2.95-5.91 ft/s.
- Vertical height of plates: 11.8-32.8 ft.
- Draft loss: 0.004-0.029 psi.
- Collection area: 4,300-10,765 ft².
- Efficiency: 93-99%.
- Migration velocity: 2.36-4.72 in/s.

General Sizing Equation
\[ E = 1 - e^{(-w A)} \]

- \( E \) = collection efficiency.
- \( w \) = drift velocity (ft/sec) = 0.2-0.33
- \( A \) = plate area (ft²)
- \( Q \) = flow rate (ACFS)

ACCESSORY COMPONENTS
- Ash handling equipment.
- Ducting, dampers, stack, air-moving equipment for wet bottom - wastewater treatment equipment.

SUPPORT REQUIREMENTS
Personnel: Operating labor per shift = 0.5 - 2 man-hr
Maintenance labor per shift = 0.5 - 1 man-hr

Training: Operator training required - usually supplied by manufacturer and/or vendor.

Skills Required: General mechanical and electrical.

Inspections: 1 general inspection/8 hr of operation; 1 detailed inspection/1,000 - 2,000 hrs of operation.

Access: Access to collecting plates, insulators, rapping mechanism, voltage supply and dust removal systems needed.

Spare Parts: Discharge wires and hangers.

Permits: Air Pollution Control.
OPERATIONAL CONSIDERATIONS

General: Key problem areas - corrosion, rapper failure, dust removal, electrical shorts.

Installation: Close as possible to emission source.

Maintenance: Routine maintenance of rappers and dust removal equipment.

Controls: Automatic voltage/current/spark rate controls available.

Scheduling: Continuous operation.

Downtime: Units are constructed in sections for redundancy, thus total system downtime can be minimized.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Protect maintenance personnel from electrical shock hazard by interlocking access doors to safety switches.

Fire Hazard: Cannot be used on flammable dusts or gases.

Explosion: Minimal.

General Environmental: Must dispose of collected material in an environmentally acceptable manner.

COST ANALYSIS

Prices for dry type (mechanical rapper or vibrator) precipitators are contained in the figure from page B-14. Prices are a function of net plate area, which can be calculated using the general sizing equation given above.

Life Cycle Analysis for Equipment; short = 5 yrs; average = 20 yrs; long = 40 yrs.

Total Capital Costs

- Total cost = purchased equipment cost + installation cost.
- Installation indirect costs = 0.67 x purchased equipment costs.
- Installation direct costs = 0.57 x purchased equipment costs.

Operating Cost Components

- Labor: see Support Requirements.
- Electrical power = 1.5 watts/ft².
- Waste disposal - as needed.
## AIR POLLUTION CONTROL

### Electrostatic Precipitator

<table>
<thead>
<tr>
<th><strong>STATE-OF-THE-ART</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>R&amp;D Needs: Adapting ESP's to wider variety of emission sources, minimizing reentrainment of dust.</td>
</tr>
<tr>
<td>Operating Systems: See entries under Successes.</td>
</tr>
</tbody>
</table>

### Manufacturers:
- Western Precipitation.
- Research Cottrell.
- United States Air Filter Corporation.
- American Air Filter.

### Risks:
Must design system specific to site specific dust resistivity. Do not apply to explosive gases or flammable dusts.

### History:
Developed in early 20th Century by Lodge in England and Cottrell in the U.S. First successful application on sulfuric acid mist and later on a power plant and smelter. ESP's are primarily designed by empirical means as opposed to theoretical formulas. Detailed mathematical models have been recently developed to predict performance.

### Successes:
Successful installations on a number of industrial applications. Primarily coal-fired utility and industrial boilers, cement kilns, incinerators, kraft pulp mills and metallurgical operations. ESP's installed on municipal solid waste incinerators in Saugas, Massachusetts; Nashville, Tennessee; Norfolk, Virginia; Ogden, Utah; Washington, D.C.; Chicago, Illinois; Baltimore, Maryland; Philadelphia, Pennsylvania. (See below.)

### Failures:
Individual cases of ESP failure on incinerators are not known. However, failure can result from excessive corrosion, improper dust resistivity, inadequate collecting area, improper gas distribution, poorly designed rapping (either too frequent or too infrequent), or excessive gas velocity.

### Key Problems:
(See above.) Actual test results on existing and new municipal incinerator facilities indicate that the new source performance standard of 0.08 grains/OSCE is technologically feasible through the use of appropriately designed ESP.

### Comments:
See References 1 and 2 for general ESP information.

### REFERENCES
Dry type Electrostatic Precipitator Purchase Prices vs. Plate Area (A)

Source: Based on data from Joy/Western Precipitation Div.
### COMPONENT DESCRIPTION

Types Available - Competing Components

- a. Venturi
- b. Flooded disc
- c. Centrifugal
- d. Spray towers
- e. Moving bed
- f. Plate
- g. Packed bed

Types Used Commercially

- Type: Venturi
- Types: Venturi

### Physical Characteristics

- A Gas with Pollutant Inlet
- B Clean Gas to Demister (Used Separate Liquid from Gas Stream)
- C Scrubber Wall Liquid Inlet
- D Scrubber Liquid at Venturi Throat Inlet
- E Venturi Throat
- F Adjustable Construction to Increase

### General Description

Scrubber utilizes moving gas stream to atomize liquid into drops, and then accelerates the drops to promote contact between particulate matter and liquid drops. Entrained liquid, captured particles, and gas flow to cyclonic dropout chamber (typically) where gas and liquid are separated.

### Principle of Operation

Particulate removed from the gas by one of the following mechanisms:

- Inertial impaction (direct droplet/particle contact).
- Interception (indirect or close contact of liquid and solid).
- Diffusion (intersection of liquid and submicron particles due to Brownian motion).
- Electrostatic (attraction between liquid and solids).

### Materials of Construction

- **Scrubber body**: 1/8 to 1/2 in. carbon steel plate -- noncorrosive 1/8 to 1/2 in. 316 or 304 stainless steel or 3/16 soft rubber lining (SRL) corrosive
- **Piping**: FRP, SRL, carbon steel
- **Ducts & stack**: Ceramic, brick or other noncorrosive

### Advantages Over Other Types

- Capability to remove submicron particles and operates at a higher overall removal efficiency -- can be used to remove gas phase pollutants as well as particulate.
AIR POLLUTION CONTROL

Venturi Scrubber

APC-D

P. 2 of 4

SIZING CRITERIA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas velocity</td>
<td>20 to 40 fps</td>
</tr>
<tr>
<td>Pressure (flange to flange)</td>
<td>0.2-3.0 psi</td>
</tr>
<tr>
<td>Liquid rate</td>
<td>.005 gal/cu-ft of gas</td>
</tr>
</tbody>
</table>

ACCESSORY COMPONENTS

- Ducting, dampers, stack, air moving equipment.
- High efficiency demister.
- May require wastewater treatment including solids concentration/removal, flocculation, and neutralization.

SUPPORT REQUIREMENTS

Personnel: Operating labor -- 2 to 8 man-hr/shift, maintenance 1 to 2 man-hr/shift.

Training: Operator training required -- supplied by vendor.

Skill required: Electrical and mechanical.

Inspections: Daily operability inspections -- internal inspections/1,000 to 3,000 hr of operation.

Access: To adjustable venturi throat and demister internals.

Spare Parts: Pumps, pH controller, nozzles.

Permits: Air pollution control district.

OPERATIONAL CONSIDERATIONS

General: Primary problem areas

- plugging
- chemical or impact scale
- corrosion (requirement adequate pH control)

Installation: Proximity of the stack.

Maintenance: Routine inspection.

Controls: pH for corrosion - pressure for plugging or scaling.

Scheduling: Continuous

Downtime: Normal maintenance.

Other Factors: N/A.
<table>
<thead>
<tr>
<th>SAFETY AND ENVIRONMENTAL CONSIDERATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>General: Key interlock or equivalent to prevent opening access doors while system is operating.</td>
</tr>
<tr>
<td>Fire Hazardous: Loss of scrubbing liquor supply should be coupled to system shutdown - protects scrubber lining (FRP and rubber) and other internals from high temperatures.</td>
</tr>
<tr>
<td>Explosion: Minimal.</td>
</tr>
<tr>
<td>Other Safety: N/A.</td>
</tr>
<tr>
<td>General Environmental: Scrubber effluent may require treatment. Gases discharged will be saturated with water: dense white plume may occur at ground level. Reheat may be required.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COST ANALYSIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost = 7117 + 408 - 0.35v^2 where:</td>
</tr>
<tr>
<td>v= 1,000 acfm, 1/8 in. carbon steel</td>
</tr>
<tr>
<td>&lt;20,000 acfm, flange to flange, pump, control demister</td>
</tr>
<tr>
<td>Economic Life Factors</td>
</tr>
<tr>
<td>• Low -- 5 years.</td>
</tr>
<tr>
<td>• Average -- 10 years.</td>
</tr>
<tr>
<td>• High -- 20 years.</td>
</tr>
<tr>
<td>Capital Costs</td>
</tr>
<tr>
<td>Installation: (0.56) x (capital cost)</td>
</tr>
<tr>
<td>Indirect: (0.35) x (capital cost)</td>
</tr>
<tr>
<td>Operating Costs</td>
</tr>
<tr>
<td>Power to overcome P and LG ratio</td>
</tr>
<tr>
<td>E = $0.0432/KWh and KWh = (0.746) (horsepower) (hours of operation)</td>
</tr>
<tr>
<td>Horsepower = pump + fan horsepower</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>STATE-OF-THE-ART</th>
</tr>
</thead>
<tbody>
<tr>
<td>R&amp;D Needs: Present activities include the development of flux-force/condensation and electrostatically aided-scrubbers.</td>
</tr>
<tr>
<td>Operating System: Virtually every industry which requires particulate matter control.</td>
</tr>
<tr>
<td>Risks: N/A.</td>
</tr>
<tr>
<td>Other Information: N/A.</td>
</tr>
</tbody>
</table>
History: Commercially available since 1947, principals of operation known since about 1900.

Successes: Venturi scrubber operation at 15-20 in W.G. were successful in reaching 0.08 grains/DSCFM at 12 percent CO₂ level. Applications to coal-fired boilers - efficiencies of 96 percent at P - 20 in W. G. have been experienced.

Failures: Carry-over of scrubber solids and inefficient demister operation reduce collection efficiency. Corrosion of internal components leads to greatest failure rate.

Key Problems: Corrosion of scrubber internals, downstream ducts and stacks and poor demister operation.

