resource recovery plant implementation

technologies

guides for municipal officials

- planning and overview
- technologies
- risks and contracts
- markets
- accounting format
- financing
- procurement
- further assistance

This publication is part of a special series of reports prepared by the U.S. Environmental Protection Agency's Office of Solid Waste Management Programs. These reports are designed to assist municipal officials in the planning and implementation of processing plants to recover resources from mixed municipal solid waste.

The title of this series is <u>Resource Recovery Plant Implementation: Guides for Municipal Officials</u>. The parts of the series are as follows:

1. Planning and Overview (SW-157.1)
2. Technologies (SW-157.2)
3. Markets (SW-157.3)
4. Financing (SW-157.4)
5. Procurement (SW-157.5)
6. Accounting Format (SW-157.6)
7. Risks and Contracts (SW-157.7)
8. Further Assistance (SW-157.8)

Mention of commercial products does not constitute endorsement by the U.S. Government. Editing and technical content of this report were the responsibilities of the Resource Recovery Division of the Office of Solid Waste Management Programs.

Single copies of this publication are available from Solid Waste Information, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

Resource Recovery Plant Implementation:

Guides for Municipal Officials

TECHNOLOGIES

This guide (SW-157.2) was compiled
by Steven J. Levy and H. Gregor Rigo

Acknowledgements are made to Robert Lowe for chapter II of this report, and to Robert Holloway, David Sussman, and Yvonne Garbe for contributions to other chapters.

U.S. ENVIRONMENTAL PROTECTION AGENCY

1976

CONTENTS

RESOURCE RECOVERY PLANT IMPLEMENTATION: GUIDE FOR MUNICIPAL OFFICIALS

Technologies

by Steven J. Levy* and H. Gregor Rigo+

SECTION I

INTRODUCTION AND OVERVIEW

The recent emergence of techniques for converting mixed municipal waste into marketable products has given municipal and regional officials a variety of new options for solving their solid waste management problems. Although these resource recovery systems cannot be expected to operate at a profit, they are becoming increasingly competitive with the cost of sanitary landfilling in many areas of the country. In addition, although they will not allow a community to close down its landfill, the life of the landfill can be extended tremendously by the weight and volume reductions achieved.

The purpose of this technology review is to aquaint the reader with the available and emerging technology options for processing of mixed municipal waste for resource recovery.

Although this report focuses only on mixed waste processing systems to recover materials and energy, it is important to remember that other strategies should also be considered and integrated with such plants for a complete resource recovery and conservation strategy. This includes particularly examination of waste reduction and source separation strategies. Fortunately such strategies will usually be found to be compatible, which allows cities to maximize recovery and minimize both waste and cost.

For each technology presented in this report the following information is presented:

---

*Mr. Levy is Manager of the Demonstration and Evaluation Program of the Resource Recovery Division, Office of Solid Waste Management Programs, U.S. Environmental Protection Agency.

+Dr. Rigo is the Principal Engineer for Systems Technology Corporation, Dayton, Ohio.

- Process description
- Product characteristics
- Status of development
- Energy balance

This information should help officials to determine if systems may be available to meet their needs; and will help them understand the technical capabilities and risks associated with various technologies.

This guide will not tell the reader which system, if any, to select. There is no universally "best" or most economical recovery technology. Every community facing a resource recovery decision must consider its own unique set of factors when selecting a course of action. Factors include available markets and local prices, capital and operating cost projections, level of risk which they are willing to assume*, and financing and management alternatives available for different systems or considerations.

Unfortunately, goals often conflict, making a choice more difficult. For example, the recovery system with the lowest projected net cost may involve the highest degree of technological uncertainty. Or, the system producing products which can be most readily marketed through firm contracts may have the highest projected costs. The final decision is subject to specific value judgements which each community must make on its own. This should normally be done with the assistance of knowledgeable consultants who can examine in detail the feasibility of alternative options, including factors such as marketing, management, and financing.

The most important factor to remember when assessing a technology is that the system must be able to produce marketable products. Technology selections should not be made until potential markets have been identified and the market requirements specified. Some communities will find that there is only one technical approach that can simultaneously meet their needs and the requirements of their markets. Most cities, however, will have the flexibility to choose from two or more technologies that meet their market requirements. the Markets guide of this series (SW-157.3) discusses markets in detail.

OVERVIEW

To give communities a better idea of the developmental status of various technologies, the systems described in this report have been classified into general categories which are defined below. Because resource recovery systems are rapidly evolving, the categorization serves only as a general guide rather than providing a precise definition

---

*Risk is a function of the total dollar investment and the degree of uncertainty that exists. Factors subject to uncertainty include availability of waste, reliability and performance of equipment, product quality, and market demand.

of status of development. Primarily, it indicates the degree and scale of operating experience. It is important that the decision maker realize that while the degree of operating experience is one detriment of the technological risk inherent in recovery systems, another factor, which may be more important, is the performance guarantee that a system vender may supply. Thus, in a particular situation, a system with an operating history, which is improperly designed or is secured by no performance guarantees, may entail more risk for a city than a newer technology designed and properly warranteed by a qualified vender.

- <u>Commercially Operational Technology</u>

  Full scale commercial plants exist which operate continuously. Thus, there are some operating data available from communities and engineers already involved in the use of the process. Though such systems are being commercially utilized, they may be technologically complex. To operate properly, they will require maximum use of available information leading to careful design and operation by knowledgeable professionals. There may be only limited operating experience with some parts of these plants. Thus, technological uncertainties may still exist.

- <u>Developmental Technology</u>

  Developmental technologies have been proven in pilot operations or in related but different applications (for example, using raw materials other than mixed municipal solid waste). There is sufficient experience to predict full-scale system performance, but such performance has not been confirmed. System design requires considerable engineering judgment concerning scale-up parameters and performance projections; consequently, the level of technical and economic uncertainty is generally greater than commercially operational technologies.

- <u>Experimental Technology</u>

  This category includes new technologies that are still being tested at the laboratory and pilot plant level. Insufficient information exists to predict technical or economic viability. Therefore, such technologies should not be considered by cities contemplating immediate construction.

The systems described in this guide are further categorized into energy recovery and material recovery. The two are not mutually exclusive; most proposed resource recovery systems have aspects of both.

Energy Recovery Systems

Energy recovery technologies are classified in this report as follows:

- <u>Waterwall Combustion System</u>

  Commonly called "waterwall incinerators," this system involves burning of solid waste in a specially designed furnace jacketed with water-filled tubes, and incorporating other boiler tubes to recover heat. In most systems built to date solid waste is burned without prior processing, on mechanical grates which move it through the furnace. A relatively recent innovation to this process involves the burning of shredded solid waste using semi-suspension type spreader stokers. In both types of systems little or no supplemental fossil fuel is used and heat is recovered as steam which can be used directly or can be converted to electricity.

- Solid Refuse Derived Fuel (RDF) System

This designates a processing system employing size reduction and classification of waste to produce both a combustible fraction and a "heavies" fraction which may be processed for materials recovery. This may be either a "wet" or a "dry" process. These systems are also called "supplemental fuel" systems, since the combustible fraction would typically be marketed as a fuel to outside users e.g. utilities and industries, for use as a supplement to coal (or possibly oil) in their existing boilers. Some waterwall combustion systems (as mentioned above) would also involve such a processing system, though the waste might be shredded more coarsely, and may or may not be classified. Similarly, some of the pyrolysis systems may employ elements of this "front end" processing to prepare waste for the pyrolysis reaction. In this report the terminology "refused derived fuel (RDF) system" is used to represent the preparation of a solid fuel to be marketed to a utility or industry for use as a supplement to a fossil fuel.

- Pyrolysis Systems

Pyrolysis is a broad term given to a variety of processes where either processed or unprocessed waste is decomposed by the action of heat in an oxygen deficient atmosphere. This results in production of combustible gases or liquids depending on operating conditions. These products may be either burned immediately to produce steam or, those whose quality is high enough, may be transported or stored for use elsewhere.

- Biological Conversion Systems

Biological conversion involves the decomposition of solid waste by bacterial action to produce combustible gases. These gases could be burned immediately to produce steam, or transported for use elsewhere if their quality is high enough. Biological conversion occurs in landfills, and gas wells may be used to collect the gas if conditions are correct. Alternatively, digestion can take place in controlled vessels.

- Waste-Fired Gas Turbine

  This technology involves the burning of solid waste in a special incinerator and the use of the resulting hot gases to drive a gas turbine for energy production (Brayton Cycle).

Typically, people tend to classify recovery systems by processing technique, as we have done here. However, since market availability is the key pre-requisite for selecting a system, it is valuable to look at technologies in terms of products produced. Viewed in this way the following array of technologies results:

Product	Technology (Process)
Steam or Electricity generated "on-site" for sale	Waterwall combustion system (bulk burning) Waterwall combustion system (processed waste) Pyrolysis to low Btu gas, which is burned in afterburner Bio-conversion to a gas, which is burned in an afterburner
Production of a solid fuel for use "off-site" as a supplement to coal or oil	Solid Refuse Derived Fuel (RDF) system
Production of a gas or liquid fuel for use "off-site" as a supplement to oil or gas	Pyrolysis to a medium Btu gas Pyrolysis to a liquid Bio-conversion to medium Btu gas

Table 1 combines technologies and products in a matrix and includes major locations where implementations have occurred. The table also shows the status of development of the technologies. Clearly, most of the systems are still in relatively early stages of development, indicating the presence of technological risk, and therefore, the need for cities to proceed cautiously. Status is further discussed below.

Commercially Operational Technology. Combustion of solid waste on mechanical grates in waterwall furnaces to recover steam is the most thoroughly proven resource recovery technology. However, most of the experience has been in Europe rather than the U.S. Approximately 200 of these systems have been installed in Europe, and another 50 exist in Japan, Brazil and elsewhere. Six waterwall combustion systems are now operating in the United States, where market and institutional arrangements have been less attractive than other countries.

Although this is a proven technology, some technical uncertainties still exist. Boiler corrosion and air pollution control problems,

TABLE 1
ENERGY RECOVERY TECHNOLOGY AND PRODUCTS

Status	TECHNOLOGY \ PRODUCT	ELECTRICITY	STEAM (for use other than generating electricity)	SOLID FUEL (for use other than in producing steam or electricity)	GASEOUS FUEL	LIQUID FUEL
COMMERCIALLY OPERATIONAL	WATERWALL COMBUSTION (MASS BURNING)	Used extensively in Europe and Japan	Braintree, Mass (O) Harrisburg, Pa (O) Norfolk, Va (O) Chicago, Ill (O) Nashville, Tenn (O) Portsmouth, Va (C) Saugus, Mass (S) Montreal, Can. (O) Quebec, Can (O)	N/A†	N/A	N/A
	(SEMI-SUSPENSION)	Hempstead, N.Y. (C) Dade Co.,Fla. (D)	Hamilton, Ont. (O) Tokyo, Japan (O) Akron, Ohio (D)	N/A	N/A	N/A
	SOLID FUEL (RDF)	St. Louis, Mo. (P.O.) St. Louis, Mo (D) Chicago,Ill (C) Ames, Iowa (S) Milwaukee, Wis (C) Monroe County, N.Y. (D)	Columbus, Oh (D) Akron, Oh (D)	Los Gatos, Cal (P.O.) Bridgeport, Conn. (D) E. Bridgewater, Mass. (S) Palmer Twp., Pa (D)	N/A	N/A
DEVELOPMENTAL	PYROLYSIS GASIFICATION LOW BTU	Luxembourg (C)	Baltimore, Md (S) Grasse, France (C)	By-Product	Possible	N/A
	MED. BTU	Possible	Possible	N/A	S. Charleston, W Va (P.O.)	N/A
	LIQUIFICATION	Possible	Possible	By-Product	N/A	San Diego County, Cal (P,C)
	CONVERSION LANDFILL	Los Angeles, Cal (O,P)	Possible	N/A	Los Angeles, Cal (O) Phoenix, Ariz (S)	
EXPERIMENTAL	REACTOR	Possible	Possible	By-Product	Franklin, Oh (P) Pompano Beach, Fla (P-D)	N/A
	WASTE FIRED GAS TURBINE	Menlo Park, Cal (P)	By-Product	N/A	N/A	N/A

*Operating status is designated as:
- P—Pilot or Demonstration
- D—Design
- C—Construction
- O—Operational
- S—Start-up

†N/A—Not Applicable

for instance, have resulted from improper design and/or operation of some systems. The overall operating experience of waterwall incinerators varies. Examples can be found of both very successful operations and those that have experienced problems. Proper design and operation, utilizing information from the most successful operations is the key to success.

A recent variation of the standard waterwall combustion system involves course shredding of waste followed by burning in a special waterwall boiler. Usually, this would be a "stoker boiler" where the course shredded waste (which may have had some metals and glass removed) is mechanically or pneumaticly thrown into a furnace and burned on a moving grate. There are several of these systems operating now or scheduled for construction in the near future, but the basic boiler technology is similar to bulk burning waterwall boilers. Also, such boilers have been used to burn bark and other waste and are standard coal burning technology.

Another system in a similar stage of development is the preparation and use of Refuse-Derived Fuel (RDF). This concept involves size reduction of solid waste using either hammermills (dry) or hydropulpers (wet) and removal of non-combustibles to produce a supplementary fuel for use in coal-fired steam generators (boilers). Although the operating experience of this technology is represented by only one full-scale demonstration plant and one commercial facility operational since early 1976, sufficient data have been collected and observations made to indicate that the concept can be feasible. RDF can be produced and, according to some electric utility officials, experience indicates that it can be fired at rates of 5 to 20 percent of a steam generator's heat output without measurably affecting boiler operation and short-term maintenance requirements.