Comments -- Additional Data
a. Venturi most often used and is applicable for high efficiency particulate control to meet NSPS.
b. References

REFERENCES: SEE C(30) FOR ADDITIONAL REFERENCES
1. Capital and Operating Costs of Selected Air Pollution Control Systems EPA 450/5-80-002, GARP, Inc.
Heat Recovery Incinerator

Types Available
A. Rotary kiln
B. Stationary grate
C. Auger bed

Type
Controlled-Air

Types Used Commercially
A, B

**General Description**

Modular incineration systems typically contain multiple factory constructed units of identical design; hence the term modular. The units are designed to operate independently, however in systems where steam or hot water production is designed the multiple units will typically use a common boiler.

Controlled air incinerators which operate with less air than that required for complete combustion (usually 30 to 40%) are called starved air or substoichiometric air incinerators. These units are also referred to as pyrolytic incinerators. This terminology however is incorrect, as the combustion process which takes place does not meet the high temperature, low air requirements of pyrolysis.

Systems which provide more than the minimum quantity of combustion air are known as excess air incinerators. The air flow into these systems is also controlled as in a starved air system.

The above terminology refers to the primary combustion chambers only. In all systems the secondary chamber is supplied with between 100 and 150% of theoretical air requirements to complete oxidation of the primary combustion products.

Feed mechanisms, materials of construction, ash handling systems and controls will vary with the manufacturer. There are numerous methods of specifying each. Typical arrangements employ a hopper and hydraulically driven ram as feed mechanisms; heavy steel and cast refractory construction; automatic water quench tank for ash handling; and semiautomatic control.

Combustion grate arrangement also varies with the manufacturer. Stationary, reciprocating, and rotary grates are all available. Data are not available to determine if a particular grate arrangement is superior to others.
Principle of Operation

Raw waste is delivered to the incinerator facility and deposited onto a tipping floor or into a pit. Oversized or otherwise unprocessable items are removed and disposed of. The waste is fed into the primary chamber in controlled batches. The batch size, usually between one and four cubic yards, varies with the waste characteristics, particularly particle size, bulk density and Btu content, as well as with the incinerator capacity.

Ongoing combustion within the primary chamber successively dries, volitalizes and then combusts the waste. During initial start-up operations auxiliary burners are used to bring the unit to temperature.

Partially combusted gases and particulates are drawn up into the secondary chamber where additional quantities of air is injected. In some designs the high gas temperature alone is sufficient to ignite the mixture. When this ignition mechanism is not adequate auxiliary fuel burners serve that purpose. Controlled air combustion in the two chambers burns virtually all the combustible gases and particulates. However the stack emissions can contain some unburned carbon, as well as inert particles and vapors. In some installations, particularly larger municipal systems (50 tpd or greater), additional stack gas cleaning devices such as electrostatic precipitators are needed to meet federal, state, and local pollution standards.

Systems which incorporate heat recovery, do so by installing either a water tube or fire tube boiler downstream of the secondary chamber. Gas temperatures entering the boiler are generally between 1,000 and 1,800°F while exit temperatures are approximately 350°F.

Ash and other incombustible residue which settle on the hearth of the primary chamber after the combustion process must be periodically removed. In the manual system, the operator must scoop out the ash (by shovel or front-end loader) after the unit has been shut off and cooled down. The ash in an automatic system is pushed or forced ahead of the burning waste until it exits the chamber, into either a water-sealed pit or an air lock chamber.

Advantages over other types

Substoichiometrically-controlled air incinerators have as an inherent advantage, the reduced air pollution control equipment requirements and blower horsepower requirements resulting from the reduced quantities of combustion gases used in the process.

<table>
<thead>
<tr>
<th>SIZING CRITERIA</th>
<th>Length (ft)</th>
<th>Width (ft)</th>
<th>Height (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivery door</td>
<td>NA</td>
<td>20</td>
<td>24</td>
</tr>
<tr>
<td>Ram feed hopper</td>
<td>20</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>(feed door elevated)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary combustion chamber</td>
<td>20</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>Secondary combustion chamber*</td>
<td>20</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Boiler (15,000 lb/hr [6804 kg/hr] capacity**)</td>
<td>26</td>
<td>10</td>
<td>11</td>
</tr>
</tbody>
</table>
Ash quench and conveyor removal 20 8 6
Tipping floor varies with holding capacity
Basis: Piggyback configuration, 1 ton/hr capacity
* Secondary chamber elevated above primary chamber.
** Boiler can be elevated above ash removal area at secondary chamber level.
(Metric Conversion Factor: 1 ft = 0.3 m)

ACCESSORY COMPONENTS

<table>
<thead>
<tr>
<th>Item</th>
<th>Reference No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight station (optional)</td>
<td>Not included</td>
</tr>
<tr>
<td>Tipping area</td>
<td>Not included</td>
</tr>
<tr>
<td>Boiler feedwater treatment</td>
<td>Not included</td>
</tr>
<tr>
<td>Bulky combustible shredder (optional)</td>
<td>MH-F, MH-g</td>
</tr>
<tr>
<td>Steam distribution/condensate return line</td>
<td>Not included</td>
</tr>
<tr>
<td>Back up boiler (optional)</td>
<td>Not included</td>
</tr>
</tbody>
</table>

SUPPORT REQUIREMENTS

Personnel: Per shift personnel required are: front-end loader operator, incinerator operator, laborer, mechanic, supervisor. Additional requirements may include: 1 clerk, 1 electrician, and a boiler operator.

Training: Training of operators, supervisors, and backup personnel should begin when the project is in the initial stages and continue through the time that the system is on-line. Total personnel time required for training averages 1 mo/person.

Skills Required: Skill requirement will vary with assignment. Highly skilled positions include: incinerator operator, mechanic, and boiler operation and experience contributes significantly to successful overall incinerator plant operation.

Inspections: All equipment should be routinely inspected to assure steady operation and to minimize lengthy down-time. A facility can expect periodic inspections from both Navy and civilian regulatory agencies.

Access: The facility should be located reasonably close to both waste generation areas and more critically to energy markets. Building must be accessible to the collection vehicles employed. Each piece of equipment should be easily accessible for maintenance purposes.

Spare parts: Recommended spare parts include hydraulic cylinders, fan motors, bearings, seals, timers, and other control mechanisms. Most major pieces of equipment have redundant companions to assure against lengthy down time. Refractory can usually be purchased locally, where this is not possible, spare refractory should be stored.

Permits: Stationary source air pollution control permits will be required for all facilities. Compliance tests are required for air pollutant emissions. Local or state pollution control agencies can usually provide information about what types of compliance tests are necessary. A formal environmental impact assessment (EIA) or, in many cases, a formal environmental impact statement (EIS) will be required for a heat-recovery incinerator plant.
OPERATIONAL CONSIDERATIONS

General: There is a degree of uncertainty and risk regarding the performance of the controlled-air system and its life cycle costs and benefits. This uncertainty is due to its brief history of operation, insufficient instrumentation and record-keeping at operating facilities, and/or industry tendency to market equipment before completing investigative and developmental work.

Installation: Installation will include site preparation, building construction and support facilities. These items can be constructed in the interim between purchase and delivery of the incinerator units.

Maintenance: Routine maintenance along with operator training are the most important components of a successful operation. Lack of maintenance has caused a number of incineration facilities to burn-out and subsequently be dismantled.

Controls: Controlled-air systems should be accompanied by thorough instrumentation and performance monitoring, to collect performance and cost data for use in project development and evaluation.

Scheduling: Start-up and shake-down periods of upwards of 1/2 - 2 years have been noted. Once in continuous operation operating systems experience only routine scheduled down-time. Most facilities are designed to operate 24 hours per day, 5 days per week.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Plant design should include facilities for personnel hygiene, meals, and meetings for working personnel. A program of safety inspection and training should be a normal part of plant operation. Minimum requirements for ventilation and illumination should be met or exceeded. General safety equipment such as first aid kits, fire extinguishers, hoses, intercom, handlights, and equipment-related devices should be furnished. Employee safety equipment (hard hats, masks, goggles, protective clothing, safety shoes, fire blankets, cots, and stretchers) should be provided.

Fire Hazard: Fire danger is low provided recommended operating procedures and housekeeping requirements are followed.

Explosions: Explosion hazard is low. Any explosion which occurs within the primary chamber should be contained within.

Other Safety: Incinerator and boiler walls and steam lines can become hot. Adequate protection and warnings should be installed.

General Env.: Modular incinerators typically emit particulates with concentrations of less than 0.2 gr/scf (12% CO₂). Federal New Source Performance Standards (Subpart E) set a particulate emission level of 0.08 gr/scf (12% CO₂) on units of 50 ton per day or greater. State and local standards for units of lesser capacity will vary but will generally be lower. Therefore, some pollution control device may be necessary. Manufacturers typically supply systems which incorporate adequate control devices.
Cost Analysis

Incinerator systems are capital intensive projects. Variations in costs between manufacturers should be considered. However, due to limited data, only operating and labor costs from systems suppliers was included (see graph on p. 6).

Life Cycle Analysis: Available data is not sufficient to determine true life cycle cost of modular incinerators.

STATE-OF-THE-ART

R&D Needs: Careful monitoring of operating facilities is needed to accurately determine system performance, cost, and maintenance requirements.

Operating Systems: There are at least 12 operating municipal heat recovery modular units in the United States. Additional facilities are in start-up or an advanced design stages.

Manufacturers: At least 20 companies manufacture modular incinerators. A partial listing of manufacturers is included under Comments Section.

Risks: Risks involving potentially changing waste characteristics, unknown reliability of major equipment, possible changes in demand for product steam and limitations on ash disposal.

Other Information:

History: Controlled-air incinerators first became commercially available in the late 1960's. Initial designs did not include heat recovery. Prior to the introduction of controlled-air units practically all incinerators were uncontrolled excess air units.

Successes: Reliable heat recovery from modular incineration has been demonstrated. Of particular interest is the 50 tpd system in Osceola, Arkansas. The facility has operated 24 hours per day 5 days per week with only 2 unscheduled days of downtime. The facility routinely produces 8,000 lb/hr of 125°F saturated steam. However, the system was installed in early 1980 and has not been forced into the refractory replacement typical of 4-5 year old systems.

Failures: There have been numerous cases where complete systems have failed and have been dismantled. The communities of Augusta, Truman, and Siloam Springs, Arkansas, all have inactive systems. The 100 tpd facility in North Little Rock, Arkansas, for years a show case facility, is now operating at one-half capacity due to lack of adequate maintenance and an over estimation of the Btu content of the waste stream.

Key Problems:

- Lack of adequate maintenance.
- Over estimating Btu content of waste stream.
- Over estimation of capturable waste quantity.
- Manufacturers selling systems prior to complete understanding of operational parameters.
Unreliable operation.
Non-redundant designs have caused entire plants to shut down for repair of a single item.