However, it should be noted that the design and operating parameters have not yet been well defined for the most cost-effective approach to RDF production, storage, transportation, or firing. The technology will be optimized through the experiences of the second and third generation plants in operation and under construction.

In addition, it should be noted that many steam generator operators are wary of the potential adverse effects of RDF on boiler operation and maintenance. This is understandable given the limited RDF firing experience to date. Most potential users are concerned enough that they require RDF firing test periods of from several months to several years during which they will evaluate the effects of RDF firing. The RDF purchase agreements usually allow the user to terminate the contract if sufficient problems are found to make the RDF economically unattractive. It is expected that as RDF firing experience is gained, these test period requirements will be dropped from purchase contracts.

Although this discussion so far has centered on fluff RDF (shredded air classified waste), a number of alternative RDF products and production systems are discussed in this report. There has been relatively little experience either with the production or the firing of these other RDF variations. Because they entail greater uncertainty, they should be classified as "developmental." The variations include densification of the fuel into pellets, briquettes, or cubettes for co-firing with coal in a stoker equipped boiler; use of RDF in oil-fired boilers, or in conventional stoker or grate equipped boilers; use of RDF in cement kilns; and the production of a very fine powdered fuel (dust RDF) for use alone or slurried in oil.

Developmental Technologies. This category includes the types of special solid refuse derived fuels described above as well as all types of pyrolysis systems and the recovery of methane from sanitary landfills.

Numerous pyrolysis systems are being developed. They are classified as developmental because the processes are still in the laboratory or pilot plant stages. However, one pyrolysis system (Monsanto's Langard system) is being demonstrated at the 1,000 ton per day scale in Baltimore, Maryland. This plant is currently undergoing extensive modifications to correct problems which arose during its initial start-up period. An assessment of the Systems' availability cannot be made until the modifications are completed and their performance is evaluated.

A 200 ton per day demonstration of the Occidental Petroleum Corporation's pyrolysis process is under construction in San Diego, California and will begin operations in the fall of 1976. Union Carbide Corporation has already operated a 200 ton per day oxygen fed pyrolysis plant in South Charleston, West Virginia. In Europe, one 200 ton per day commercial Torrax pyrolysis plant (Andco Incorporated) is nearing completion, and two other units are soon to be started. Several other small-scale pyrolysis systems are currently being tested.

Communities may wish to consider some of these processes for implementation, realizing that the technological uncertainties generally exceed those for commercially operational technologies. Both Andco and Union Carbide consider development and demonstration of their respective systems to be far enough along to warrant marketing of full size plants.

Recovery of methane from sanitary landfills is also considered developmental because although the technology is not complicated, it is not yet possible to evaluate the feasibility of such a system. Long-term monitoring is necessary to determine projected yields over extended periods of time. Also, more information is needed to define the parameters (such as depth of fill, soil characteristics, field moisture, etc.) necessary to predict yields and thus system economics. Nonetheless, at least one compnay (the NRG Nufuel Company) has sufficient confidence in the process that they are seeking landfill sites suitable for commercial application.

Experimental Technologies. Anaerobic digestion in controlled reactors, and direct generation of electricity in a high pressure gas turbine are presently being pursued at the research level. Neither of these systems will be ready for commercial consideration until they are first proven in operating pilot plants.

Materials Recovery Systems

Mechanical processing of mixed or partially concentrated waste is often combined with energy recovery in comprehensive recovery plants. However, total materials recovery systems are also possible. Table 2 is a list of material recovery processes with some brief notes concerning installations and products.

Commercially Operational Technology

Composting of waste has been practiced commercially in both the United States and Europe, and thus, can be considered commercially operational technology. Unfortunately, composting does not have wide applicability because of the limited market for the humus product. In the 1960's, many composting systems were built and operated in the United States. All but the Altoona, Pennsylvania, plant have been closed because of lack of market for the compost.

Of the unit processes for recovering materials, ferrous metals recovery is clearly a proven technology. Ferrous metal recovery has been demonstrated to be commercially available and economically viable. Systems are in use to recover ferrous metal from incinerator residue, from coarsely ground solid waste prior to disposal in a shredded waste landfill, following shredding operations in refuse derived fuel systems and even from raw unprocessed solid waste in areas where a high market value and high ferrous metal content make the operation feasible. The major concern in considering ferrous metal recovery is to carefully define the market specifications for the project prior to implementation of the subsystem, so that the equipment can be designed to extract a marketable product.

Wet processing for fiber recovery is a patented process of the Black-Clawson Company. This process has been demonstrated in only on instance to date. A 150 ton per day plant has operated successfully on a daily basis in Franklin, Ohio, for approximately five years. The plant produces a low grade paper fiber which is used by a roofing felt manufacturer located near the Franklin plant. However, markets for this low-grade fiber are limited. Despite the relatively small scale and singularity of the Franklin demonstration, the technical success of the project suggests that it is near to

TABLE 2.
MATERIALS RECOVERY SYSTEMS LOCATIONS AND PRODUCTS

	System or Subsystem Type \ Product Type	Color Sorted Glass Cullet	Mixed Glass Cullet	Aluminum and Foils	Ferrous Scrap	Soil Conditioner	Paper Pulp
COMMERCIALLY OPERATIONAL	Fiber Recovery Wet Separation Dry Separation						Franklin, Oh (O) * Rome, Italy (O)
	Composting					Altoona, Pa (O) others were not financially viable	
	Magnetic Separation				St. Louis, Mo (P,O) Columbus, Oh (O) Charleston, SC (O) Atlanta, Ga (O) San Diego County, Cal (C) Plus Many Others		
DEVELOPMENTAL	Aluminum Recovery Wet Processing Dry processing			Franklin, Oh (P) Ames, Iowa (S) Milwaukee, Wis (C) Monroe Co, NY (D) New Orleans, La (D) San Diego County, Cal (C)			
	Glass Recovery	Franklin, Oh (P)	New Orleans, La (D) San Diego County, Cal (C)				

*operating status is designated as:

P—Pilot
D—Design
C—Construction
O—Operational
S—Start-up

to being commercially operational. A large-scale plant utilizing the wet pulping technology is scheduled for construction by Black Clawson in Hempstead, New York. The pulp, however, will be used as a fuel rather than as a paper fiber.

Developmental Technology. Processes to recover aluminum and glass must still be considered developmental. A considerable amount of pilot work is presently underway, and economically viable systems may soon be available. This will occur through a combination of optimization of recovery equipment to produce purer materials and a lessening of industry product specifications as more experience is obtained in using these materials recovered from municipal solid waste.

Processes to recover glass and aluminum usually operate on a pre-concentrated materials stream rich in metals and glass. The final concentration step in glass recovery technology has focussed on two basic approaches: froth floatation, which produces a very pure, small particle, non-color-sorted product; and optical sorting, which produces a large particle, color-sorted product. The availability of froth floatation must await its full-scale demonstration (the first such plant will begin operations in San Diego County in late 1976) in order to test the economic and technical viability of the process and in order to produce a sufficient quantity of glass to test its marketability.

Optical sorting has been demonstrated at Franklin, Ohio by EPA and the Glass Container Manufacturing Institute. To date, however, the equipment has not been able to economically produce a product which can consistently meet the specifications of the glass industry for ceramic contaminants. Newer, more efficient equipment will soon be tested. In addition, some manufacturers have begun to show a willingness to accept glass which does not fully meet the industry specification.

The most promising final concentration method for recovering aluminum from solid waste appears to be electromagnetic devices, referred to as "aluminum magnets." Three companies are currently developing these devices. The first full-size system to use such a device is in Ames, Iowa. As of this writing, the equipment was still going through normal start-up procedures.

Conclusions

Assessing and selecting resource recovery technologies is a complicated endeavor which the City should undertake with the assistance of adequate in-house or consulting expertise. A procurement of a recovery system involves many non-technological issues such as procurement method, management, financing and risk sharing.

These issues are discussed in other sections of this series entitled Resource Recovery Plant Implementation: A Guide for Municipal Officials. (SW-157.1 to SW-157.8)

However, understanding the basic capabilities and status of development of technologies is an important link in the implementation chain. This report presents a background of such information for the municipal official. Clearly, the local markets and other circumstances surrounding each situation will influence the attractiveness and suitability of various technologies. In short, it is difficult to evaluate technologies in a vacuum. However, this report is intended to provide factual basic information on various technologies as an aid to municipal decision-making.

The categorizing of technologies into various stages of development in this report is an attempt to give cities a rough idea of how much experience there is with various technologies. However, it is only a general guide.

As a whole, resource recovery technologies are still in a relatively early stage of development and entail risks. Such risks include the possibility that equipment will not perform as designed, that products will not meet market specifications, and that consequently a city will suffer an economic penalty. This penalty could range from a major capital loss for a plant that will not function properly and must be "written off," to an increase of a few dollars in net costs for additional operating expenses.

On the other hand, there is sufficient experience with some technologies and promising early results from some developmental technologies that the risks involved may not be unreasonable. This is particularly true of plants designed and backed by knowledgeable, experienced companies.

Costs of resource recovery are discussed only briefly in this report (Section II). It is EPA's firm belief that attempts to predict (and compare) costs of various types of plants in a general way, apart for local circumstances, is more likely to mislead than inform. The range of assumptions regarding specific design, reliability, markets and other factors is too great to make such an analysis meaningful. We will note only that all but the "experimental" technologies discussed in this report have been shown or predicted by reliable engineers to be a roughly "competitive" disposal alternative, particularly for cities with higher disposal costs, under "reasonable" assumptions of capital and operating costs and product revenues.

SECTION II

GENERAL CONSIDERATIONS FOR RESOURCE RECOVERY SYSTEM DESIGN

To help a community evaluate and select the technology that best meets its needs, subsequent chapters of this Guide provide descriptions of available and developing resource recovery technologies. However, evaluating and selecting a technology are only part of the implementation process.

There are several additional aspects of a technical nature that must be considered:

1. Markets for recovered products
2. Waste generation (quantity)
3. Waste composition
4. System reliability
5. Plant location
6. Land required for the plant site
7. Community acceptance
8. Plant costs and revenues

These factors, which apply to all technologies, must be considered in the design of any system and are discussed briefly below.

Markets for Recovered Products

The successful implementation of a resource recovery system depends upon the ability to sell the recovered products. Revenues from the sale of recovered products can help to offset the cost of owning and operating the plant; without such revenues, the cost of most resource recovery systems would be prohibitively high.

To be marketable, products reclaimed from energy and materials recovery systems must have qualities that are acceptable to the user. Steam and electricity produced from solid waste are similar to those products from other sources. However, refuse-derived-fuels (solid, liquid, and gaseous) have characteristics that are different from conventional fossil fuels. Some of the more important fuel characteristics are: ash content, higher heating value, corrosiveness, viscosity, and moisture content. Similarly, the quality of recovered materials must be commensurate with user specifications.

For all products derived from refuse, considerations such as reliability of supply and quantity are also important. A higher price can usually be obtained for a certain supply than for an unreliable source. This is particularly true for fuel processing. Additional information on markets is available in the Markets guide of this series (SW-157-3).

Waste Generation (Quantity)

The amount of waste that the community generates must be estimated carefully so that the resource recovery plant (and accompanying elements in the total solid waste management system, i.e. transfer stations and sanitary landfills) can be designed at the proper size. An oversized plant will have under-utilized equipment and will cost more than necessary. An undersized plant will not be able to accept the quantity of waste that must be processed.

There are several ways to estimate waste generation quantities. Some of these may appear costly; but, considering the potential costs of over - or under-designing a plant, estimating waste quantities is an essential and prudent investment.

Alternative methods for obtaining these data are discussed below.

In many communities (and in particular smaller ones) no weight records are maintained. A common procedure for determining generation rates is to count the trucks and then, assuming they are fully loaded, estimate the tonnage based on the total volume of the trucks entering the site. Such a procedure can be very misleading and should be avoided.

Communities lacking scales at their disposal sites have several alternatives that can be utilized instead of volume measurements. The best approach, short of installing a platform scale, is to reroute the collection vehicles to an existing scale on a temporary basis. A highway weigh station or a privately-operated scale, such as at a grain elevator or trucking firm, may be available. The weighing schedule should be set up to allow for enough data to span seasonal and daily variations in generation rates. If only part of a community's waste will go to the recovery facility, demographic differences should also be accounted for in the weighing schedule.

In lieu of such a weighing program individual axle weights can be measured using portable scales at the disposal sites. However, care must be taken to make an adequate number of weighings, even though axle weighing is more cumbersome and time consuming than the use of platform scales.

A final option, one which should be used only as a last resort, is to utilize national average per capita generation data applied to the population to be served by the facility. This approach leaves considerable chance for error because local waste generation often is significantly different from national averages. In addition, quoted per capita generation rates may include different waste sources than those which will go to the recovery facility. (Commercial waste and construction debris are two examples where confusion could arise.) Thus, national average data should be avoided as a primary estimate.

Waste Composition

Evaluation, selection, and design of any resource recovery system requires accurate data about waste composition, i.e., what materials are present in the waste and in what proportions they occur. This is particularly true where materials recovery subsystems are involved, as the composition of many valuable components (such as ferrous metal or aluminum) can vary significantly among different communities. Waste composition variations such as heat content, moisture content and ash content can impact on selection and design of energy recovery components.

Table 3 presents national average'data on waste generation and composition. The limitations described above on using these data as a substitute for estimating local waste quantity also apply to their use for determining composition.

TABLE 3
MATERIAL FLOW ESTIMATES OF RESIDENTIAL AND COMMERCIAL POST-CONSUMER SOLID WASTE
1973

Material	Pounds Per Capita Per Day	Percent
Paper	1.36	38.9
Glass	0.36	10.3
Metals	0.35	9.9
Plastics	0.14	4.1
Rubber and leather	0.10	2.7
Textiles	0.06	1.6
Wood	0.13	3.6
Total nonfood product waste	2.50	71.1
Food waste	0.47	13.3
Total product waste	2.97	84.4
Yard waste	.50	14.1
Misc. inorganics	.05	1.5
Total	3.52	100.00

However, the solid waste industry, is not in agreement as to how much, if any, waste sampling for composition should be done. The major drawback is cost. A waste composition study could cost a community $5,000 to $20,000. This is a small price compared with the millions of dollars of capital investment that it affects. However, some persons argue that the combustible fraction of the waste stream does not change significantly in percentage from place to place and, thus, that a facility designed to recover primarily energy (and perhaps ferrous metals) can be designed without such a composition analysis. (This would be particularly true where waterwall incineration is involved.) Although there is merit to this argument, moisture, heating value, and ash content are important data for design of energy recovery systems and should be determined.

If recovery of aluminum or glass is being considered, a composition analysis is far more critical, as these materials vary significantly in precentage composition from place to place, and quantity in the waste stream would bear heavily on economic feasibility of recovery.

Clearly, the safest route is to conduct a waste composition analysis, and EPA believes that the benefits justify the investment. However, each community will make its own decision based on the cost trade-off it sees, and the type of recovery technology it expects to employ.

System Reliability

A solid waste management system must accept all the waste that is generated, and it must accept it when it is generated. Reliability of the entire solid waste management system is a function of plant reliability plus the availability of alternative processing or disposal facilities. Therefore, the system, including the resource recovery plant and the sanitary landfill, must be designed to operate reliably. This discussion focuses on the reliability of the resource recovery plant.

Reliability as defined here is the ability of the plant to accept and process the community's waste on a regular basis. Reliability is achieved by a combination of the following:

1. Operational reliability of the equipment;
2. Redundancy of equipment or systems; and
3. Storage capacity, combined with excess processing capacity to handle backlogs and current demands at the same time.

Excess processing capacity can be achieved by using:

1. Intentionally oversized equipment; and
2. Overtime use of primary processing lines.

The community must specify the degree of reliability it requires of the resource recovery plant and must communicate this to the system designer. Because reliability is achieved only with an increase in cost, the degree of reliability desired will have to be evaluated in terms of capital and operating costs of the system. Differences in the type or degree of reliability designed into a plant is one reason for significantly different capital costs of plants which are functionally similar.

There are no simple guidelines on the degree or type of reliability which is best. However, the decision maker should take care to ensure that a reasonable degree of reliability is included in the design even though it may increase initial costs. A "bare bones" facility could cause operational headaches.

Plant Location

Solid waste processing plants should be located as near as possible to centers of solid waste generation in order to minimize haul costs and be readily accessible by major roads where the truck traffic will present minimal environmental impacts. The location should also be compatible with market requirements. For example, waterwall boilers should be located as close as practical to steam users to avoid large steam transmission losses and costs. When solid fuels or recovered metals, paper, and glass are being sold to distant markets, access to rail sidings and major thoroughfares should be available. The site should be industrially zoned. Public utilities such as power, gas, water, and sewage should be available at reasonable installation costs. Truck traffic through residential areas should be minimized.

Land Required for the Plant Site

The land area required for the plant site will vary with the type of system, the size of the system, and certain site-specific constraints such as highway access, height limitations, and typography. The following data are rough estimates indicating the order of magnitude of land requirements.

Smaller processing plants (with capacities in the 200 to 500 tpd range) will generally require three to five acres of land. Larger plants (processing over 1,000 tpd) require at least 5 to 10 acres. Trying to squeeze a plant into too small a site can be very costly, resulting in severe limitations on operating and maintaining the plant. Therefore, care should be given to providing adequate space.

Community Acceptance

Resource recovery system planners should be aware of the need to make resource recovery plants good neighbors. A long history of poorly operated solid waste disposal facilities has convinced the public that such facilities should be built "somewhere else." Objections which are most often voiced include increases in truck traffic, spillage from trucks, noise, harborage of rats and vectors, dust and air pollution, unsightly plants, etc.

Such factors need not be problems in properly designed recovery plants. Plant designers should recognize these objections and incorporate measures to eliminate them. Adequate allowances for attractive architectural treatment of the buildings and landscaping (both for decorative purposes and to screen out noise, etc.) are necessary. Additional acreage, in order to provide a buffer zone, should also be considered. Siting should take into account the routes the trucks must follow. Only commercial thoroughfares should be used and adequate roadways should be built on the property so that trucks need not queue up on city streets. Adequate housekeeping of the facility and grounds must be included in both the design and the operating procedures. Sound dampening enclosures should be used to house noisy pieces of equipment.

The decision maker must anticipate siting problems early and design a program to deal with them properly. Eliminating the reasons for objections is not enough, however. The decision maker must also initiate aggressive communications with the public to prove to them that their concerns will be met and their interests will be protected. The caliber, timing, and extent of this effort may be the most critical task in successfully implementing a new solid waste disposal facility. The value of professional assistance in conducting this effort should not be overlooked.

Plant Cost and Revenues

Cost is usually the major factor in decisions about whether to implement large-scale mixed-waste resource recovery plants. Cost considerations are also important in formulating State and Federal policies relating to such implementation. Thus it is important that sound methods of evaluating and comparing cost figures be used.

Unfortunately, very little useful economic data are available as no full-scale mixed-waste separation plants have begun regular operation at this time. In the absence of operating data, cost projections must be based upon preliminary estimates by consulting engineers and system development companies; these estimates are derived from experience with pilot-scale operations and from equipment supplier quotations.

A major problem in projecting costs has been the general lack of comparability among cost estimates. There are two apparent causes for this. First, different cost-accounting methods are employed by various designers, making it difficult to compare cost projections in proposals from companies bidding on the same contract. Secondly, most estimates have been site-specific and reflect a wide range of factors which vary from site to site. Capital costs on a 1,000 ton per day plant may range from $15 to $35 million or more, depending on the type of system chosen, land and site preparation costs, and construction costs, including labor, materials, and equipment. Cost ranges of this magnitude have been experienced even for a given type of technology.

Annual costs, which include amortized capital cost and operating and maintenance costs, may vary from $10 per input ton to $25 per input ton, depending on, among other things, the utilization of capacity, the interest rate on borrowed funds, wage rates, utility rates, fuel prices, local taxes, residual waste disposal costs, and assumptions concerning plant reliability and maintenance costs.

Selling prices for the recovered products are also a great source of uncertainty. They exhibit large variations among geographic regions and have been subject to extreme fluctuations over time. Future negotiable prices for recovered fuels and materials are subject to additional uncertainties due to technical questions about product quality.

Considering all of these variables, it is obviously difficult to provide "typical" costs of various resource recovery plants. We believe that any such costs would be more likely to mislead than inform. We will note only that the projected net costs of the 10 or so plants under design or construction in this country are in the $5 to $15 per ton range.

Now that several plants are about to begin regular full-size operation, reliable data will be becoming available. Analysis and dissemination of these data are high priorities of EPA's Office of Solid Waste Management Programs.

Until such data is produced, planners and managers should consult, among others, the persons and literature mentioned in the Resource Recovery Plant Implementation: Guides for Municipal Officials: Further Assistance (SW-157.8). One publication, highly recommended because it illustrates how net plant costs are sensitive to site specific factors, is entitled Resource Recovery Plant Cost Estimates: A Comparative Evaluation of Four Recent Dry-Shredding Estimates (SW-163) by Frank A. Smith, published by EPA's Office of Solid Waste Management Programs.

One final note of caution about interpreting plant cost information. The careful manager will not accept a capital cost figure or a net cost per ton figure without asking many questions about the configuration of the system. Typical questions include plant size, type of technology, plant reliability, redundancy, land cost, method of transportation of products, etc. (As an aid to comparing cost estimates of different systems, the reader is encouraged to use the <u>Accounting Format</u> (SW-157.6); which is part of this Implementation Guide series.) Furthermore, the careful manager will ask whether the reported costs are based on a preliminary process flow diagram, a final engineering design, or some other stage in the development of a system. Obviously, actual costs are the most reliable; estimates based on a preliminary process flow diagram are far less reliable as predictors of what actual costs will eventually be; and so on.

SECTION III

ENERGY RECOVERY SYSTEMS

Interest in recovering energy from municipal solid waste has increased sharply in recent years because of the receding availability and rising cost of conventional fuels, and the continuing problem of solid waste disposal. Roughly 70 to 80 percent of urban waste is combustible; reported heating values of raw urban wastes range from 3500 Btu/lb to 6500 Btu/lb and average about 4600 Btu/lb. Since the current rate of generation of municipal solid waste is approximately 3.5 pounds per person per day, each person in the community discards the energy equivalent to 1.5 pounds of coal each day. As a result, solid waste is now being regarded as an energy resource.

The objective of energy recovery systems is to utilize the heat of combustion (the energy) contained in the waste while providing a means of reducing the volume of solid waste to be disposed.

This section discusses the following alternative means of recovering energy from municipal solid waste: the direct generation of steam in waterwall furnaces; preparation of solid refuse derived fuels; pyrolysis to produce steam or gaseous, and liquid fuels; biological gasification systems; and generation of electricity in a turbine with gases from burning waste. For each of the alternatives there is a brief process description, a review of the current status of the process, a calculation of the amount of energy recovered, and a discussion of any special considerations or product characteristics.

Energy Balances

Energy balances were calculated from data available in the literature and from vendor contacts. The definition of thermodynamic efficiency is compatible with the one used in the utility industry: the ratio of energy produced (exported) to raw energy input. Similar to utility practice, electrical energy and auxiliary fuel consumption has been subtracted from the total energy produced to arrive at the net marketable energy produced. Also, these input energy sources have been close-looped within the process, that is, it has been assumed that all external energies were produced within the system. Thus, for example, for each process the amount of fuel produced which would be needed to produce the electricity used in running the process is subtracted. The amount of fuel needed to produce a unit of electrical energy varies for each system because each of the fuel products has a different conversion efficiency. By doing so, the reported thermodynamic efficiency reflects true energy yield from a unit of solid waste.

Three efficiency values are reported. Fuel efficiency (F) indicates the percentage of energy in the solid waste contained in the fuel product after accounting for in-plant energy consumption. This fuel is then assumed to be used in a boiler to produce steam. The efficiency of the boiler (B) is multiplied by fuel efficiency to yield total system efficiency (S) for a process converting solid waste into steam. Thus:

- F is the parameter which determines the amount of fuel produced by various processes.
- B specifies the fraction of the fuel which can be converted into useful work (here assumed to be steam). The fuel purchaser uses this measure to evaluate the relative value of equivalent amounts of alternative fuels.
- S indicates the fraction of the input waste which is converted into a usable end product (steam). This parameter enables different types of energy products to be compared on an equivalent basis.

For the sake of simplicity, the incoming municipal solid waste has been assumed to have a composition as shown in Table 3 and a higher heating value of 5000 Btu per pound. Table 4 presents a summary of the energy efficiencies for the various processes.

Waterwall Combustion Systems - Unprocessed Waste

Traditionally, the generation of steam from raw refuse has been accomplished by connecting waste heat boilers to refractory-lined, stoker-fired incinerators. However, increasingly stringent air pollution standards created a need for a more effective combustion unit--the waterwall furnace. This type of furnace has virtually replaced the use of refractory-lined furnaces because these units (1) are easier and cheaper to maintain, (2) are smaller and less costly to build and (3) are more efficient in recovering the energy available in the solid waste.

Although this technology was developed more than 50 years ago for use with low grade coal and other types of waste fuels, it has only been used for municipal solid waste for about 20 years. However, in Europe and Japan its acceptance has been rapid and widespread and several hundred units have been built in sizes ranging from 60 to 2600 tons per day. In the United States and Canada 10 plants have been built, all since 1967.

Steam is produced at a rate of from one to three pounds per pound of solid waste, depending on design and operating conditions, and the heat value of the solid waste. The steam can be used directly

TABLE 4
COMPARISON OF ENERGY RECOVERY EFFICIENCIES FOR VARIOUS SOLID WASTE ENERGY RECOVERY PROCESSES

Process	Net Fuel Produced	Total Amount Available as Steam
	(Expressed as percent of heat value of incoming solid waste)	
Water Wall Combustion	—	59
Fluff RDF	70	49
Dust RDF	80	63
Wet RDF	76	48
Purox Gasifier	64	58
Monsanto Gasifier	78	42
Torrax Gasifier	84	58
Oxy Pyrolysis	26	23
Biological Gasification*		
With use of residue	29	42
Without use of residue	16	14
Brayton Cycle/combined cycle Waste Fired Gas Turbine	19 plus 12 directly as electricity	

*Includes energy recovered from sewage sludge.

in turbines to drive the major items of equipment in the plant, or it can be used in a turbo-generator to produce electricity for in-plant use. There is sufficient steam produced, however, that most of it is available for off-site use, either as steam or as electricity. If this excess steam cannot be sold to a nearby industry or utility or used in other municipal facilities, then it must be condensed and cooled before it can be recirculated to the furnace.

Process Description. Municipal solid waste is deposited on a tipping floor or in a large storage pit from which it is transferred to the furnace feed hopper (Figure 1). From the feed hopper, the waste is fed onto mechanical grates where it burns as it moves continuously through the furnace. Noncombustible material falls off the end of the grate where it is quenched with water and then conveyed to trucks or a temporary storage pit. Ferrous metal is routinely recovered from the residue and in Europe the ash is often used as a road building material.