Comments

Partial list of modular incinerator manufacturers:
- Basic Environmental Engineering, Glen Ellyn, IL.
- Burn-Zol, Dover, NJ.
- C.E. Bartlett-Snow, Chicago, IL.
- Clean Air, Inc., Ogden, Ut.
- Contro Division, Meadville, PA.
- Consumat, Richmond, VA.
- Environmental Control Products, Charlotte, NC.
- Kelley Company, Inc., Milwaukee, WA.
- Lamb-Cargate, New Westminster, B.C., Canada.
- Morse-Boulger, Corona, NY.
- Simonds Company, Winter Haven, FL.
COMPONENT DESCRIPTION

Refractory Wall Heat Recovery Incinerator

Types Available - Competing Components
a. Solid unprocessed  d. Co-firing
b. Liquid  e. Pathological
c. Sludge

Types Used Commercially
a, b, c, d, e

Physical Characteristics

General Description

The heat recovery refractory-lined incinerator has refractory lining in the combustion chamber where as-discarded solid waste is combusted over air-cooled traveling or stoker grate. Final hot gases are directed to a heat recovery boiler and then to a pollution control device. Some modular incinerators work as controlled-air units. Excess air is generally 100-300% to keep the refractory cool, and to avoid slagging. The units are provided with manual or continuous ash dumping systems. In some instances, with high moisture content refuse auxiliary fuel is needed for startup or continued incineration.

Principle of Operation

Field-erected units are of Dutch-oven design. Gasification occurs in the Dutch oven section and combustion of the volatile combustibles occurs in the baffled zone after turbulent mixing with air. In modular units, vaporization occurs in the primary chamber by exchanging heat between hot refractory wall and ceiling and refuse. The combustible gases are combusted in the refractory line secondary combustion chamber. Wide variety of refuse could be accepted in such incinerators. Modular systems are addressed elsewhere in this document. For batch and intermittent operations, the refractory walls should be kept hot during downtimes. High excess air use makes the incinerator less efficient in heat recovery. Field-erected units are generally over 100 tpd capacity. Such units normally require costly pollution control equipment systems.

Materials of Construction

2. Refractory-alumina bricks or castables and fire bricks at the face of the casing.
3. Grate: Cast iron (fixed grate) or formed steel (travelling).
Advantages Over Other Types

- Less costly, i.e., $/ton of investment capital is low.
- Relatively simple operating procedure.
- Moderate operating costs.
- Many manufacturers in the market, so competitive pricing possible.
- Waste heat recovery possible by using a waste heat boiler.

SIZING CRITERIA

- Quantity of refuse to be disposed/hr or day.
- Average heating value of refuse to be disposed.
- Physical characteristics of refuse.
- Energy recovery at 3 lb/lb of refuse (as discarded).

ACCESSORY COMPONENTS

- Automatic ram feeds.
- Automatic ash/residue removal.
- Automatic auxiliary burner control.
- Automatic combustion air control.

SUPPORT REQUIREMENTS


Training: Operators - 2 weeks necessary/operator.

Skills Required: Mechanically oriented, hard labor class.

Inspections:

- Refractory lining.
- Pollution controller.
- Grate plugging with slag and debris.
- Feeder wear and fume leakage.

Access: 10 ft to 15 ft on all sides for maintenance work. 20 ft in the front for feeder pull out.

Spare Parts: All drive components, refractory bricks and cements.

Permits: Environmental impact, health and air pollution permit, zoning.
OPERATIONAL CONSIDERATIONS

General: For continuous operation, 2 days storage of refuse; for batch operation dispose as it comes. For weekend operation and no-delivery, storage space for burning refuse during nondelivery hours needed.

Installation: Close to waste producer.

Maintenance: Routine and weekend refractory patch-up work.


Scheduling: For batch operation - operate as needed. Keep refractory hearth hot.

Downtime: Only when needed to repair refractory or grate.

Other Factors: Close watch should be kept on furnace wall and shell. Discoloration of shell indicates refractory wear and hot-flash to steel casing.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Should not be located in congested neighborhood, good access for refuse trucks, ambulance, and firetrucks.

Fire Hazard: Good housekeeping, fire hose near furnace and loading zones. Sprinkler system in building.

Explosion: Aerosol and other explosive materials should be avoided.


COST ANALYSIS

Capital cost of field-erected refractory lined heat recovery incinerator depends upon the equipment system, location, wage rate, transportation costs and other factors. Vendors refuse to quote ball-park cost data.

Operating and maintenance costs: labor costs depend upon type of facility, hours of operation, and local labor rates. For safety reasons, a minimum of 2 men/shift is required for municipal and 1 man/shift for industrial installations. Auxiliary fuel cost depends upon the type of refuse and shutdown. Schedules average auxiliary fuel consumption: 1 MCF/tpd.

Life Cycle Cost Analysis:

Electric power cost = 0.5 KW/tpd

Water use = 2 gal/ton for ash quench + 3 gal/ton for other uses

Maintenance labor 2 percent of plant facilities investment (pfi) capital cost

Maintenance supplies = 2% of pfi
STATE-OF-THE-ART

R&D Needs: Refractory incinerators are old technology. Many have been working successfully for years.

Operating Systems: Most of the units are provided with waste heat boilers (field-erected units).

Manufacturers: Basic, Consumat, Air-Preheat, Kelley

Risks: Heavy refractory maintenance for batch operations. Air quality degradation if operated without appropriate air pollution controls.

History: Non-energy recovery incinerators have refractory combustion chambers. The choice between burning refuse in refractory incinerators or providing for energy recovery is not clear cut. Many industrial and commercial wastes are combusted in refractory-lined incinerators with heat recovery. Heat recovery in refractory incinerators are coming into focus because of energy crisis. It has low capital cost but high maintenance cost.

Successes: Many refractory-lined municipal incinerators have been running for years without major failures. The use of silicon carbide or high alumina bricks give long refractory life. It is widely used in hospitals, shopping centers and in many commercial facilities with remarkable success.

Failures: Most of the failures have been due to poor maintenance of the refractory.

Key Problems: Slagging and short life of the refractory. Incinerators with waste heat boilers experience tube corrosion and erosion of refractories and grate plugging problems. Air-cooled refractory has solved many of the ills of short-life refractory linings.

Furnace Wall: To reduce slagging to a minimum and extend furnace life, silicon carbide face brick with air-cooled walls are recommended. The silicon carbide refractory extends from the grate line to approximately 6 ft above grate.

Instrumentation and controls:
- Overfire air, wall cooling air and the underfire air.
- Gas temperature in the furnace, inlet to the settling chambers.
- Draft control.
- Refractory wall temperature.
- Under grate air control.

Field-erected refractory incinerators are generally 200 tpd and above capacity. For units of 50 tpd, modular shop-assembled units are available.

REFERENCES
5. Personal communications with Basic Environmental Engineering.
**COMPONENT DESCRIPTION**

**Shop-assembled or site-erected**

**Types Available - Competing Components**
- a. Solid unprocessed
- b. Solid processed
- c. Liquid burning
- d. Sludge burning
- e. Co-firing

**Types Used Commercially**
- a, b, c, d, e

**Physical Characteristics**

**General Description**

In watertube wall incinerators, the walls of the combustion chamber are lined with boiler tubes that are arranged vertically and welded together in continuous sections. The tubes are insulated on the outside to reduce radiant heat losses. Such incinerators can accept processed or unprocessed wastes. Depending on the degree of processing, mass, suspension or vortex firing can be achieved. For mass burning, reciprocating, traveling, or barrel grates are used to convey solid wastes through furnace.

**Principle of Operation**

In water wall incinerators, water circulates through the tubes that form the walls of the furnace, and absorbs heat generated in the combustion chamber. The heated water is used to produce steam. When water walls are used in place of refractory materials, they are not only useful for the recovery of steam, but also extremely effective in controlling furnace temperature without introducing excess air. This reduces flue gas quantity (30-40% over refractory furnace) and smaller pollution control equipment is therefore needed.

**Materials of Construction**

Advantages Over Other Types

- Excess air requirements are usually on the order of 40-80% as compared to 100-200% often used in refractory furnaces.
- Can be co-fired with coal or sludge.
- Smaller pollution control and air-handling equipment system.
- Lower maintenance.
- High heat release rates per unit volume of furnace.

SIZING CRITERIA

Physical and chemical characteristics of refuse and feed rate are the two important sizing criteria. The capacity utilization factor of a given water wall incinerator will depend upon type of refuse, its heating value, (moisture, ratio of combustibles to noncombustibles) and maximum charging rate. Average steam producing capacity of a pound of refuse is 3 pounds of steam. However, steam generating capacity control vary from 1.3 to 4.3 lbs steam/lb refuse.

Water wall incinerator sizes will depend upon refuse type, firing device and throughput rate. Size of 250 tpd to 400 tpd is typical. Water wall incinerators of <1 to 3 tph capacity are not too prevalent. The heat release rate per unit furnace volume ranges from 25,000 to 40,000 Btu/ft³.

ACCESSORY COMPONENTS

- Truck scales.
- Storage pit.
- Feeding crane.
- Front-end processing equipment (if suspension or vortex firing).
- Stoker: traveling, reciprocating, or reverse stroking type, and rocking grate.
- Pollution control equipment.
- Waste heat boiler and accessories.
- Ash-handling and residue-handling systems.

SUPPORT REQUIREMENTS

Personnel: 12.5 tpd - 1.0 man-hr/ton
25.0 tpd - 0.5 man-hr/ton
50.0 tpd - 0.25 man-hr/ton

Training: 3 months on job training, 1 year or more plant running responsibilities.

Skills Required: Boiler operator, electrical and piping technicians, instrumentation and control person.

Inspections: Annual - boiler watertube surface. Half-yearly firing and feeding system and controls.

Access: 15 ft 0 in on all sides tube removal space.
OPERATIONAL CONSIDERATIONS

General: Refuse feed rate proportional to steam production desired.
Installation: Close to steam user.
Maintenance: Routine daily maintenance.
Controls: Boiler - automatic with manual override.
Scheduling: Refuse storage at least 2 days operation load.
Downtime: Minimum, unless absolutely necessary.
Other Factors: Pollution control equipment and feedwater system should be maintained regularly.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Installation in open area away from congested neighborhood. Good access road for refuse trucks, ambulance, and fire trucks.
Fire Hazard: Refuse storage area ventilated with exhaust fan and provided with sprinkler system and provision for fire hose.
Explosion: If processing required, dust explosion possible and provision for preventing such explosion should be made. Explosive materials, like gas tanks, or pressured containers, should be pre-sorted.
Other Safety: First aid station, safety shower, and general good housekeeping is required.
General Environmental: Air, water, and land environment, and aesthetic appearance of processing station should be maintained.

COST ANALYSIS

The variables that affect the operating cost are: the capacity of the unit, the percentage of capacity at which the system is operated, and the percentage of operating time per year. Typical operating cost of a 50 tpd unit is labor = $6.03/ton, utilities = $2.13/ton and maintenance = $1.07/ton. Administration costs are extra. (See graphs on page C-15).