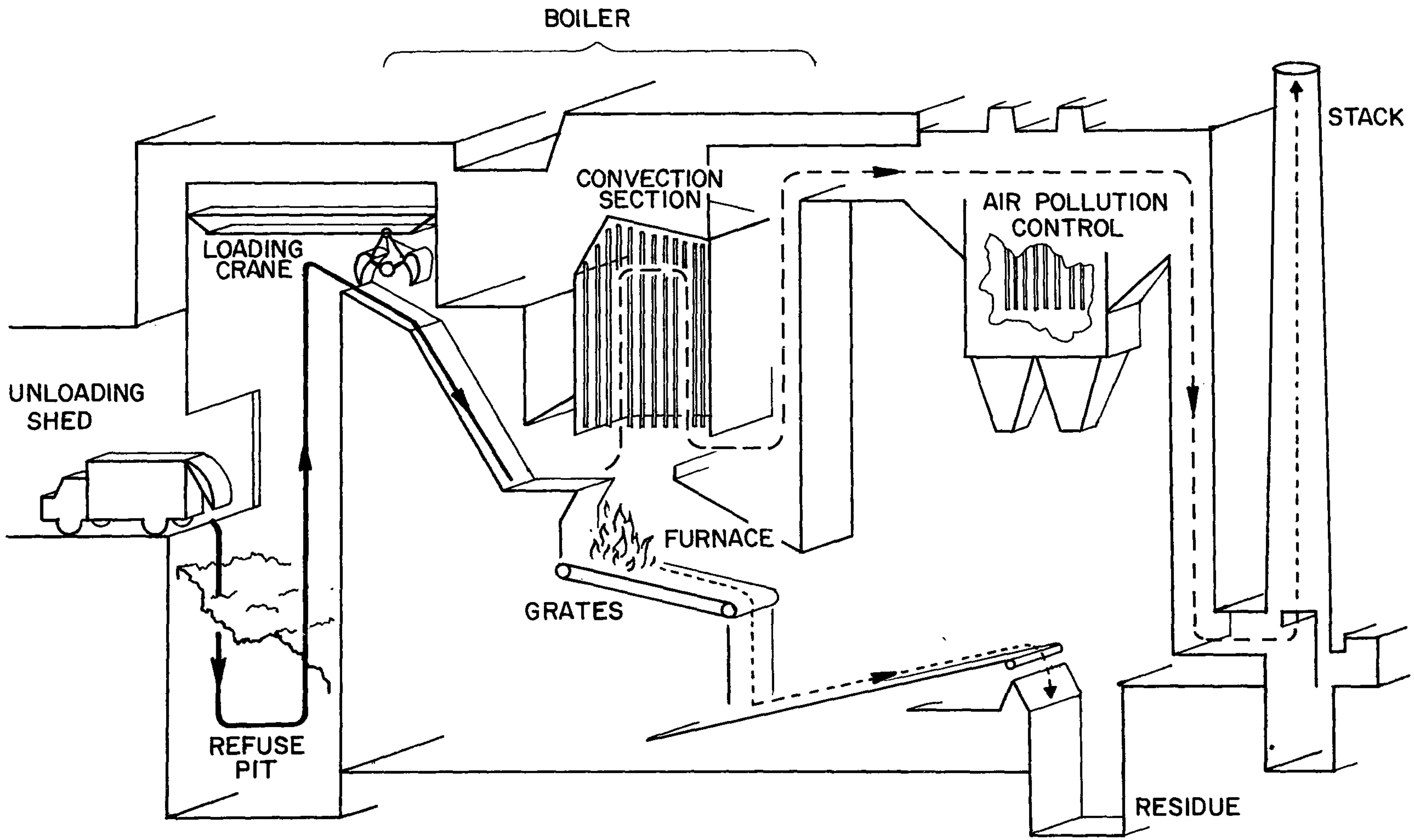

Figure 1. Typical Waterwall Furnace for Unprocessed Solid Waste

Waterwall furnaces are enclosed by closely spaced water filled tubes. Water circulating through the tubes recovers heat radiated from the burning waste. Integrally constructed (attached) heat recovery boilers generate steam while reducing the temperature (and the volume) of the exhaust gases. The boilers consist of various zones or tube packages referred to as heaters, economizers, reheaters, etc. depending on the function of the particular zone. Marketable product (steam) is created while permitting the use of smaller gas cleaning equipment (gas volume is proportional to absolute temperature).

In the combustion process, oxygen (air) is required to burn the fuel and release heat. Air is introduced into the furnace beneath the grates (underfire air) to aid in combustion and help keep the grates cool. Air is also introduced above the fuel bed (overfire air) to promote mixing of the gases (turbulence) and to complete combustion in the furnace.

The combustion gases, after being cooled as they pass through the various boiler sections, are passed through air pollution control devices (generally electrostatic precipitators) and are then vented to the atmosphere through a stack.

Status. The use of waterwall furnaces for the recovery of steam from the combustion of solid waste has been practiced widely in Europe for over 20 years. Conditions that facilitated development of steam recovery facilities in Europe include the lack of availabile land for landfills, the relatively high costs of fossil fuels, and institutional factors (the responsibility for both refuse disposal and power generation are often in the hands of one governmental entity). More than 50 waterwall incinerators are operating in the Federal Republic of Germany alone.

Application of waterwall incinerator technology in the United States for the recovery of waste heat has been recently encouraged by the success of European experience. The first large-scale United States solid waste burning furnace utilizing waterwalls and recovering steam is at the U.S. Naval Station, Norfolk, Virginia. This 360 ton per day plant has operated successfully since 1967. The steam produced is used to satisfy the station's requirements for heating and cooling. Other facilities have been successfully operated for several years, but, for nontechnical reasons, steam has been sold only intermittently. These facilities are located in Chicago, Illinois; Braintree, Massachusetts; and Harrisburg, Pennsylvania.

In Nashville, Tennessee, a 720 ton per day facility has been in operation since 1974. Steam from this plant is distributed through a utility loop to several dozen large government and private buildings. During the summer the steam is used to operate a chiller so that cooled water can be distributed for air conditioning use. This plant has experienced severe design and operating problems. Failure to employ design features already proven in other plants, largely due to an attempt to cut costs, is the primary reason for the problems experienced.

Another new steam generating incinerator, which is located in Saugus, Massachusetts, sells superheated steam to an adjacent industrial user. The market was obtained before the plant was built. This plant, which began operating in 1976, was privately constructed as a profit-making venture. It is owned jointly by a combustion systems manufacturer and a waste disposal contractor.

The overall operating experience of waterwall combustion systems in the U.S. and Europe varies. There are examples of both good and bad operations. That is, some units have performed reliably, been economically acceptable, and sold steam or electricity to a user on a regular basis. This is particularly true of units in Europe installed within the past 5 to 8 years by reliable, experienced companies. Other facilities which have been either designed or operated poorly or which have not developed markets for their steam output have exhibited technical or economic problems.

Waterwall combustion systems or components are available from a variety of manufacturers. Wheelabrator-Frye (representing the Von Roll Company of Zurich) and Universal Oil Products (representing the Josef Martin Company of Munich) are marketing complete systems. Components (boilers and stokers) are available from Babcox and Wilcox, Combustion Engineering, Foster-Wheeler, Riley Stoker and Detroit Stoker.

Energy Balance. Figure 2 shows an energy balance for a waterwall furnace burning mixed municipal solid waste. In a well designed and operated unit, more than 97 percent of the combustible matter is consumed to liberate heat for steam generation. European design and operating practices indicate that approximately 62 percent of the energy in the refuse can be converted into steam. After accounting for the energy used to operate the waterwall furnace, 59 percent of the input energy is available for sale to a customer. This is among the highest energy efficiencies of any of the systems discussed in this report.

Recent design changes have been made by Wheelabrator-Frye in the plant they have installed in Saugus, Massachusetts, which may enable the waterwall furnace to operate at 70 percent excess air. If these changes resolve the severe corrosion problems encountered in previous attempts to operate at low excess air, then up to 67 percent energy recovery could be realized.

Residues produced from the combustion of refuse in waterwall incinerators represent approximately 10 percent by volume of the input waste and 25 to 35 percent of their original weight. Residues consist of ash, glass, ferrous and nonferrous metals, and unburned organic materials. Recovery techniques use the unit operations described in Section IV. Unrecovered residue must be buried in sanitary landfills to minimize leaching problems.

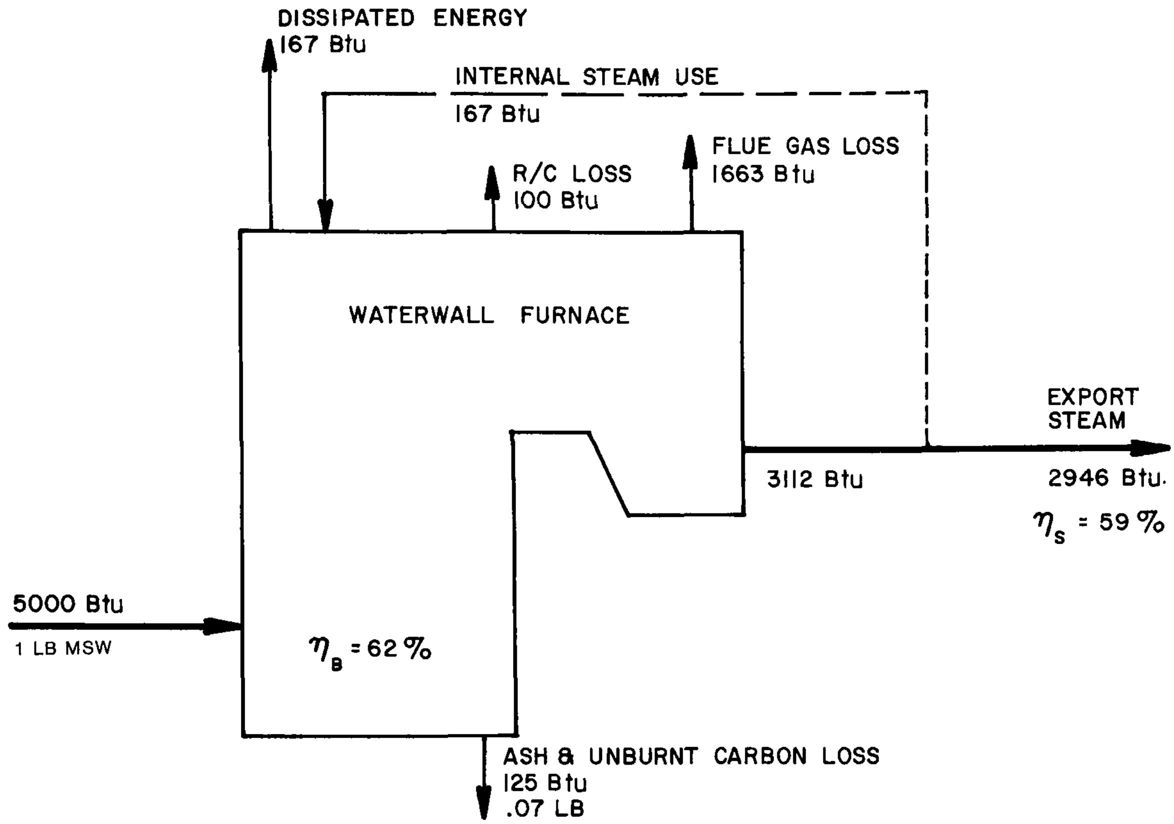

Figure 2. Waterwall Furnance Energy Balance*

*This balance was based upon data obtained from:

Stabenow, G., Performance of the New Chicago Northwest Incinerator, In Proceedings; 1972 National Incinerator Conference, New York, June 4-7, 1972. New York, American Society of Mechanical Engineers, p. 178-194.

Barniske, L., and W. Schenkel, Entwicklungsstand der Muellverbrennungsanlagen mit Waermeverwertung in der Bundesrepublik Deutschland, In Proceedings; Conversion of Refuse to Energy, Montreux, Switzerland, November 3-5, 1975. New York, Institute of Electrical and Electronics Engineers, p. 91-96.

Stephens, W. C., and R. I. Simon, An Economic and Financing Model for Implementing Solid Waste Management/Resource Recovery Projects, In Proceedings; Conversion of Refuse to Energy, Montreux, Switzerland, November 3-5, 1975. New York, Institute of Electrical and Electronics Engineers, p. 422-427.

Product Characteristics. Steam produced in incinerator facilities may be used in-house or for district heating and cooling, electricity generation, or to drive machinery in industrial processes. Steam customers are usually utilities or large industrial complexes. Steam temperatures range from 250 F to 1050 F, and pressures range from 150 pounds per square inch guage (psig) to 950 psig. As a rule, higher temperatures result in a more marketable steam product, but they also result in larger maintenance expenses. In steam distribution systems, steam temperatures are kept low to minimize heat losses. In electric power plants, however, high temperatures and pressures are desirable because they increase generating efficiency.

While steam is an almost universally usable source of energy it would not be economic to transport it more than 1 or 2 miles. In addition, the marketing of steam requires a suitable distribution or delivery system.

If the steam customer has no alternative or standby source of steam than he must be assured a reliable supply. Providing this reliability will probably require the installation of a standby fossil fuel fired boiler for use during emergencies. Of course, the value of the steam is enhanced by the increase in its reliability.

Waterwall Combustion Systems - Processed Waste

Waterwall furnaces are also being designed to burn coarsely shredded solid waste. The concept is that by first shredding the solid waste (and possibly removing the ferrous metal and other noncombustibles) a more homogeneous and thus more controllable fuel can be produced. The shredded waste is fed into the furnace by spreader stokers which propel the waste across the combustion chamber, where it then lands on a traveling grate. This type of firing is often referred to as semi-suspension firing because the waste is ignited while it is falling through the chamber but combustion is completed while it rests on the grate.

One such plant is currently in use in Hamilton, Ontario on municipal solid waste, and several others are in use for burning industrial wastes. Similar plants have been announced for Akron, Ohio (construction is expected to begin in 1976) and proposed for Niagra Falls, New York. Also, the Black Clawson Company has been contracted by the Town of Hempstead, New York to build, own and operate a semi-suspension waterwall incinerator that will burn the wet-pulped fuel produced by their patented wet pulping process. A similar plant is expected to be built in Dade County, Florida and a 150 ton per day demonstration plant is in operation in Tokyo.

In addition to producing a more attractive fuel for the incinerator, shredding enables recoverable materials which would otherwise be consumed or degraded in the burning process to be extracted prior to combustion.

The cost of shredding the waste must be balanced against the benefits of a more uniform fuel and "front-end" materials separation. Also, there is less experience with these semi-suspension systems than with burning unprocessed waste on a grate.

Solid Refuse Derived Fuel Systems

Mixed municipal solid waste can be processed to produce a supplementary fuel for fossil-fuel fired steam generators. The waste fuel is commonly called refuse-derived fuel (RDF). The fuel can supplement coal (and possibly oil), and has a heating value of about one half that of coal.

In this approach a system consists of a processing plant where the solid waste is shredded and classified, and a separate facility (market) where the RDF is burned. Utility or industrial steam generators provide a potential market for the RDF. These steam generators must be proximate to the source of solid waste and have adequate capacity, load factor, and ash handling systems. An attractive feature of this system is that the capital, operating and maintenance costs of the steam generation and auxiliary equipment are already being borne by the user of the RDF. This can be particularly significant in terms of capital costs. However, the cost of modifying an existing generator or designing a new generator to fire RDF, as well as the incremental costs of operation and maintenance attributable to firing the RDF will be passed back to the waste processing system, usually by reducing the price paid for the RDF.

Users could be expected to pay the same for RDF as they pay for the primary fossil fuel, on a fuel value basis. Of course all costs and savings associated with handling the RDF would be deducted to determine the net value.

Because the steam generator is designed to fire fossil fuel primarily, the RDF must have the physical and combustion properties necessary to make it compatible with the specific boiler-furnace firing and ash handling system being considered.

Consequently, several types of RDF are being offered to potential users: fluff RDF, densified RDF, and dust RDF.

Fluff RDF - Dry Processing Systems

Fluff RDF is waste that has been processed so that it will burn efficiently in suspension as it falls down through the fire-ball (center of turbulent flame patterns) of a boiler-furnace. It can be fired into the large utility-class boilers (greater than 500 million Btu per hour input or 50 megawatts of power output) including both suspension fired and cyclone fired boilers, and in certain stoker and spreader-stoker fired boilers.

Fluff RDF can be defined for purposes of this discussion as RDF with a particle size of from 1/4 inch to 2 inches (but generally about 1 inch) and with most of the heavy, dense materials, both organic and inorganic, removed.

The particle size and the degree to which the heavy, dense materials are removed depends upon the specific characteristics of the boiler-furnace that will fire the RDF. For example, very large utility boilers may be able to efficiently burn RDF with a relatively large particle size and containing some of the wood, rubber, and plastics. This is because larger furnaces have more turbulent fire-balls and the RDF particles are suspended in the furnaces and subjected to the 2200 to 2600 degree temperatures longer.

Because stoker fired boilers have relatively small furnaces, the RDF has very little time to burn as it falls through the furnace. Instead, grates at the bottom of the furnace hold the burning particles until they are completely combusted.

Process Description. The RDF dry processing concept was originally demonstrated at St. Louis, Missouri where solid waste was passed through a single shredder to reduce the particle size to 1-1/2 inches. The shredded material was then injected into an air classifier where a vertical column of turbulent air separated the light RDF from the inorganics and the heavy, dense organics that will not completely burn in suspension. About 80 to 85 percent of the shredded waste was separated as RDF.

The RDF was fired in two Union Electric Company 125 megawatt pulverized coal-fired boilers at rates ranging from 5 to 27 percent on a power output basis.

A typical RDF system may use primary shredding to reduce the particle size to four to eight inches, followed by an air classifier that separates from 50 to 85 percent of the shredded material as RDF (Figure 3). To increase its heat value and reduce its abrasiveness during pneumatic firing, the shredded material is then passed over a screen or trommel to remove glass fines. After screening, the RDF is passed through a secondary shredder to reduce the particle size to a range of from 1/4 inch to 2 inches, depending on the requirements of the specific boiler being considered. The RDF is then stored, transported, and fired, as required.

Status. Based on the general success of the St. Louis demonstration project, the fluff RDF approach is being implemented in several cities.

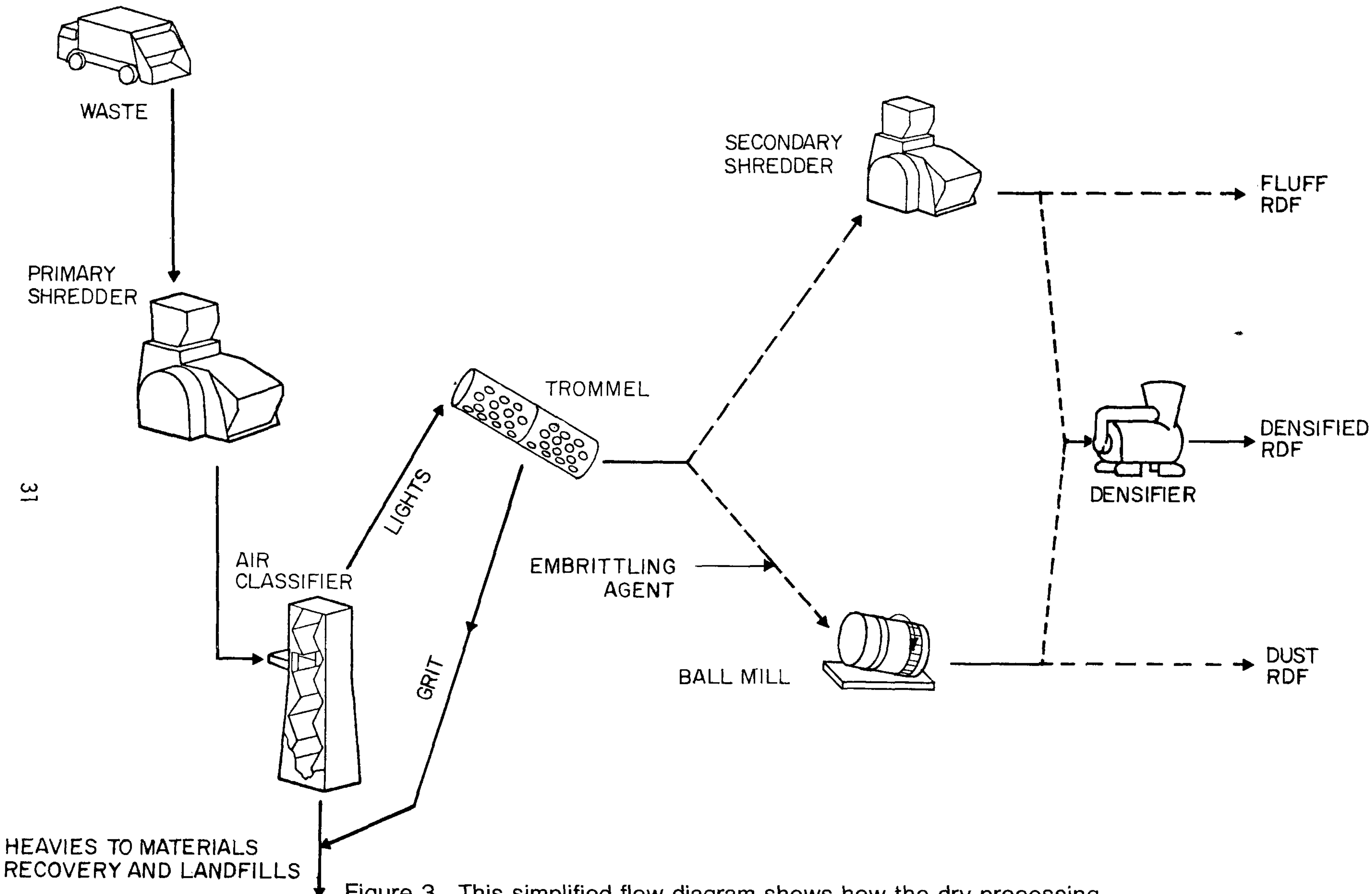

Figure 3. This simplified flow diagram shows how the dry processing approach (no water slurry) can be used to produce fluff, densified, or dust RDF.

Consulting engineers are recommending implementation of the concept where feasible. In addition, about ten companies are marketing systems that they will design and construct for a fixed price.

One additional plant is already in operation in Ames, Iowa, and Plants in Milwaukee and Chicago, are scheduled for completion in 1976. However, the experience with RDF technology is limited. Though a process of shredding and air classification can produce a sized, mostly organic fuel, the process is far from optimized. Furthermore, burning of this fuel as a supplement to coal is still in its infancy. Thus, willing buyers are not readily available.

Design questions that remain to be answered and some comments on RDF plant considerations follow:

- Shredding. Is two stage shredding (primary followed by secondary) actually more cost effective than a single stage? What is the most cost effective hammer configuration and hammer retipping material? What is the optimum final RDF particle size for each boiler firing system?

- Air Classification. Which configuration (design) is most efficient? What is the optimum degree of removal of non-burnables for each boiler firing system? Where should the air classifier be located in the waste processing system--between the shredders, after secondary shredding, before or after screening?

- Screening. Is screening cost effective? What kind of screen is most cost effective? Where should the screen be located--before primary shredding, between shredders, etc.?

- Storage. Fluff RDF is a very difficult material to handle--it bridges easily (hangs up in hoppers), has a negative angle of repose (in a bin, the top of a pile of RDF will not fall when the RDF directly underneath it has been removed), it does not flow easily, and it binds like paper-mache' after several days of storage and when wet. The best way to handle RDF would be to keep it in motion at all times. However, this is not practical, so when storage is required, it should be stored in a bin in which the unloading device is able to retrieve the RDF from every point on the bottom on the bin. In addition, to avoid bridging, the sides of the bin must flare outward toward the bottom.

- Firing. Erosion of the elbows (curves) of the pneumatic firing system can become a major maintenance problem unless replaceable elbows and an abrasion resistant material are used at these high wear points. Which abrasion resistant material is most cost effective? Another consideration is the optimum elevation of the RDF firing nozzles to enhance RDF combustion but to minimize ash carryover in the form of particulate stack emissions.

- Stack Emissions. Based on evaluations at St. Louis, sulphur oxides, nitrogen oxides, mercury vapor, and chloride emissions are not significantly changed when RDF is fired with coal at rates of from 5 to 27 percent on a power output basis. In addition, particulate emissions did not significantly increase at all RDF firing rates as long as the boiler loading was at or below its design capacity of 125 mw. However there was an increase in emissions when the boiler was run at 140 mw using RDF and coal, as opposed to coal only. Unfortunately, this boiler is routinely operated at this higher load.

  These higher emissions must have resulted from a decrease in electrostatic precipitator collection efficiency because the uncontrolled emissions (inlet to the precipitator) did not increase significantly, even at the higher boiler loading. It is felt that precipitator efficiency decreased because the volumetric gas flow rate increases when RDF is used to supplement the coal. This increase in gas flow rate is due, in part, to the fact that the moisture content of the RDF (on a heat value basis) is six times that of coal.

  If this decrease in precipitator efficiency results in emissions that exceed standards, a number of steps could be taken to correct the problem: (1) RDF could be fired only at lower boiler loads so that the combined firing exhaust gases do not exceed the precipitator's design flow rate; (2) modifications could be made to the precipitator to increase its collection efficiency; or (3) the RDF could be dried to reduce the quantity of exhaust gases. Each situation must be investigated individually to determine the most cost effective approach.

- Bottom Ash. If an accumulation of unburned RDF organics and ash would overload the bottom ash handling facilities, the accumulation could be logically reduced by taking one of several steps to improve the combustion of the RDF: (1) reduce the quantity of heavy dense materials recovered with the RDF by adjusting the air flow rate of the air classifier during waste processing and thus recovering a lower percentage of waste as RDF; (2) increase the surface area of the RDF particles by reducing the RDF particle size; or (3) increase the retention time of the RDF in the boiler by raising the elevation of the RDF firing nozzels.

- Boiler Operation. At St. Louis the Union Electric Company has indicated that they have not experienced any problems with maintaining power levels, slagging, erosion within the boiler, fouling, or corrosion.

Energy Balance. An energy balance has been developed for a typical fluff RDF system (See Figure 4). It is based on a system having two stage shredding; a trommel screen; air classification; and truck transport to a user 15 miles away. Sixty-two percent of the raw waste is assumed recovered as RDF.