Life Cycle Analysis consists of analyzed capital cost and operating cost. Annualized capital cost is calculated as: plant investment cost x CRF/365 x tpd x utilization factor.
CRF for 20-yr life at 10% = 0.11746, utilization factor may be assumed = 0.7. Total operating cost (capital + operating) $12.50 to $16.50/ton.

STATE-OF-THE-ART

R&D Needs: Water wall incineration process is a fully developed commercial technology. R&D work should be in the field of boiler tube corrosion, ash-handling, and slagging problems.

Operating Systems: Most operating systems produce saturated steam 150-1,500 psig.

Manufacturers: B&W, and other custom incinerator mfgrs.

Risks: Boiler tube failure, air pollution with particulates and acid fumes.

History: While common in Europe, the conversion of solid waste to energy in the United States was, until recently, only an interesting idea. Recent energy crises have drawn more than 20 cities to start projects for steam and power generation from MSW. U.S. EPA has spent a great deal of effort and money in promoting this concept of energy recovery.

Successes: Several successful large-scale water wall type incinerators are now in operation (i.e., Sangus, Chicago Northwest, Harrisburg, PA; Nashville TN; Hamilton, Ontario; Montreal, Canada; Quebec, Canada; and many smaller installations are operating now in the United States, Canada, and Europe).

Failures: Slagging, acid corrosion, and fly ash erosion of the water wall tubes are the main causes of failure. Air pollution associated with particulates and acid fumes and pollution associated with MSW feeding have caused many shutdowns.

Key Problems: Arises from mixing of household refuse with commercial (i.e., industrial and building demolition wastes). Incineration of processed wastes have problems associated with feeding, ash-handling, and pollution control.

REFERENCES

Heat Recovery Boiler

Types Available
- a. Solid waste burning
- b. Waste heat boiler
- c. Hot water
- d. Steam
- e. Firetube
- f. Watertube

Types Used Commercially
- Modular - firetube & watertube
- Site erect - watertube

Physical Characteristics

General Description

Heat recovery boiler can be of firetube or watertube variety. Small modular units are generally of firetube variety. The boiler may be designed to receive hot products of combustion from a refuse burning incinerator or refuse can directly be fired in the boiler combustion chamber as a fuel. For watertube boiler, a portion (35 to 50\%) of the heat produced in the combustion chamber of an incinerator, can be harnessed by a water wall either surrounding the combustion chamber or inbedded in the refractory wall. For waste heat boiler, the incinerator serves as the combustion chamber. For integral type boiler, the boiler heat transfer sections (convection and radiation) forms an envelope surrounding the boilers combustion chamber.

Principle of Operation

In firetube boiler, flue tubes are immersed into a water bath. The combustion flame travels through the flue tubes, and transfers heat to the water surrounding the tubes. Firetube boilers are slow to produce steam but contains a large reservoir of heat.

For watertube boiler, water circulates through the tubes, receives heat by convection and radiation from the flames and hot products of combustion. The heat transfer is from hot combustion product to the watertube by convection and radiation and from watertube to water by conduction and convection. The watertube boiler has the capacity to produce steam within short time of firing. The water circulating through the tubes needs to be conditioned and treated to avoid scale formation and consequent failure of tubes. Normally, most of the field-erected units (large) are of watertube variety.
### Materials of Construction

Boilers are normally manufactured by ASME Boiler and Pressure Vessel Code, Section 1, Power Boilers, June 30, 1970, and subsequent addenda. Steam drums are normally LSA-285, A, B, or C grade carbon steel. Fiberbox quality plate is used for any part of a boiler subjected to pressure and exposed to the fire or hot products of combustion. For such use SA-515 grade 70 is used. In writing boiler specification, "ASME approved stamp is required," should be incorporated. This stamp can only be put on the boiler when the boiler has been constructed in accordance with the appropriate ASME boiler code.

### Advantages Over Other Types

- **Firetube boiler**: Generally, shop assembled, modular unit, and cheaper than watertube boiler. Has low thermal efficiency.
- **Watertube boiler**: Higher thermal efficiency and more costly than firetube boiler. They are more complicated and required higher maintenance than firetube boilers. They have a quick response to steam-load and can be built to large steam producing capacities.

### Sizing Criteria

- Btu/hr input to the boiler. Typically efficiency is 65 - 72%.
- Waste flow rate to the boiler.

### Size of Boilers (typical) (See graph on Page 5.)

- Fire boiler - 5,000 to 25,000 lb/hr
- Watertube boiler - 25,000 lb/hr steam to above capacity

### Accessory Components

**For waste heat boiler - water tube variety:**

- Water treatment facility.
- Condensate return system.
- Pollution control device.
- Boiler automatic control system.
- Soot-blowing system.

**For directly-fired incinerator - boiler system:**

- Feed mechanism (refuse).
- Ash handling system.
- Water treatment.
- Condensate return.
- Pollution control.
- Soot-blowing system.
- Combustion and boiler control system.
SUPPORT REQUIREMENTS

Personnel: 1 man/shift for industrial operation and 2 men/shift for municipal.

Training: Stationary engineer for waste heat boiler and licensed boiler operator for combustion boiler.

Skills Required: Mechanically oriented, pipefitting and electrical.

Inspection: General boiler tubes - refractory and feeding system, air pollution control device and water treatment system, pumps and accessories.

Access: 8-10 ft all around.

Spare Parts: Gauges and general maintenance items.

Permits: As boiler is an accessory to solid waste incineration, all permits necessary for operation of incinerator plus boiler insurance and inspection certificate are required.

OPERATIONAL CONSIDERATIONS

General: A heat recovery boiler should be treated as a supplementary accessory to the solid waste incinerator. This indicates that the disposal rate of solid waste does not depend upon the steam demand. If there is no steam demand, the hot flue from the incinerator bypasses the boiler and is exhausted to atmosphere. It is desirable, however, that in the decision of having a heat recovery boiler with the solid waste incinerator, the demand for steam or hot water should be investigated.

Installation: Depends upon the location of the solid waste incinerator. It is either closely coupled to the incinerator or designed as an incinerator-boiler. For installation as incinerator-boiler, all the considerations of locating a solid waste processing station have to be given.

Maintenance: Routine scheduled boiler maintenance. Half-yearly maintenance is normally required for boiler.

Controls: For waste heat boiler: general boiler operation controls. For incinerator boiler: general boiler controls plus combustion control equipment.

Scheduling: None for boiler itself. It depends upon incineration operation. Such a boiler is an integral part of the incinerator. For incinerator-boiler unit, the storage of solid wastes adequate for continuous operation is desirable.

Downtime: Boiler life (refractory and other accessories) is enhanced with minimum downtime.

Other Factors: As the flue gas originating from the incineration of solid waste contains high concentrations of particulates and acid fumes (from burning of plastics), it is important that scheduled soot-blowing is practiced and the boiler tubes are observed carefully for acid corrosion and fly ash erosions.
## Combustion Equipment

### Heat Recovery Boiler

#### SAFETY AND ENVIRONMENTAL CONSIDERATIONS

**Installation:** Where the incineration project is located.

**Fire Hazard:** None from the boiler, other than boiler explosion, which seldom occurs.

**Explosion:** None expected.

**Other Safety:** Normal automatic controls for boiler operations.

**General Environmental:** Pollution control equipment dry or wet type is mandatory for the operation.

### COST ANALYSIS

#### Operating Cost

**Water Use:** Depends upon boiler system design. For 100% condensate return system, the makeup water use is estimated as 3%; for no condensate returning system, 100% makeup water will be required.

**Labor:** 1-2 man/shift at $20,800/yr including benefits.

Boiler operates normally 24 hr/day but for incinerator-boiler when incineration is stopped. Boiler is down. It keeps normally hot by closing dampers and sometimes by firing with fuel oil or gas.

**Maintenance Supplies:** 2% of plant facilities investment capital. Maintenance labor = 2% of plant facilities investment.

#### Life Cycle Cost

Man-hour/ton remains fairly constant for a given size boiler up to 50 tpd capacity. As the input to the boiler is associated with refuse incineration rate, manpower rate is function of incineration load.

Heat recovery boiler is an integral part of the heat recovery incinerator. The capital cost of boiler alone cannot be estimated. The boiler operating cost depends upon the type of boiler and the accessories. For example, a boiler designed with 100% condensate return will have negligible makeup water cost. Otherwise the cost of water use will equal the water equivalent to steam flow rate plus water treatment cost. A waste heat boiler has smaller maintenance and labor cost. Incinerator boilers will require more manpower and maintenance.

Waste heat boiler is part of a heat recovery incinerator system and normally vendors quote boiler cost along with incinerator. Normally an incinerator-boiler system costs $12,000 to $18,000/ton/day capacity of incinerator. The plant facilities investment for 50 tpd incinerator-boiler unit will range from $600,000 to $900,000.

**Capital Cost** = (plant investment cost + land + organization and startup + interest during construction + working capital)

Life expectancy of refuse heat recovery boiler = 25 years.
STATE-OF-THE-ART

R&D Needs: Waste heat recovery boiler technology is proven on a variety of plant wastes, which may or may not result in the formation of condensible acids. A low pressure (150 to 300 psig) waste heat boiler utilizing products of combustion of solid waste is subject to acid corrosion of boiler tubes.

Normally, if the gas temperature is higher than 300°F and lower than 800°F, acid corrosion is minimal. However, operating with high exhaust temperatures results in reduced thermal efficiency combustion products from general solid waste will contain a variety of these compounds, and this presents a definite corrosion problem and also possible air pollution concerns. Correction of these problems will impact both the economics and reliability of the waste heat recovery boiler system. R&D in acid corrosion of tubes is needed.

Operating Systems: Very large mass burning incinerators are now equipped with steam generators, examples, Sangus, Chicago, Harrisburg, Nashville, Hamilton, Montreal, Quebec, and many others. Many modular units also are operated at the Nelson Co., Chicago; Casting Engrs, Illinois; Dominion Foods, Illinois; North Little Rock, Arkansas; Masonite Corp, Penn. and many, many others all over the country.

Risks: Use of waste heat recovery boiler itself has little risk. If the incinerator system works, boiler works. Pollution is not related to waste heat boiler but to incinerator.

Other Information: Boilers have good record of operation, and technology is quite developed for highly efficient operation.

REFERENCES

4. Company literature of:
   a. Basic Environmental Eng. Inc.
   b. O'Conner Envirotech Corp.
   c. Kelley Co.
   d. Consumat
   e. C. E. Bartlett Snow
## COMPONENT DESCRIPTION

### Pyrolysis Chamber Type

**Auger Bed**

### Physical Characteristics (50 ton/day unit)

A long (110 ft) double-walled cylinder with an inside diameter of about 32 in. enclosing a rotating auger attached to a large tubular core. Details of the internals of the auger-reactor are proprietary. The auger is driven by large slow-speed chain drive systems at both ends of the unit.

### Principle of Operation

As waste material is slowly augered through the length of the reactor, it is heated by passing hot gases from a furnace between the outer walls of the reactor and through the central core of the auger. The waste is therefore heated by all the surfaces it contacts, as well as mixed and turned by the auger. The gas, oil, and water vapor generated by the reaction are removed for separation through a discharge manifold. The char remaining are transmitted to a conveyor for collection and disposal as waste of solid fuel.

### Materials of Construction

Materials of construction are proprietary.

## SIZING CRITERIA

For facilities of up to 200 tons/day capacity, the use of multiple 50 tons/day reactors is proposed. Larger facilities would use 200 tons/day reactors.

## SUPPORT REQUIREMENTS

No data available

## OPERATIONAL CONSIDERATIONS

No data available

## SAFETY AND ENVIRONMENTAL CONSIDERATIONS

No data available

## COST ANALYSIS

No long-term data are available to make an estimate of design life and life cycle costs.
Interest in this pyrolysis system has not been sufficient to generate required funds for further development and demonstration. The more rapid development of less technologically complex and innovative methods for the recovery of energy, such as direct combustion, make such further development very doubtful.

History

Development of the auger-type pyrolysis reactor was carried out with private funds in the mid 1970's. Operation of a 50 ton/day facility was demonstrated in 1978 at South Gate, California.

Successes/Failures

The test facilities demonstrated the short-term technical feasibility of the process. Long-term viability and economics have not been demonstrated.
**Component Description**

**Pyrolysis**
- **Type:** Vertical Shaft
- **Competing Components:**
  - a. Rotary kiln.
  - b. Dual fluidized bed.
  - c. Auger
- **Types Used Commercially:** None

**Physical Characteristics**

- Waste material is fed in through an airtight seal at the top of the shaft. The material is progressively heated as it works its way down the shaft, first driving off the moisture, then volatilizing the organics, and finally reaching the lower zone where the input of oxygen or air permits combustion to take place.

**Principle of Operation**

**Sizing Criteria**

No data available

**Accessory Components**

No data available

**Support Requirements**

No data available

**Operational Consideration**

Gas with a sufficient energy content to be considered for external use can only be produced if pure oxygen is used rather than air.
SAFETY AND ENVIRONMENTAL CONSIDERATIONS

No data available

COST ANALYSIS

Pyrolysis is a capital and technology intensive process. Its feasibility in small-to-medium scale energy recovery operations is doubtful at its present state of development.

STATE-OF-THE-ART

No facilities for waste to energy conversion, other than proof-of-concept, pilot plants, and research and development work have been constructed and operated successfully. The economics of the system, and competition from other, less complex systems places further development in doubt: Davey Powergas Systems, Union Carbide.

Gasification systems of this type can trace their development back to the technology developed 80 to 100 years ago for production of gas from coal and wood. PUROX (Union Carbide) has been under development for several years, with a redesigned and upgraded facility now in the final design phase.
Pyrolysis Chamber

Type
Rotary Kiln


Types Used Commercially: None

Physical Characteristics (Monsanto Landguard®)

General Description
The kiln shown is 19 ft in diameter, 100 ft long, and rotates at 2 revolutions per minute. The refractory lining keeps the heat of the reaction within the kiln and prevents erosion of the kiln shell. Additional heating requirements are provided by fuel oil burners in the lower end of the shaft.

Principle of Operation
Waste is fed into the inclined rotating kiln through ram feeders. The kiln flights and spikes churn the waste as it passes down the kiln, being partially combusted as it moves from the inlet end to the burners. The pyrolysis gas is removed at the upper end and is combusted in later processes.

Materials of Construction
Refractory Lining: Various castable refractory materials were used with limited success while operating as a pyrolysis unit.

OPERATIONAL CONSIDERATIONS
Numerous operational deficiencies were encountered with the rotary kiln pyrolysis reactor as originally designed. Resolutions of those problems involved conversion of the kiln from a pyrolysis reactor to starved-air incinerator.

COST ANALYSIS
No long-term data are available to make an estimate of design life or life cycle costs.
STATE-OF-THE-ART

Due to the development of competing energy technologies, and the demonstrated difficulty in proving the economic and technological viability of pyrolysis of wastes, continued interest is very limited.

History: Development began with a small scale (0.3 to 0.6 ton/day) prototype in 1968 and a 35 ton/day prototype in 1969. Further development of another 35 ton/day facility in 1974 led to the design of a 1,000 ton/day facility later that same year.

Successes/Failures: The 1,000 ton/day facility did not operate as originally designed. After multiple efforts to modify and retrofit to improve performance, the use of pyrolysis was abandoned in favor of starved-air incineration.

Key Problems: Failure of the refractory lining; lack of sufficient control of input material; insufficient temperature control leading to slagging or incomplete reactions.
COMBUSTION EQUIPMENT

Fluidized Bed

CE-H

P. 1 of 5

COMPONENT DESCRIPTION

Fluidized Bed Combustor (AFBC)

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<td>Atmospheric</td>
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Types Available - Competing Components

a. Solid burning (atmospheric)
b. Solid burning (pressurized)

Types Used Commercially

None

Physical Characteristics

![Fluidized Bed Combustor Diagram]

General Description

Fluidized bed combustor consists of a lower section called windbox for distributing fluidizing air, a midsection containing inert solid particles of high fusion temperature where feed is inserted and reaction occurs, and the upper section called freeboard where combustion products pass out of the bed. The ancillary equipment includes storage and retrieval bin for pulverized solid waste, the feed mechanism, the fluidizing blower, the cyclone, the ash removal system and waste boiler and accessories.

Principle of Operation

The fluid bed is a dense uniform suspension of inert solids maintained in a turbulent motion by an upward moving airstream. The turbulent mixture of air and solids behaves as if it were a fluid and possesses characteristics of a boiling liquid. The temperature of the inert bed is raised to the ignition temperature of the material. The waste material is added to the bed and the optimum contact between inert solids and refuse occurs by the large surface area of the inert solids causing rapid heat transfer and subsequent combustion.

Materials of Construction

1. Low carbon hot-rolled steel casing ASTM-36 or equivalent.
2. Refractory insulating firebricks and L. I. firebrick facing or castables.
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<th>Combustion Equipment</th>
<th>Fluidized Bed</th>
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**Advantages Over Other Types**

High heat reservoir (16,000 Btu/ft\(^3\) at 1,400°F), extremely high combustion efficiency (90%), low excess air, reduced size for flue gas handling and cleaning equipment, negligible unburned hydrocarbons negligible NO\(_x\), and low operating temperature. Such units have high volumetric heat generation rates leading to compact combustor size and lower unit capital costs. The combustor is flexible to accept solid, liquid, gas, slurry, and sludge feed without affecting operation.

**Sizing Criteria**

- Waste flow rate.
- Volumetric heat generation rate - (100,000-200,000 Btu/hr-ft\(^3\)).
- Percent combustion efficiency (80-90%).
- Percent heat exchange efficiency (50-80%).

Steam Production = 3.22 lb/lb of refuse at 4,500 Btu/lb.

**Accessory Components**

- Screw or Ram feeder.
- Fluidizing blower.
- Auxiliary fuel oil or gas burner for high moisture feed (sludge type).
- Ash removal system (quench tank, etc.).
- Venturi scrubber or cyclone.
- Front-end loader.
- Dump trucks.

**Support Requirements**

Personnel: 10 tpd = 1 man-hr/ton, 40 tpd = 0.25 man-hr/ton.

Training: Trainee - 1 mo, Apprentice - 3 mo.

Skills Required: Stationary engineer, electrical and pipe fitting and mechanics.

Inspections: Emissions, health and safety - semi-annual.

Access: 15 ft on all sides for front-end load and dump truck.

Spare Parts: All major components related to feed preparation, drives, and conveyors.

Permits: Environmental impact, emissions, noise, zoning, and building.

**Operational Considerations**

General: If the function of the AFBC is to dispose of solid waste, the unit can be operated to meet the solid waste disposal rate need. However, if the AFBC is to generate steam or electricity, the waste disposal rate has to be maximized to meet steam or electricity commitment.

Installation: Close to energy use if waste energy is being utilized, otherwise close to solid waste generation source.
**Maintenance:** Inert bed level has to be maintained and monitored. The air flow rate through the perforated bed plate needs to be watched and regular ash dumping should be scheduled.

**Controls:** Semi-automated with manual override.

**Scheduling:** Prepared refuse storage 2 days capacity to smooth out operation.

**Downtime:** Minimum short-term downtime.

### SAFETY AND ENVIRONMENTAL CONSIDERATIONS

**General:** Plant site access to refuse trucks, fire and ambulance.

**Locations:** Outlying part of the Navy base, away from congested personnel housing.

**Fire Hazard:** None from AFBC proper. However fire hazard exists in indoor refuse receiving, processing, and storage. Processing plant building should be provided with sprinkler system, fire hydrant, and smoke alarm system.

**Explosion:** None.

**Other Safety:** Auxiliary fuel lines (liquid and gaseous) provided with automatic shutoff valves.

**General Environmental:** General appearance and aesthetics acceptable to visitors. Malodorous situation can be avoided by using deodorizers and by providing for waste receipt to match processing load.

### COST ANALYSIS

**Life Cycle Analysis:**

### STATE-OF-THE-ART

**R&D Needs:**
- Means to prevent plugging of air distribution board.
- Ash removal without losing inert bed material.
- Slagging problem.
- Uniform distribution of fluidizing air.


**Manufacturer:** ERCO, Combustion Power, Johnston, York-Shipley, Fluidyne.

**Risks:** The disposal of solid waste in fluidized bed combustor has not been developed to commercial status.

**Other Information:** Fluidized bed combustor has wide applications. Federal (DOE) funding is forthcoming to Combustion Power and Argonne National Lab to conduct demonstration of AFBC for solid waste disposal process.
**History:** The solution to the need for multi-fuel burners capable of achieving high efficiency in combustion is found in the technology of fluidized bed combustion. This combustor is capable of burning all kinds of fuels either individually or simultaneously. It does so with improved efficiency and emission performance that can meet EPA standards.

**Failures:** Most failure occurs when glass contents of the solid wastes melt and plug the holes of the air distribution plate. Slagging is another problem.

**Key Problems:**
- Plugging of air distribution plates.
- Excessive slagging that causes clinker to form.
- Refractory wear.
- High inert material loss.
- Nonuniform fluidizing air distribution.

**Comments: Additional Data**

The future of solid waste disposal through AFBC is uncertain. ERCO, Combustion Power, Johnston, and many other companies have invested large sums of money but have not been successful. The key problem is slagging, melting of glass and nonmetals, and critical fluidizing parameters that are difficult to attain with solid waste as feed.