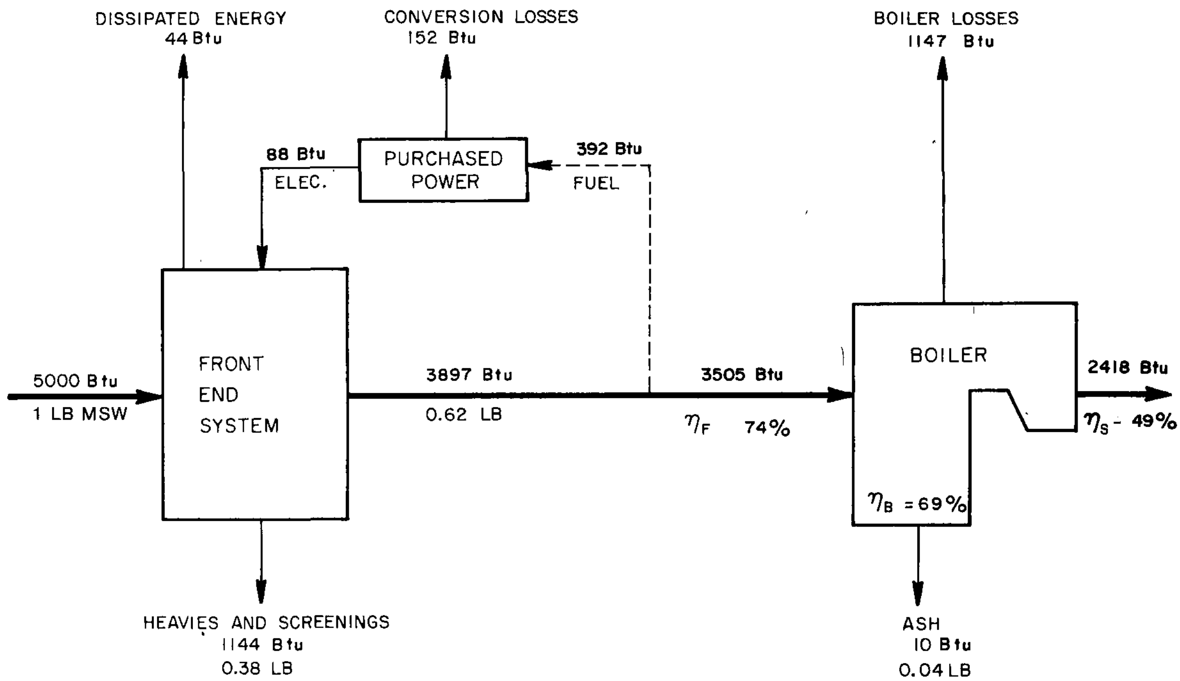

Figure 4. Fluff RDF Energy Balance*

*This balance was based upon data obtained from:

Shannon, L. J., M. P. Schrag, F. I. Honea, and D. Bendersky, St. Louis/Union Electric Refuse Firing Demonstration Air Pollution Test Report, August 1974. Washington, Office of Research and Development, U. S. Environmental Protection Agency. 108 p.

Proceedings; National Center for Resource Recovery, Inc., Seminar, U. S. Environmental Protection Agency, Municipal Environmental Research Laboratory, Cincinnati, Ohio, December 3-4, 1975. Session V, "Unit Processes for Materials Recovery."

Rigo, H. G., Technical Evaluation of the Feasibility of Burning Eco-Fuel at Philadelphia Naval Shipyard, January 1974. Construction Engineering Research Laboratory, Letter Report E-25. 54 p.

Product Characteristics. RDF is clearly an inferior fuel to coal in practically every parameter except sulfur content (Table 5). However, when fired at low rates--10 to 20 percent of power output--boiler operation and maintenance problems are not expected to increase measurably. However, there is only very limited experience to verify this.

TABLE 5.
COMPARISON OF FLUFF RDF AND COAL

Property	Per Pound Fluff RDF	Per Pound Coal	Per Million Btu Fluff RDF	Per Million Btu Coal
Heating Value (Btu/lb)	5,000 – 6,500	11,500 – 14,300	10^6	10^6
Bulk Density (Lb/Ft^3)	5 – 9	42		
Moisture	20 – 30%	3 – 12%	31 – 60 Lb	2 – 10 Lb
Average Size (In.)	1/4 – 2			
	%	%	Lb	Lb
Ash	19.	3 – 11	29 – 38	2 – 10
Carbon	28.	6.2 – 81	43 – 56	43 – 70
Hydrogen	6.9	4.3 – 6.0	11 – 14	3 – 5
Nitrogen	0.6	1.0 – 1.7	.9 – 1.2	.7 – 1.5
Oxygen	45.	4.8 – 17.4	64 – 90	15
Sulfur	0.2	0.6 – 4.3	2.5 – .35	.4 – 3.7

Fluff RDF - Wet Processing Systems

Fluff RDF can also be produced by a wet processing system where the waste is converted into a slurry.

Process Description. Wet processing to produce RDF involves size reduction, removal of non-combustibles, and dewatering steps. Solid waste is conveyed to a wet pulping machine (hydropulper) where it is mixed with water (see Figure 5). The waste material is reduced to an aqueous slurry by the action of high speed cutting blades located at the bottom of the pulper. Large items, such as tin cans, rocks and other inorganics, are ejected through an opening in the side of the hydropulper. Ferrous metals can be recovered from this material.

The remaining slurry is pumped to a liquid cyclone where heavier materials such as glass, nonferrous metals, thick plastics, wood, etc., are removed by centrifugal action. The heavy fraction can be processed to recover aluminum and glass. The lighter, mostly paper fraction is then dewatered to the desired moisture content and used as RDF.

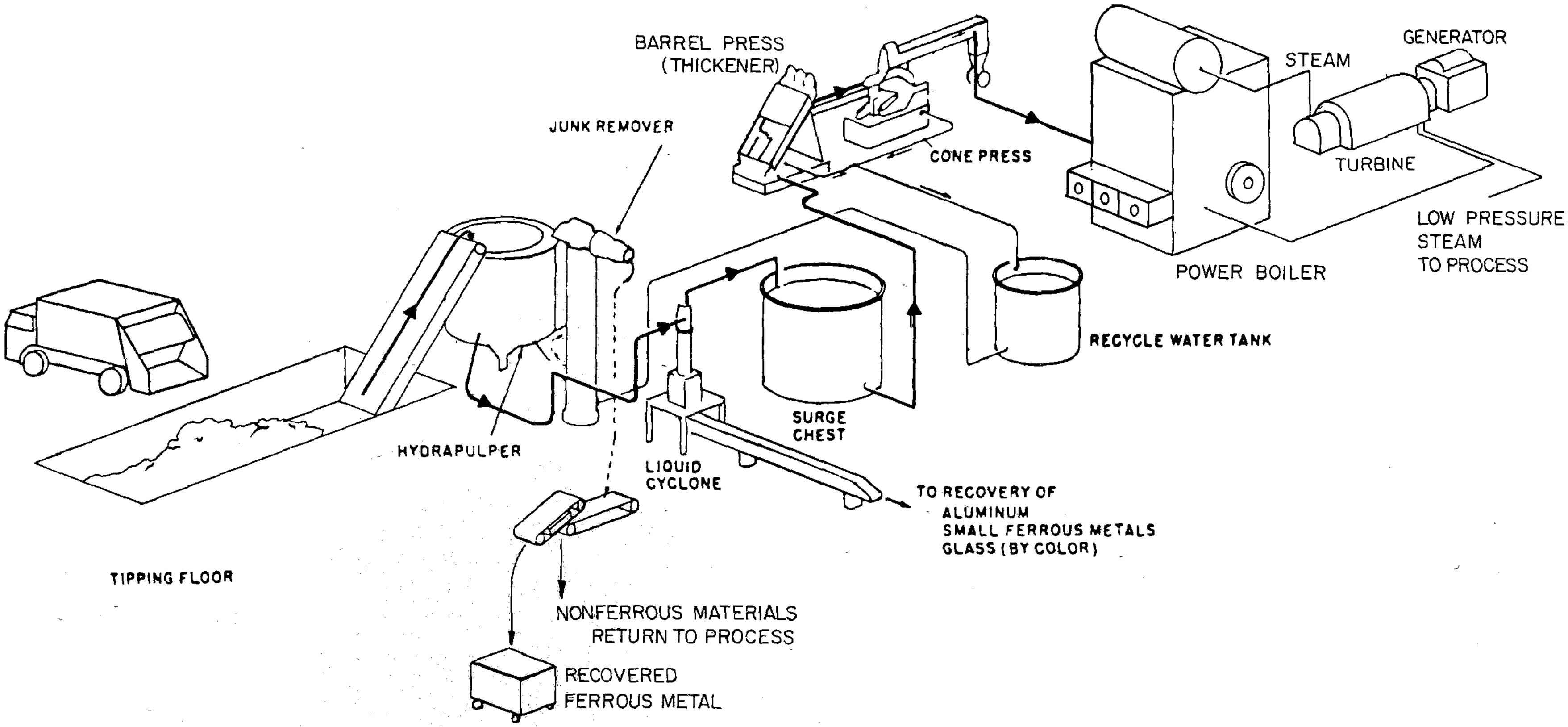

Figure 5. Wet Process Energy Recovery System

Although dewatering the slurry is expensive, the wet pulping approach has several advantages over the dry processing approach. Perhaps the most important is the ability to easily handle sewage sludges. By blending sewage sludge with the pulped slurry, the resulting mixture can be simultaneously dewatered for use as fuel. Of course, the particular sludge being considered must be investigated for materials (like heavy metals) that may cause air pollution problems during combustion. However, dewatering the slurry is expensive, especially if a 20 or 30 percent moisture content is required as may be the case for use as supplementary fuel in some steam generators. Consequently, the wet processing approach to producing a supplementary fuel will probably not be as popular as dry processing. Rather, the RDF produced by most wet processing systems will probably have a 50 percent moisture content and be used as the primary fuel in steam generators designed specifically to handle this material (see discussion on Waterwall Combustion Systems - Processed Waste).

Nevertheless, at least two communities Memphis, Tenessee, and Norwalk, Connecticut have seriously studied the feasibility of wet processing to produce RDF for use as supplementary fuel in existing coal-fired steam generators.

Other advantages include reduced likelihood of explosions and fires during size reduction, fewer dust control problems, and greater flexibility of handling and shipping.

Status. The basic RDF wet processing steps have been demonstrated in a 150 ton per day EPA demonstration plant located in Franklin, Ohio. The plant has been consistently processing about 35 tons per day of waste since 1971. The Franklin plant dewaters a pulped slurry of nonrecoverable fiber to a moisture content of about 50 percent before burning it in a fluidized bed incinerator without heat recovery. Nonetheless, the RDF preparation components have been successfully demonstrated.

Energy Balance. An energy balance has been developed for a typical wet processing system (Figure 6). Comparing this to the energy balance for fluff RDF it can be seen that although a greater percent of the combustible material is recovered as fuel, its lower combustion efficiency results in a lower net yield of steam.

Product Characteristics. Wet process RDF is homogeneous (uniform composition and particle size) and has an as-received heating value of approximately 3500 Btu/lb, at a moisture content of 50 percent, and an ash content of approximately 20 percent. The high moisture content of the fuel product precludes the use of this product in many existing boilers (however, it can be used as a primary fuel in specially designed furnaces). Many industrial and utility boiler operators are requesting that the material be between 15 and 20 percent moisture. At this moisture, the RDF can be suspension or spreader stoker fired or it can be densified (briquetting or pelletizing) for use in

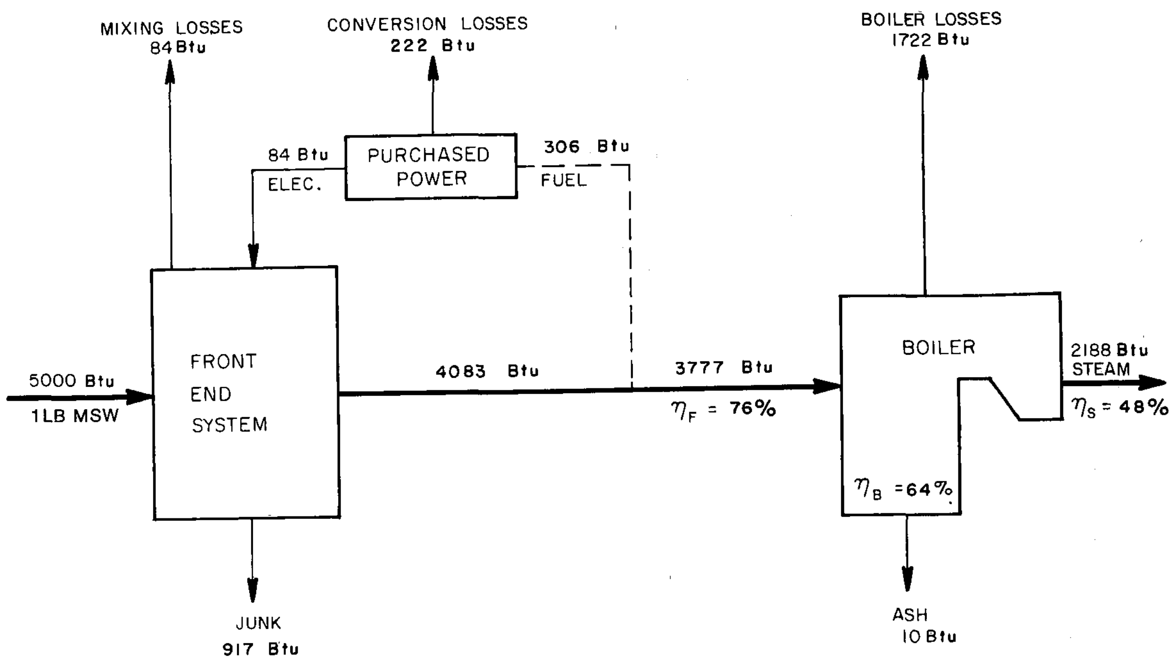

Figure 6. Wet Process RDF Energy Balance *

*This balance was based upon data obtained from:

Wittmann, T. J., et al, A Technical, Environmental and Economic Evaluation of the "Wet Processing System for the Recovery and Disposal of Municipal Solid Waste," Final Report SW-109c, U. S. Environmental Protection Agency, 1975. 217 p.

chain grate, underfed, or mechanical or pneumatic spreader stoker equipped industrial and utility boilers. Drying wet process RDF requires significant amounts of energy. A 10 percent reduction in moisture content consumes between 4 and 8 percent of the fuel, depending on the specific design of the dryers.