**REFERENCES**

2. S. Freeman, et al., Commercialization Task Force on Industrial AFBC, NTIS-TID-28854.
## Component Description

**Component**
Pyrolysis Chamber

**Type**
Dual Fluidized Bed

**Competing Components:**
- Vertical shaft.
- Auger.
- Rotary kiln

**Types Used Commercially:**
None

### Physical Characteristics

**General Description**

Two vertical shafts connected so as to allow the movement of the contained materials from the top of each reactor to the bottom of the other. Force for the fluidization of the sand/refuse mixture is provided by the injection of steam at the bottom of each reactor.

**Principle of Operation**

By dividing the pyrolysis unit into two chambers, the heating requirements of the pyrolysis reactions can be met without contaminating the pyrolysis gas with carbon dioxide from the combustion process or nitrogen from the intake air. In one chamber, sand or other carrier is heated by the combustion of refuse with air and the injection of steam. The hot sand is then transported to the other reactor, where pyrolysis of refuse takes place in the absence of air.

**Advantages Over Other Types**

Use of the solid waste to provide most of the energy required by the process without contaminating the product gas with combustion products.

### State-of-the-Art

The use of dual fluidized beds represents one of the few pyrolysis technologies still under active development. Results from the facility presently in construction should be analyzed before further development is considered.
History:

Development of the system shown has occurred in Japan. After small-scale tests in 1972-1974, a 40 ton/day demonstration plant was constructed. The first commercial plant is under construction near Tokyo, with a capacity of 450 ton/day.

Success:

No data on the performance of the full-scale facility are available. The demonstration plant has been used to test the disposal of municipal refuse, pulp and paper sludge, and plastic waste.
Component Description

Digestion Tank

Physical Characteristics

General Description

Sidewalls and bottom are commonly field-constructed of reinforced concrete. Top is either a floating or fixed steel cover with entryways (for maintenance) and the mixing and gas draw-off systems.

Principle of Operation

Waste enters the digester in a slurry (approximately 12% solids) and is retained in the digester for a residence time of 5-15 days. Heat is provided by recirculating heated slurry or by heating coils. Gas from the decomposition of the wastes is drawn off the top of the tank, while waste slurry is drawn off from the bottom or center. Mixing can either be mechanical or by recirculation of the product gas.

Materials of Construction

Larger systems are primarily reinforced concrete with smaller tanks constituted of mild steel with a corrosion protection coating.

Sizing Criteria

The digester is sized to provide the required retention time at the specified slurry solids concentration. Solids concentration is limited by the inability to pump or to provide mixing and heat transfer in thick slurries. Typical conditions would require 250-300 cu ft of digester per input ton of slurry solids.

Support Requirements

Personnel: System could be automated to provide unattended operation overnight, but daily feeding and performance check is required.

Skills Required: Laboratory analysis of wastewaters and sludges, mechanical repair.
OPERATIONAL CONSIDERATIONS

Digesters are sensitive to the skill of the operator. The rapid determination of the causes of digester upsets, and the ability to eliminate them, are essential to providing a working system.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Effluent sludges, especially from high temperature systems, are relatively pathogen-free and can be disposed of in sanitary landfills.

Explosion: Improper operation can result in an unsafe build-up of gas pressure within the system, or an accumulation of methane gas in buildings.

COST ANALYSIS

Estimated cost of the digester in a 20-ton/day system is $100,000 to $200,000.

STATE-OF-THE-ART

R&D Needs: Digester design is relatively well developed. Problem areas are in pumping, heating, and disposal of the slurry for solid waste digestion.

Operating Systems: Many systems are operating at sewage treatment facilities. A solid waste digester is being operated by Waste Management, Inc. at Pompano Beach, Florida.

Manufacturers: Envirotech, Ralph B. Carter, Rex-Chainbelt, and many others.

Risks: A long-term track record of operation using a solid waste feed has not yet been established.

History: Anaerobic digesters have been used for decades at sewage treatment facilities. Their use for large-scale waste conversion to energy has been researched at least since the 1960's. Based on the bench and pilot-scale studies carried out primarily at academic institutions, Waste Management, Inc. has constructed a 100 ton/day facility for testing and evaluation.

Failures: System failures due to improper operation, non-biodegradable feed material, and mechanical breakdown were common in the R&D work.

Key Problems: Feed material is an abrasive fluid with extremely poor pumping characteristics. Systems which are designed to function well under one set of operating conditions can easily fail if these conditions are altered.
### Component Description

**Gas Burner**

- **Type:** Fuel gas produced from gasified refuse

**Types Available**

- a. Pipeline - quality gas burner
- b. Low Btu gas burner (LBG)
- c. Medium Btu gas burner (MBG)

**Types Used Commercially**

- a, b

### Physical Characteristics

![Diagram of Gas Burner]

**General Description**

Industrial gas burners may be classified as premixing, nozzle mixing and long-flame burners, according to the position and manner in which the gas and primary combustion air are brought together. Gas burners are either of atmospheric or high-pressure type. "Closed" type burners usually supply all of the air for combustion through the burner, whereas the "open" type may induce air flow into the combustion space through the opening around the burner. Many burners are equipped as either an open or a closed burner. An industrial burner normally is fitted with a burner tile (refractory block) with a conical or cylindrical hole (flame tunnel) through its center. The tile serves to maintain ignition and to reduce flash-back and blow-off. Some LBG burners are equipped with a pilot flame.

### Principle of Operation

The functions of a burner, are to deliver fuel and air to the combustion space, to turbulently mix the fuel and air, and to provide for continuous ignition of the fuel-air mixture. Some of the important factors to be considered in gas burner operation are fuel/air mixture, flue gas volume, flame temperature, flame shape, stability, turndown ratio and ignitability. The ultimate objective of every gas burner is to transform the thermal energy of the gas into useful heat which is absorbed by the object being heated.

Refuse-derived fuel gas may be of Low Btu Gas (LBG) (as from Torrax Process), or Medium Btu Gas (MBG) (as from Purox Process). LBG contains 1/7 to 1/6 of the energy on a volumetric basis that of a pipeline quality gas. The stoichiometric air/fuel mixture, which establishes the burner size and other requirements, increases only by 30 to 40% and the flue-gas volume is only 19 to 21% more for LBG than natural gas. For MBG, the combustion-air requirements are only about 5% greater than those for pipeline quality gas. The amount of flue-gas produced by the combustion of MBG is about the same as it is for pipeline quality gas.
In Scroll-type burners, the LBG is introduced through a large Scroll to inject the gas stream into the combustion zone into annulus between two zones of combustion air. By introducing the LBG between two counter-rotating air streams, the burner promotes rapid mixing of the gas and air. The result is the successful combustion of a variety of low pressure LRG within existing boilers, new cold furnaces, high heat release boilers or other process furnaces. Heat release rate per unit volume of LBG is quite different from natural gas so the burner for LBG is to be designed for ignition stability and load range factor.

### Materials of Construction


### Advantages Over Other Types

- Scroll-type burner allows large volume of LBG with a very low pressure drop, and eliminates the need for gas boosters or gas compressors.
- Such burners can accept supplementary fuel oil or natural gas in any quantity up to and including full burner capacity.
- Such burners can accept LBG of varying heating value and maintain flame stability.
- The large openings in the gas Scroll allow passage of tar particulates that are usually found in LBG streams.

### Sizing Criteria

To arrive at a burner size, the following information is needed:

- Chemical composition of the gas (proximate and ultimate analysis).
- Heating value.
- Temperature.
- Volume Rate.
- Tar and particulate concentration, if any.
- Gas pressure.
- Required volumetric heat release rate.
- Single fuel or dual fuel; if dual fuel, what is the alternate or supplementary fuel.

### Size

- $10 \times 10^6$ Btu/hr or larger. (See graph on Page 4.)

### Accessory - Components

- Gas regulator.
- Pilots.
- Purge interlock.
- Flame detector (UV or IR).
- Automatic shut-off valve of fuel on failure of air supply.
- Closed-position switch for burner shut-off valves.
- Shut-off of fuel in the event of low fuel pressure and excessive fuel-gas pressure.
### SUPPORT REQUIREMENTS

**Personnel:** (Operating): None. Burners are an integral part of a combustor. Burning of a gaseous fuel is maintained automatically by the burner control device. Safety equipment and accessories protect the combustor and the installation from fire hazard.

**Maintenance Personnel:** Burners using closed-coupled gasifier producing low or medium Btu gas are subjected to dirt, tar, and other fouling elements and need routine and constant maintenance. Manufacturer's guidelines for maintenance in cleaning, adjustment, and replacement of worn out parts is normally followed.

**Skills Required:** Mechanical aptitude, electrical wiring, and other piping work.

**Inspections:** Occasional or monthly flue gas analysis by Orsat or other instrument to estimate the combustion efficiency (% CO in flue gas).

**Access:**
- Frontal room adequate to remove the burner gun barrel.
- Adequate room for workers to rebuild or to replace the refractory burner block.
- Access for overhead crane or jury-rigging to hold and hang the burner assembly.

**Spare Parts:** As advised by the burner manufacturer. Burner accessories like fuel gas regulator and flame detector, etc., should be stocked.

**Permits:** Nothing separate but Factory Mutual or equivalent agency's approval will be required to obtain the necessary insurance coverage.

### OPERATIONAL CONSIDERATIONS

**General:** LRG cannot be transported to long distance point, so the gasifier should be in close proximity to the burner. The burner should be piped for burning at least one additional fuel type (gas or oil). In case of gasifier breakdown, the burner could be switched to the alternate fuel to maintain the thermal input to the combustor or boiler.

**Installation:** A closed-coupled gasifier enables the burner and the combustor to reap the benefit of the sensible heat recovery from the gas. A heated gas/air mixture produces higher flame temperature, increases flame stability, decreases flame blowout, and increases overall thermal and combustion efficiencies.

**Controls:** Gas/air flow ratios, flame stability and flame failure.

**Downtime:** Scheduled maintenance will minimize downtimes.
### SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: For a burner properly designed to burn a specific refuse-derived fuel gas would normally be able to achieve complete combustion of the fuel. Natural gas burning generates considerable \( \text{NO}_x \). Therefore the burning of LRG is expected to produce some \( \text{NO}_x \). Some of the prevailing steps such as staged combustion, reduced air and other devices may be required to reduce \( \text{NO}_x \) emission (depending upon the existing local, state, and federal regulations for the specific process).

Fire Hazard: Burner safety controls should be kept in excellent working condition. Normal fire safety steps of water house, sprinkler system, etc., are recommended.

Explosion: Pipeline carrying LRG should be designed and built to prevent gas leakage and consequent explosion.

Other Safety: Safety shut-off valves in fuel line, for low and high fuel pressure, for fan failure and flame blowout.

### COST ANALYSIS

A gas burner is merely an accessory to a combustor or a boiler. The maintenance cost and capital involve replacement of parts only and is very nominal in reference to the overall maintenance and life cycle costs for a waste-to-energy recovery system. (See graph on Page 4.)