Dust RDF

A dust-like RDF has been developed by Combustion Equipment Associates as a high quality all-purpose fuel. According to the developer, it can be fired in suspension with coal and oil in most steam generators with adequate ash handling facilities. In addition, it may prove feasible to slurry the fuel with oil for firing in the oil-fired boilers, thus eliminating the need for separate firing lines.

Process Description. Solid waste is first shredded, air classified, and screened, the same initial steps used to produce fluff RDF (Figure 3). However, instead of using a secondary shredder to reduce the particle size further as in fluff RDF production systems, an embrittling agent is added to the coarse shredded material. This chemical hardens the cellulose fibers so that the paper and cardboard becomes friable and will shatter upon impact. The treated material is then run through a ball mill similar to those used by electric utilities to pulverize coal. The material is pulverized in the ball mill until it will pass a 100 mesh screen. The dust RDF product has a particle size of less than 0.15 millimmeter.

Status. According to company officials, a four ton per day pilot plant operated continuously from Spring 1974 to October 1975.

A 20 ton per hour facility is being constructed at East Bridgewater, Massachusetts. The fuel from this facility will be trucked 75 miles to be used as an auxiliary fuel in several oil-fired steam generators producing industrial process steam.

The dust RDF is to provide 60 percent of the heat input to the generators. Although the company is investigating the feasibility of slurrying the dust RDF with oil, the RDF and oil will not be premixed for this project.

Energy Balance. An energy balance has been developed for a typical dust RDF system (Figure 7). Eighty percent of the energy is recovered in the fuel fraction. Its excellent combustion characteristics make it a very efficient fuel so that when fired in a boiler the steam yield would be 63 percent of the energy value of the incoming solid waste. This would be the highest yield of any of the systems examined in this report.

Product Characterists. According to company officials, the dust RDF has a heating value of 6,900 Btu's per pound, and contains 10 percent ash and two percent moisture. Its bulk density is approximately 25 to 32 pounds per cubic foot. There are no known limits on shelf life. It is expected that the product can be handled and stored like a powder using conventional pulverized coal handling equipment.

Although dust RDF has superior combustion properties to fluff RDF, the production costs are likely to be greater than for fluff RDF. Also, special care in handling and storage is necessary to minimize the danger of explosions. The cost trade-off can be determined only through operating experience with these systems.

Densified RDF

Processes for densifying RDF are being investigated by a number of organizations. By densifying RDF, it is anticipated that some of the handling and storage problems of fluff RDF can be avoided, that stoker and spreader-stokers can more easily fire processed waste, and that it can be fired at higher rates than fluff RDF.

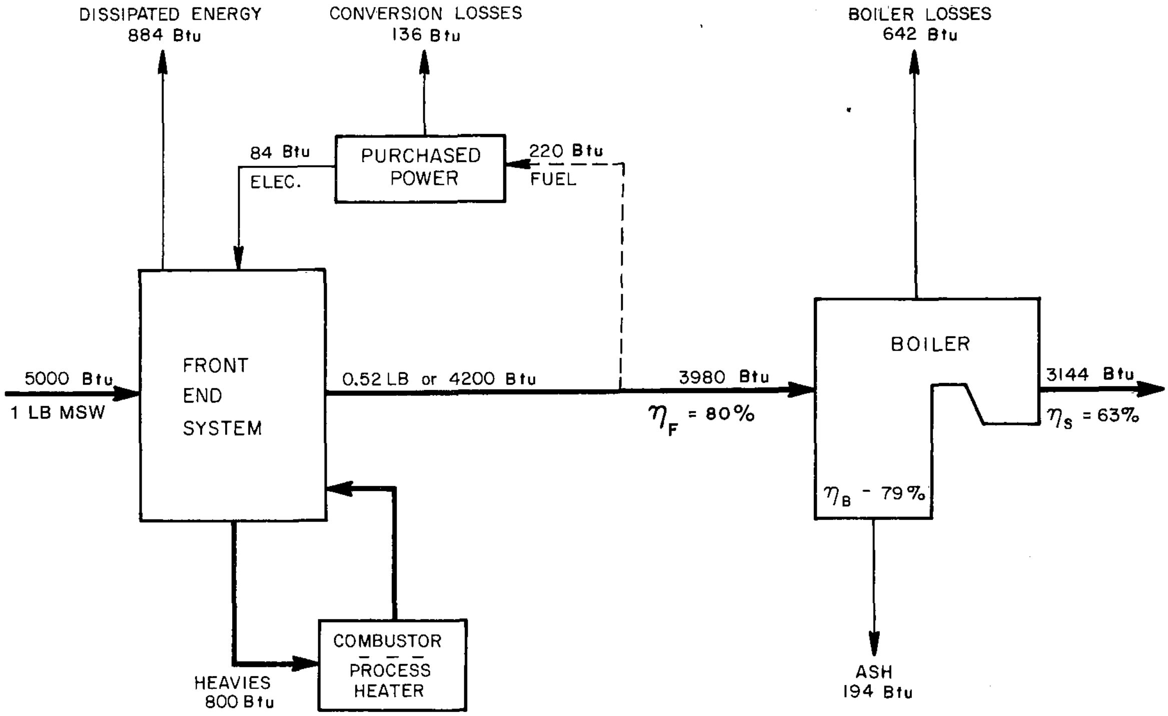

Figure 7. Dust RDF Balance*

*This balance was based upon data obtained from:

Beningson, R. M., K. J. Rogers, T. J. Lamb, and R. M. Nadkarni, Production of Eco-Fuel[R]-II from Municipal Solid Waste CEA/ADL Process, in Proceedings; Conversion of Refuse to Energy, Montreux, Switzerland, November 3-4, 1975. New York, Institute of Electrical and Electronics Engineers, p. 14-21.

Process Description. Densified RDF is produced by pelletizing, briquetting, or extruding fluff RDF. It is also anticipated that dust RDF can be densified by adding a chemical binder and processing in a briquetter.

Status. Densified RDF has been produced in small quantities at several pilot plants around the country. Several trial burns in stoker-fired steam generators have been encouraging. However, this concept has not yet been demonstrated on a commercial scale.

Several areas need to be investigated further:

1. Densifying Costs. What is the cost of densifying RDF? How rapidly do the dies used in the process need replacement? How much energy is required? What kinds of production rates can be achieved with conventional equipment?

2. Handling and Storage. Does the densified fuel hold together, or tend to break up with time or when handled? Are the materials handling properties improved relative to fluff RDF so that lower cost storage and handling facilities can be used? What is the optimum moisture content?

3. Firing. Can densified RDF be premixed with crushed coal for firing in stoker or spreader-stoker steam generators, thus avoiding the cost of a separate RDF firing system?

These questions are being addressed by a project recently initiated by the EPA.*

Product Characteristics. The densified RDF will have basically the same chemical properties of the fluff or dust RDF feedstock. But, the bulk density will be increased to about 35 to 42 pounds per cubic foot, which is similar to that of coal.

Pyrolysis Systems

Pyrolysis is the destructive distillation of the organic fraction of solid waste. It occurs when organic material is exposed to heat in the absence or near absence of oxygen. Pyrolysis differs from incineration in that it is endothermic (heat absorbing) rather than exothermic. Processes under development use heat from part of the waste to provide the heat absorbed during pyrolysis and recover the remaining heat in the form of steam or a gaseous or liquid fuel.

All processes reduce the solid waste to three forms: gases (primarily hydrogen, methane carbon monoxide and carbon dioxide), liquids (water, and organic chemicals such as acetic acid and methanol), and solids (a carbonaceous char). The form and characteristics of the fuel fraction varies for each of the different processes under development and is a function of the reaction time, temperature and pressure of the pyrolysis reactor, the particle size of the feed, and the presence of catalysts, and auxiliary fuels.

To maximize gas production, reactor temperatures are held in the range of 1400 F to 3000 F; for oil, temperature is on the order of 900 F. Pressures range from 1 to 70 atmospheres. Ideally, the reaction is allowed to take place in the absence of diluting gases so that the product is the volatile matter of the solid waste. If air is used in the reactor, the gases produced will be diluted by the nitrogen in the air (air is approximately 79 percent nitrogen and 21 percent oxygen). As a result, some processes have been developed

---

*"Preparation, Use and Cost of d-RDF as a Supplementary Fuel in Stoker Fired Boilers," Office of Research and Development, U.S. EPA.

which use oxygen, thus resulting in a higher heat content fuel gas. Other systems indirectly transfer the heat to the gasifier to minimize dilution of the product gas.

Heating solid waste releases gases and leaves a carbon residue called char. In some reactors, the residue reaches such high temperatures that the ash and other noncombustibles, such as cans and glass, melt to form a slag which can be removed from the reactor in a molten state and quenched to form a glassy aggregate.

Residues produced from pyrolysis are biologically inactive and may be safely disposed in sanitary landfills. Solid residues from the noncombustible portions of the refuse, such as glassy aggregate, may be used for construction and paving. If the char is not consumed in the process, it has a higher heating value of approximately 9000 BTU/lb. Its high ash content (50 percent), however, severely limits its usefulness. Clearly, failure to consume all the char in the process represents a loss in energy recovery.

This report describes the four pyrolysis systems which can be classified as "developmental." There are presently no commercially operational pyrolysis systems, and there are numerous other systems which can be considered "experimental." All four of the systems described have been previously operated on a small pilot scale and full size plants of 200 tons per day or larger have been or are being built. Two of the systems produce low BTU gas which is used "on-site" to produce steam. The third system produces a medium BTU gas which can be sold to a nearby industrial user or may be suitable as a chemical feedstock. The fourth system produces an oil-like liquid fuel which can be stored and transported for use "off-site" in large industrial or utility boilers.

Low BTU Gas - Monsanto Langard System

Process Description. The Monsanto Langard system employs a controlled air primary furnace chamber (pyrolysis) and immediate combustion of low heat value gases in an afterburner for recovery of heat (Figure 8). Waste is shredded, conveyed to a storage silo, and subsequently fed to a rotary kiln where it is pyrolyzed. Fuel oil is also burned in the kiln to provide some of the heat for the pyrolysis reaction. The burner is arranged to provide a countercurrent flow of gases and solids, thus exposing the waste to progressively higher temperatures as it passes through the kiln. The finished residue is exposed to the highest temperature 1000 C (1800 F) just before it is discharged from the kiln and quenched in a water-filled tank. The residuals are split into three fractions, glassy aggregate, ferrous and char. The glassy aggregate and ferrous materials are recovered for sale and the char is dewatered and landfilled.

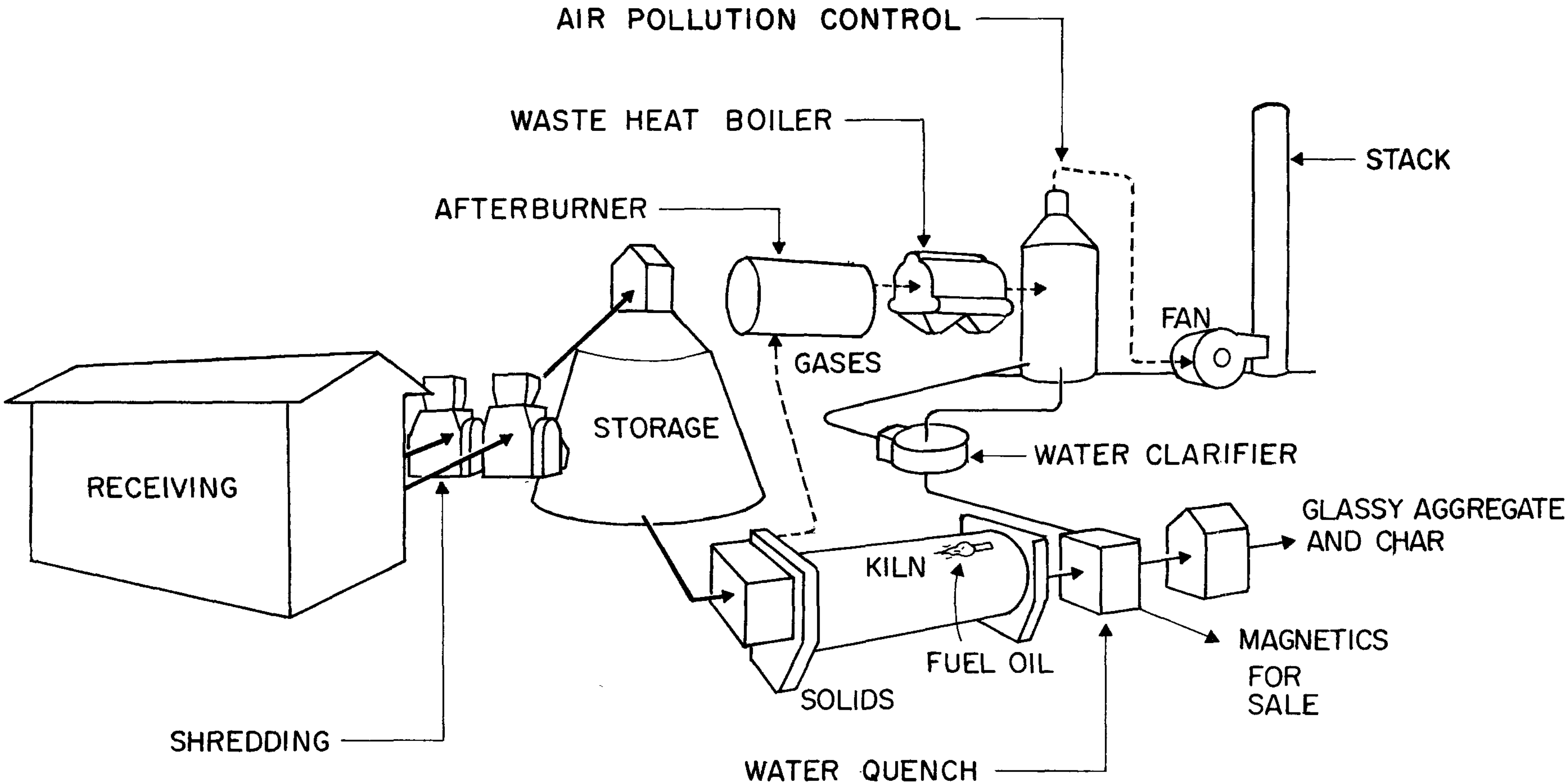

Figure 8. The Monsanto Landgard System produces a low Btu gas which is immediately burned on-site for the production of steam.