Capital Cost (per quotation - COEN burner)

Note: Burner safeguard, combustion control, fan and accessories cost 80% of the burner assembly cost and the equipment is same for all size burners. So there is very little cost change for a burner with size.

### STATE-OF-THE-ART

R&D Needs:
- LBG generally has high concentrations of particulate matter. Hot gas clean-up system should be developed if the sensible heat of the gas is to be recovered.
- LBG contains high moisture and tar. For a gas system where the gas has to be transported to a short distance (i.e., the system that is not closed-complete with a boiler/combustor), the gas should be scrubbed to take out particulate matter, tar, and moisture. A R&D program involving such gas cleaning system is essential.
- Appropriate \( \text{NO}_x \) emission control device should be developed.

Operating Systems: Refuse-derived LBG or MBG systems are not operating in the United States at this time. The Torrax Process has been installed in several locations in Europe and they are operating with limited success. The Purox System has been demonstrated by the production of MBG in the private sector. Enterprise and Pan-American Systems have the potential to produce LBG/MBG.
Manufacturers:
- COEN Co., Burlingame, California.
- North American Burner - Cleveland, Ohio.
- Maxon Burner Co. - Muncie, Indiana.
- Other boiler manufacturers.

Risks: Coal-derived LBG and MBG have been successfully test-fired. Burner manufacturers have LBG burners in catalogues. The technology has been developed and demonstrated, and is now commercially available.

REFERENCES
5. COEN Company's catalog.
## COMPONENT DESCRIPTION

**Oil Burner**

*Type*
- Light Oil

**Types Available**
- a. Air atomized
- b. Steam atomized
- c. Mechanically atomized

**Types Used Commercially**
- a, b, c

**Physical Characteristics**

- Air, Possibly With Several Registers
- Nozzle and Gun
- Oil With Air or Steam
- Ignition Device

---

### General Description

A burner is a device for feeding fuel and air to the boiler such that combustion can be maintained. The burner is designed to give the proper mixing between oil and air to sustain combustion over whatever the burner's operating range may be.

### Principle of Operation

First the oil must be atomized or converted to a fog. The oil is atomized by blowing through a nozzle with dry steam or air or pressure or mechanical device. The air and oil can be mixed with the oil and flame in one step or through several stages by use of multi-register burners or overfire air ports.

### Materials of Construction

Normal tool steel can be used. If the oil is mixed with abrasive solids, the nozzle will require modification. Special tungsten-carbide inserts have been used. Ceramic inserts are also in the developmental stage.

### Advantages Over Other Types

Steam-atomized burners have a wider operating range but have steam losses. Mechanically-atomized burners require less energy but may require more maintenance. Some smaller units may also use air atomization. When the oil contains solid particles, air or steam atomization is preferred over mechanical.

### SIZING CRITERIA

The size depends on the size of the boiler and turndown required. Firetube units tend to have one burner only. Larger watertube units may be multiburner.
## ACCESSORY COMPONENTS
- Fuel pumps.
- Forced draft fans.
- Burner and combustion controls.

## SUPPORT REQUIREMENTS
- **Personnel:** Boiler operator
- **Training:** Boiler operator
- **Skills Required:** Boiler operation
- **Inspections:** Boiler certification
- **Access:** Burner assembly can be pulled out
- **Spare Parts:** Guns and nozzle
- **Permits:** Air pollution control district

## OPERATIONAL CONSIDERATIONS
- **General:** Most problems involve nozzle deterioration so oil should pass through a strainer.
- **Installation:** The burner sizes (firing rate and physical dimension) vary dependent on boiler size, and shape.
- **Maintenance:** Nozzle and fuel pumps give most problems.
- **Controls:** Air, fuel feeds are controlled to give required steam or hot water.
- **Scheduling:** Can be changed while boiler is still hot.
- **Downtime:** Very small.
- **Other Factors:** Guns are usually retracted when not in use.

## SAFETY AND ENVIRONMENTAL CONSIDERATIONS
- **General:** Major safety control device is flame detector.
- **Fire Hazard:** Leaks in fuel lines could start fires as well as cause loss of oil pressure.
- **Explosion:** If flame goes out, explosion could result if fuel flow is not stopped.
- **Other Safety:** Also bad combustion can produce CO which is toxic and an explosion hazard.
- **General Environment:** Burning conditions influence NOx, CO, hydrocarbon and particulate emissions.
COST ANALYSIS

$8,200 for 10 \times 10^6$ BTU/hr unit - includes pump, controls, fan - equipment cost only.
$33,000 for 75 \times 10^6$ BTU/hr unit - includes pump and controls - equipment cost only.

Cost are Manufacturer's Estimates

STATE-OF-THE-ART

R&D Needs: Low NOx burners and burners for oil -- solid slurries.

Operating System: Better combustion controls to increase efficiency.

Manufacturers:
- CEA.
- Combustion.
- COEN.
- Forney.
- North American Manufacturing.
- Peabody.
- Ray.
- Zink.
- Zurn.
- Others.

Risks: Low NOx burners may cause flame impingement and flame instability.

Other Information: Low excess air burners are also a promising area.

History: Oil burners have been around for many years. Waste fuels have also been burned for long periods. The problems have arisen when the oil was dirty and gave burner plugging problems. Also, if waste oil characteristics are much different than that of the light oil, only small amounts of waste oil are usually used.

Comments: Additional Data

The burners described are typical light oil burners. If the waste oil is different than light oil, there could be problems with flame stability. Also if solid waste is mixed with the oil, the nozzle must be checked for erosion. Changes in the flame shape could indicate nozzle erosion. Also the waste fuel must be free of dirt to prevent plugging of nozzle.

REFERENCES

2. "Steam" by Babcock & Wilcox.
<table>
<thead>
<tr>
<th>COMPONENT DESCRIPTION</th>
<th>Liquid Fuel</th>
<th>CE-M</th>
<th>P. 1 of 3</th>
</tr>
</thead>
</table>

### Oil Burner

**Type**
- Heavy Oil

**Types Available**
- a. Air atomized
- b. Steam atomized
- c. Mechanically atomized

### Physical Characteristics

Air, Possibly Several Registers

Oil, with Air or Steam

A burner is a device for feeding fuel and air to the boiler such that combustion can be maintained. The burner is designed to give the proper mixing between oil and air to sustain combustion over the burner's operating range.

### Principle of Operation

First the oil must be atomized or converted to a fog. The oil is atomized by blowing through a nozzle with dry steam or air pressure or mechanical device. The air and oil can be mixed with the oil and flame in one step or through several stages by use of multi-register burners or overfire air ports.

### Materials of Construction

Normal tool steel can be used. If the oil contains abrasive solids, the nozzle will require modification. Special tungsten-carbide inserts have been used. Ceramic inserts are also in the developmental stage.

### Advantages Over Other Types

Steam-atomized burners have a wider operating range but have steam losses. Mechanically-atomized burners require less energy but may require more maintenance. Some smaller units may also use air atomization. When the oil contains solid particles, air or steam atomization is preferred over mechanical.

### SIZING CRITERIA

The size depends on the size of the boiler and turndown required. Firetube units tend to have one burner only. Larger watertube units may be multiburner.
ACCESSORY COMPONENTS

- Fuel pumps.
- Forced draft fans.
- Burner and combustion controls.

SUPPORT REQUIREMENTS

Personnel: Boiler operator
Training: Boiler operator
Skills Required: Boiler operation
Inspections: Boiler certification
Access: Burner assembly can be pulled out
Spare Parts: Guns and nozzle
Permits: Air pollution control for entire boiler system.

OPERATIONAL CONSIDERATIONS

General: Most problems involve nozzle deterioration so oil should be strained.
Installation: The burner sizes vary dependent on boiler shape.
Maintenance: Nozzle and fuel pumps give most problems.
Controls: Air, fuel feeds are controlled.
Scheduling: Can be changed while boiler is still hot.
Downtime: Very small.
Other Factors: Guns are usually retracted when not in use.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Major safety control device is flame detector.
Fire Hazard: Leaks in fuel lines could start fires as well as cause loss of oil pressure.
Explosion: If flame goes out, explosion could result if fuel flow is not stopped.
Other Safety: Also bad combustion can produce CO which is explosion hazard.
General Environmental: Burning conditions influence NOx, CO, hydrocarbon and particulate emissions.
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<tr>
<th>COST ANALYSIS</th>
<th>Liquid Fuel</th>
<th>CE-M</th>
<th>P. 3 of 3</th>
</tr>
</thead>
<tbody>
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<td>$13,000 for 10 \times 10^6$ BTU/hr unit - includes pump, controls, fan -- equipment cost only.</td>
<td></td>
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<tr>
<td>$33,000 for 75 \times 10^6$ BTU/hr unit - includes pump and controls - equipment cost only.</td>
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</tbody>
</table>

**STATE-OF-THE-ART**

R&D Needs: Low NO$_x$ burners and burners for oil - solid slurries.

Operating Systems: Better combustion controls to increase efficiency.

Manufacturers:
- CEA.
- CDE.
- Forney.
- North American Manufacturing.
- Peabody.
- Ray.
- Zink.
- Zurn.
- Others.

Risks: Low NO$_x$ burners may cause flame impingement and flame instability.

Other Information: Low NO$_x$ burners are also a promising area.

History: When one installation tried to mix waste with heavy oil, their steam-atomized burners led to incomplete combustion and burner fouling. They solved the problem by switching to low excess air.

Successes: Parallel flow burners. The new burners used natural gas as the atomizing medium. They also only fire 4 out of 6 burners on the waste fuel. (See January 1981 issue of "Power," McGraw-Hill.)

Comments: Additional Data

The burners described are typical heavy oil burners. If the waste oil burned is different than heavy oil, there could be problems with flame stability. Also if solid waste is mixed with the oil, the nozzle must be checked for erosion. Changes in the flame shape could indicate nozzle erosion. Also the waste fuel must be free of dirt to prevent plugging of nozzle.

**REFERENCES**

2. "Steam" by Badcock & Wilcox.
Component Description

Gas Turbines

Types Available:
- a. Direct fired
- b. Indirect fired
- c. Regenerated

Types Used Commercially:
- a, b, c

Physical Characteristics

General Description

Gas turbines are continuous combustion engines consisting of an axial or radial compressor, combustion system, high pressure (compressor drive) turbine and a low pressure (power) turbine. The regenerated turbines also have a heat exchanger.

Principal of Operation

Air (or exhaust gas) is compressed, heated, and expanded. The expansion produces the power required by the compressor as well as a net power output. The power output is dependent on the mass flow rate, the inlet temperature, and the pressure ratio.

Materials of Construction

- Compressor: high strength alloys.
- Combustor: corrosion and high temperature resistant alloys.
- Turbine: alloys displaying 9000 creep, fatigue corrosion and erosion resistance.

Advantages Over Other Types

Instrumented for remote operation, quick and easy installation, high horsepower to size ratio, short start-up time, relatively vibration-free.

Sizing Criteria

Load: Kilowatts or horsepower = 100 - 100,000 hp design operation.
Fuel Consumption: Specific fuel consumption, tons per day.
**ACCESSORY COMPONENTS**

- Fuels treatment.
- Storage tanks.
- Cogenerator (heat recovery)
- Water cleaning/injection for pollution/NOx control.

**SUPPORT REQUIREMENTS**

Personnel: Systems automated can be unattended (statutory requirements).
Training: Minimal for operation, extensive for maintenance.
Skills Required: Maintenance personnel/mechanic.
Inspections: Regular inspections required, depends on duty.
Access: Minimum needed for maintenance removal.
Spare Parts: Spares and maintenance/support available from manufacturers.
Permits: Must meet EPA emissions criteria.

**OPERATIONAL CONSIDERATIONS**

General: Waste usage increases with demand.
Installation: Fuel and electrical hookup.
Maintenance: Cleaning, borescope inspection.
Controls: Mostly automated.
Scheduling: 24 hour operation possible.
Downtime: Startups hardest on engine. Maintenance down time frequent, and often lengthy.

**SAFETY AND ENVIRONMENTAL CONSIDERATIONS**

General: Noise control, covered air intakes.
Fire Hazard: Exhaust temperatures range from 850° - 1100°F.
Explosion: Possibility if startups fail. Nozzle plugging can cause irregular flame pattern.
Other Safety: Over-speed shutdown, vibration shutdown, lubrication monitor/shutdown.
General Env.: Emissions must be monitored, can be adjusted, depending on fuels.
COST ANALYSIS

Maintenance Costs: $7.50/kw-year.
Supplemental fuel to burn 10 tons/day = $20k.

STATE-OF-THE-ART

R&D Needs: Combustor design to handle variety of fuels.
Operating Systems: Electric generation, propulsion, pipeline pumping.
Manufacturers: Major engine manufacturers.
Risks: N/A.
Other Information: Can burn most types of liquid fuel with some treatment.
Cost of Equipment: Data unavailable.

History: Developed during World War II, the turbines have undergone significant development. Currently, they are used as reliable airplane engines, in marine propulsion, pipeline and electric generation.

Successes: Coast Guard successfully burned a .5 percent mixture of spent lube oil in 1973. Manufacturers okayed this mixture. Many engines have been burning Bunker C which can be as dirty.

Failures: Exhaust temperatures are high if cogenerators are not used, without such a significant loss in efficiency occurs. No data is available to suggest that waste oil has been unsuccessfully burned.

Key Problems: Turbines work at high internal temperatures. The temperatures multiply corrosion problems. Cooling of higher temperature models. Ability to handle wide variety of fuels. Each major increase in firing temperatures requires major component improvement.

Comments: If the gas turbine is on site, it can be adapted to burn waste-derived oil or spent motor oils in low mixtures. Higher mixtures could be used if the waste oils are cleaned. The cost of supplemental fuel is the main consideration. Unless the turbine is going to be used all the time, it is not viable to burn waste oil in them.
REFERENCES

COMPONENT DESCRIPTION

IC Engines

Types: Diesel, Otto Cycle, Rotary

Types Used Commercially: Diesel, Otto Cycle

Physical Characteristics

A

B

C

Spark

Fuel/ Air In

Exhaust

Fuel/ Air In

Exhaust

Spark or Compression

Low Speed

Moderate

High

0-200 Rpm

200-1,800

1,800+

General Description

Diesel and Otto Cycle engines consist of varying numbers of cylinders in line, or opposed. Systems consist of a carburetor, valves, cam(s), crank shaft(s), injector nozzles, combustion chamber, moving piston in a cylinder. Rotary (c) consists of rotor, cam(s), crank shaft(s), valves and injection nozzles, and spark plugs.

Principal of Operation

Fuel/air mixtures (adjusted by carburetor) enters on intake stroke, is compressed, ignited by the compression or by spark. The expanding combustion gases work on the piston. Final stroke scavenges exhaust gases. Rotary intakes air/fuel, compresses it, ignites it with a spark, the gases force the rotor to turn, and finally scavenges the exhaust.

Materials of Construction

All types: block is cast from steel or aluminum. Valves and pistons are temperature, corrosion, and stress tolerant steels.

Advantages Over Other Types

Internal combustion engines, especially diesels, are the most efficient liquid fuel burners, small enough for prime movers, easily applied to electric generation. Lots of research being done, many manufacturers.

SIZING CRITERIA

Size of engine (typical): 40,000 diesel burning 0.10% mix would burn about 20 tpd.

\[(40,000 \text{ hp})(0.40)(1\text{ lb/}\text{hp/\text{hr}})(24 \text{ hr/day})(1 \text{ ton/2,000 lb})(0.1 \text{ mix ratio}) = 20 \text{ tpd.}\]
ACCESSORY COMPONENTS

Waste fuel clean-up system - filters, strainers, coalescers, purifiers, etc. Some combination of these will treat the waste oil. Pre-combustion chamber increases fuel's flexibility. Must be included in original engine, cannot be modified.

SUPPORT REQUIREMENTS

Personnel: Diesels can be run automatically after startup.
Training: Mechanic.
Skills Required: None for operation.
Inspections: Cylinder, valve wear, emissions check annually or as needed.
Access: Maintenance.
Spare Parts: Available with support from engine manufacturer.
Permits: Must meet EPA standards.

Operational Considerations

General: Fuel composition should be monitored for maintenance.
Installation: Can be on mobile beds or permanent installation.
Maintenance: Routine maintenance depending on duty cycle.
Controls: Temperature monitors output. Automatic.
Downtime: Can utilize backups or standbys or increase loads.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

General: Units should be insulated or away from working environments to control noise. Exhausted in well ventilated area.
Fire Hazard: Exhaust temperatures to 500°F. Should be kept clear of combustibles. Fuels are highly volatile. Leaks are a fire hazard. Safe (floating head) needed for storage tanks.
Explosion: IC engines do not explode. Overspeed governor possible asset.
Other Safety: IC engines are safe. Minimal safety requirements.
General Environment: Air pollution considerations, NOx, COx, SOx, etc. will increase with the dirtier waste fuels.

COST ANALYSIS

See graph on Page 4.
STATE-OF-THE-ART

R&D Needs: Combustion research to burn dirtier fuels. Air pollution increases with dirtier fuels.

Operating Systems: U.S. Coast Guard waste oil burnoff in diesel engines and boilers using a 10% mix. Coors Beer Company using a filtered 3% mix with diesel. Kroger Company, Cincinnati, operating on a filtered 5% mix.

Manufacturers: Major engine manufacturers.

Risks: Air pollution trends with waste fuels may be a problem.

Other Information: Slower speed designs have the largest capacity to burn waste and mixed fuels. Wear becomes more pronounced in higher speed models.

History: Major engine manufacturers had tested burnability of waste oil in the early fifties. Recent resurgence has resulted from dwindling supplies of regular petroleum products. Several recent tests have been made.

Successes: Engines have been proven adaptable, are mobile and have the ability to burn a wide variety of fuels with proper adjustment. Shown to be able to use up to 10% lube oil mixed with diesel. This test indicated no short-term effects. Recommendations are waste fuel to normal fuel ratios 1:100, 5:100 max for no adverse effects.

Failures: No information available.

Key Problems: The technology is available to solve most of the problems associated with burning any type of fuel. Fuel treatment is also economically justifiable. The waste oils contain large quantities of trace metals, which adversely effect performance, emissions, and wear. Manufacturers endorse the mixing up to 5:100 ratios. Further mixing rates would require treatment.

Comments: The waste-derived oil properties have to be determined. The oil may or may not be capable of being fired directly. With an analysis of the properties, the mixing requirements can be determined. Filtering, cleanup systems may be purchased, for bulk waste oil treatment, then the oil may be distributed. The waste oil, when cleaned, is suitable for low mixture rates in existing engines. The engines are not very fuel tolerant. May cause reliability and availability problems for the Navy.

REFERENCES


* Based on 0.34 lb/hp/hr SFc, 10% waste oil mix with regular fuel. Equipment is usually available.

Maintenance costs run around $9/kw/year. Supplemental fuel costs to burn 10 tons/day = $22k/day.
DISTRIBUTION LIST

AAP NAVORDSTA IND HD DET OIC, McAlester, OK
ARMY Ft Engr. Letterkenny Army Depot, Chambersburg, PA
AF AERO DEF COM HOS/DEE (T. Hein), Colorado Springs CO
AF HQ LEEEU, Washington, DC
AFB (AFIT/LDE), Wright Patterson, OH; ADTC(AFSC) (Hathaway) Tydall, FL; AF Tech Office (Mgt & Ops), Tydall, FL; DET Wright-Patterson OH; HQ AFSC/DEEE Andrews AFB MD; SAMSO/MNND, Norton AFB CA; Samsos/Dec (Sauer) Vandenburg, CA; Scoll of Engng (AFIT/DET); Sunfo Library, Offutt NE; W. McFaul, Dover DE
AFWL CE Div., Kirtland AFB NM
ARMY - CERL Library, Champaign IL
ARMY CORPS OF ENGINEERS MRD-Eng. Div., Omaha NE; Seattle Dist. Library, Seattle WA
ARMY ENG DIV HNDED-CS, Huntsville AL
ARMY ENGR DIST. Libray, Portland OR
ARMY ENVIRON. HYGIENE AGCY Dir Env Qual Aberdeen Proving Ground MD; Environ. Chem., W630, Edgewood Arsenal MD
ARMY MISSILE R&D CMD SCI Info Cen (DOC) Redstone Arsenal, AL
ASO PWO, Philadelphia PA
ASST SECRETARY OF THE NAVY R&D Washington, DC
ASTM E-38 & D-34, Philadelphia, PA
BUREAU OF RECLAMATION Code 1512 (C. Sander) Denver CO
CAL RECOVERY INC Richmond, CA
CINCLANT CIV ENGR SUPP PLANS OFFR NORFOLK, VA
CINCPAC Fac Engng Div (J44) Makautapa, HI
CINCPACFLT SFC, Pearl Harbor HI
CINCSNAVEUR Fleet Civil Engr, London, England
COMFAIRMED SFC, Code N55, Naples IT
COMFLEACT, OKINAWA PWO, Kadena, Okinawa
COMFLAIR SFC (Code 321) Atsugi JA
COMNAVLOGPAC SFC, Pearl Harbor HI
COMNAV MARIANAS Code N4, Guam
COMNAVUSPAC SFC, Pearl Harbor HI
COMOCEANEXSPAC SFC, Pearl Harbor HI
DEFENSE DEPOT OGDEN PWO, Ogden, UT
DEFENSE ELECT SUP CEN PWO, Dayton OH
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