Gases resulting from the pyrolysis reaction have a high temperature (1200 F) and low heating value (120 BTU/cubic foot) making off-site transportation uneconomical; therefore; they are immediately mixed with air and burned in an afterburner to liberate the heat of combustion. The combusted gases then pass through waste heat boilers where steam is generated for distribution.

Product Characteristics. Steam from the Baltimore plant is produced at up to 200,000 lbs. per hour. Saturated steam at a temperature of about 400 F is delivered to the Baltimore Gas and Electric Company's existing downtown steam loop via a new mile long pipeline.

While this is the most economic arrangement for the Baltimore facility, other end uses for the gas produced in the kiln might also be possible. For instance, if a Landgard plant were built immediately adjacent to a large utility boiler, it might be feasible to direct the hot, combustible kiln off-gas directly into the utility's boiler, thus eliminating the need for a separate afterburner, waste heat boilers, and air pollution control equipment.

Status. A 1000 ton per day prototype plant has been built in Baltimore, Maryland. Construction of the plant was completed in February, 1975 under a turnkey contract with Monsanto. However, normal operation of the plant has not been possible because a number of process changes are needed in order to insure proper operation. Engineers from Monsanto and the City of Baltimore are now working on a series of medications in an effort to correct the problems plaquing the plant.

As originally built, exhaust gases are cleaned by means of a large spray tower. Initial tests of the spray tower showed that it could not clean the gases sufficiently to meet the required local and Federal ordinances. All efforts to modify plant operations to meet the standard have failed, and as a result it has been decided that additional air pollution control equipment must be added.

Energy Balance. The energy balance for the Languard system is shown in Figure 9. Here again it is assumed that the energy to produce the purchased electricity and contained in the purchased quench oil (7.2 gallons of No. 2 fuel oil per ton of solid waste) was provided by the system's energy product. Losses in the process include the energy remaining in the carbonaceous char and conversion losses experienced in the waste heat boiler. As a result of these losses and provisions for the system's input energy needs, 78 percent of the energy in the incoming waste is available in the combustible gas. This gas is then burned in an afterburner and the heat is recovered as steam in a "waste-heat" boiler. The burner-boiler combination has a heat recovery efficiency of 54 percent so the net recovery of energy in the form of steam is 42 percent of the energy available in the "as received" solid waste.

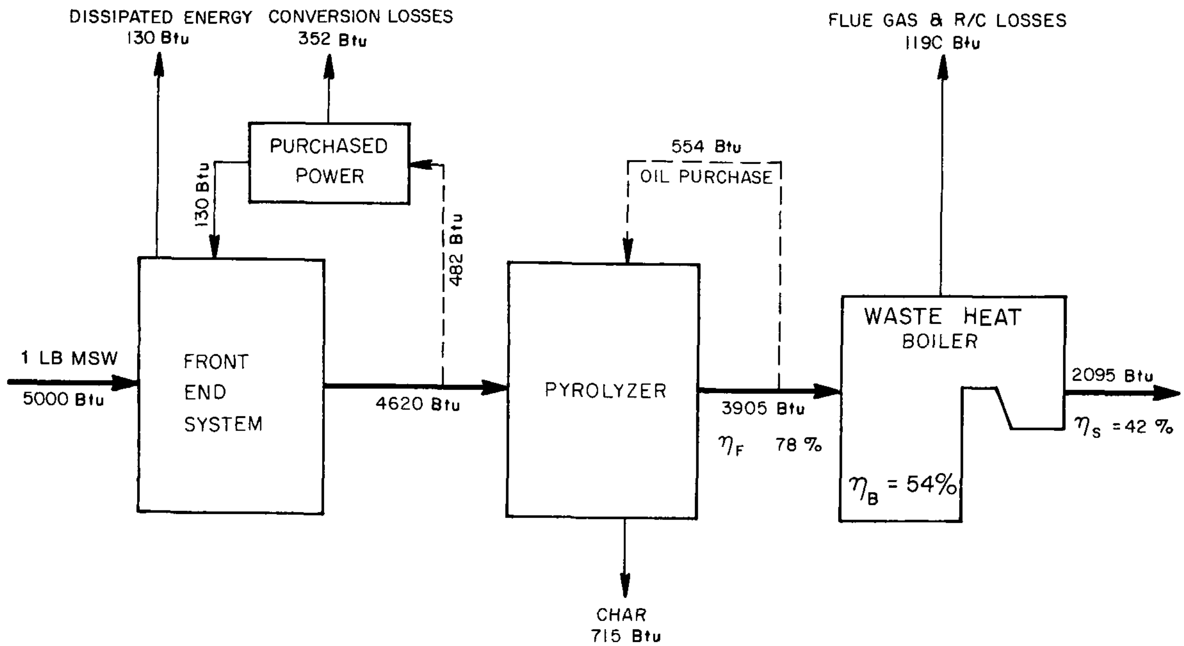

Figure 9. Monsanto Landgard Energy Balance *

*This balance was based upon data obtained from:

Sussman, D. B., Baltimore Demonstrates Gas Pyrolysis, Resource Recovery from Solid Waste, First Interim Report SW-75d.i, U. S. Environmental Protection Agency, 1975. p. 12-13.

Levy, S. J., San Diego County Demonstrates Pyrolysis of Solid Wastes to Recover Liquid Fuel, Metals, and Glass. Environmental Protection Publication SW-80d.2. Washington, U. S. Government Printing Office, 1975. 7 p.

Low BTU Gas - Andco Torrax System

Process Description. The principal components of the Torrax System are the gasifier, secondary combustion chamber, primary preheating regenerative towers, energy recovery/conversion system, and the gas cleaning system (Figure 10). The solid waste is charged as received from the solid waste pit, without prior preparation, into the gasifier. The gasifier is a vertical shaft furnace designed so that the descending refuse burden and the ascending high temperature gases become a counter-current heat exchanger. The uppermost portion of the descending solid waste serves as a plug to minimize the infiltration of ambient air. As the solid waste descends, three distinct process changes occur. The first is the drying where the moisture is driven off; the second is the pyrolyzing due to the heat transfer from the ascending, hot gases to the solid waste; and the third is combustion in the hearth where the carbonaceous char is oxidized to carbon dioxide, and melting of the inert fraction of the solid waste.

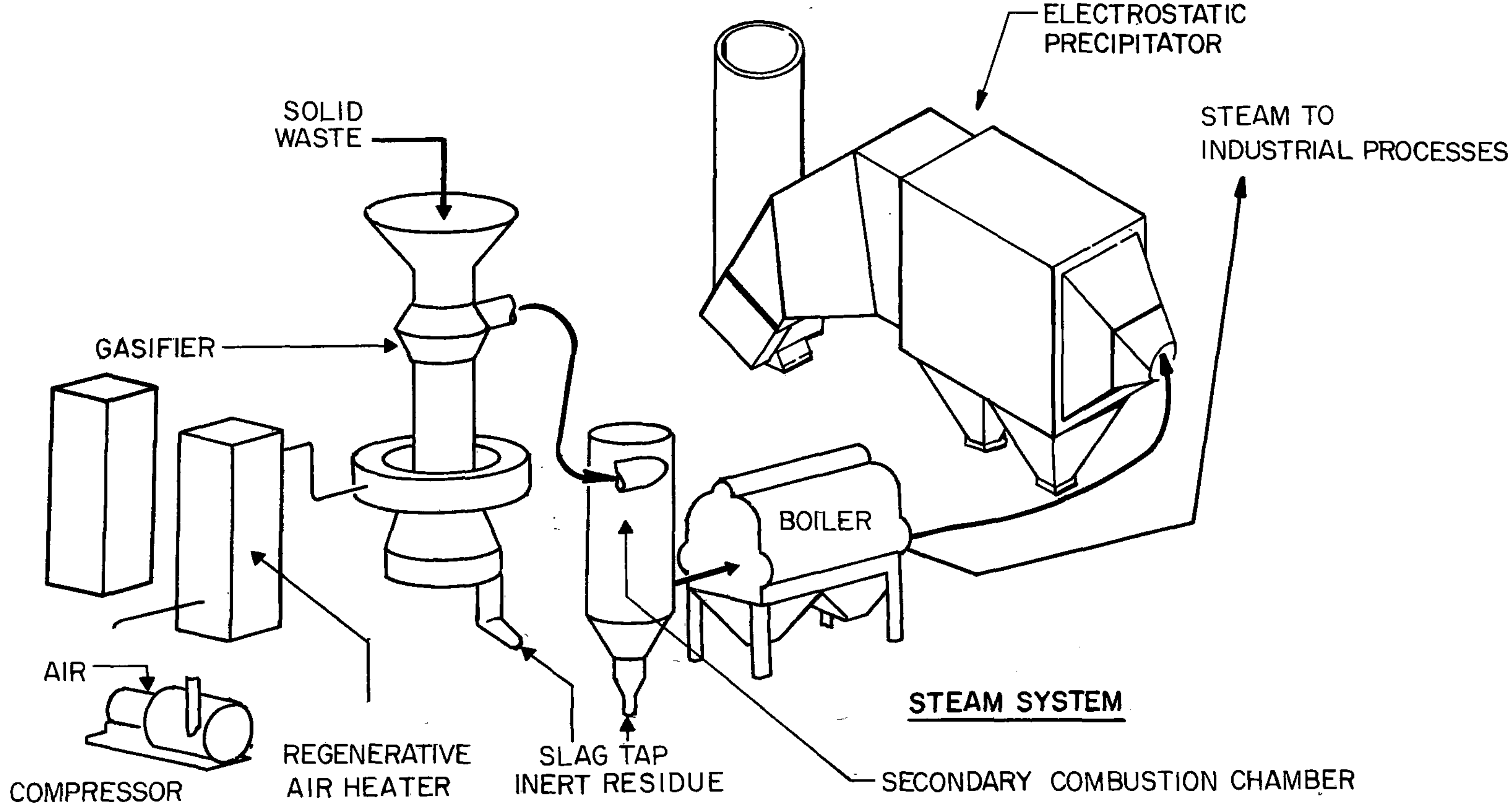

Figure 10. Torrax Slagging Pyrolysis System

The heat for pyrolyzing and drying the solid waste and for melting the inert fraction is produced by the combustion of the carbon char with 2000 F preheated air supplied to the hearth zone of the gasifier. The heat thus generated melts the inerts to form a molten slag, which is drained continuously through a sealed tap into a water quench tank to produce a black, sterile, granulated residue.

As with the Monsanto system, the BTU value of the gas is too low to make off-site transportation of the gas economic. Instead the gases are injected into an after-burner or secondary combustion chamber where they are burned to completion. The heat which is thus released is then directed to a waste heat boiler where it is recovered as steam.

A portion of the hot waste gas from the secondary combustion chamber (about 15 percent) is directed through regenerative towers where its sensible heat is recovered and used for preheating the process air supplied to the gasifier hearth. These regenerative towers, successfully used for many years in the steel industry, but as yet untested for this system, are two refractory lined vessels containing a high heat capacity refractory checkerwork material. Hot products of combustion from the secondary combustion chamber and ambient process air are passed through the towers on a cyclical basis for preheating the 1000 C combustion air. The remainder of the secondary combustion chamber existing flow is supplied to a waste heat boiler designed for inlet gas temperatures of 2100 F to 3000 F.

The cooled waste gases from the regenerative towers are combined with the exiting flow from the waste heat boiler and are ducted to a hot gas electrostatic precipitator of conventional design.

<u>Status</u>. The principles of the Torrax process were originally proven on a 75 ton per day pilot plant operated intermittently since 1971. This plant, located in Erie County, New York has been used to process municipal solid waste and solid waste/sewage sludge. Test runs with controlled percentages of waste oil, tires, and PVC plastics were also run. The pilot plant differs significantly from the above described system in that the hot blast combustion air is heated using natural-gas-fired air-to-air heat exchanger instead of the regenerative towers.

The Carborundum Corporation, which was involved in the original development of the Torrax process, has recently turned its marketing rights in the U.S. over to Andco.

A 200 ton per day prototype plant is undergoing startup in Luxemburg and at least two other plants are also scheduled to be built in Europe in the near future.

Energy Balance. An energy balance for the system is shown in Figure 11. About 15 percent of the energy value in the solid waste is utilized to preheat the combustion air or replace the energy needed to supply the purchased electricity used in the plant. The heat ultimately delivered to the waste heat boiler is converted to steam at an efficiency of 69 percent leaving a net system output (as steam) of 58 percent of the original energy in the solid waste.

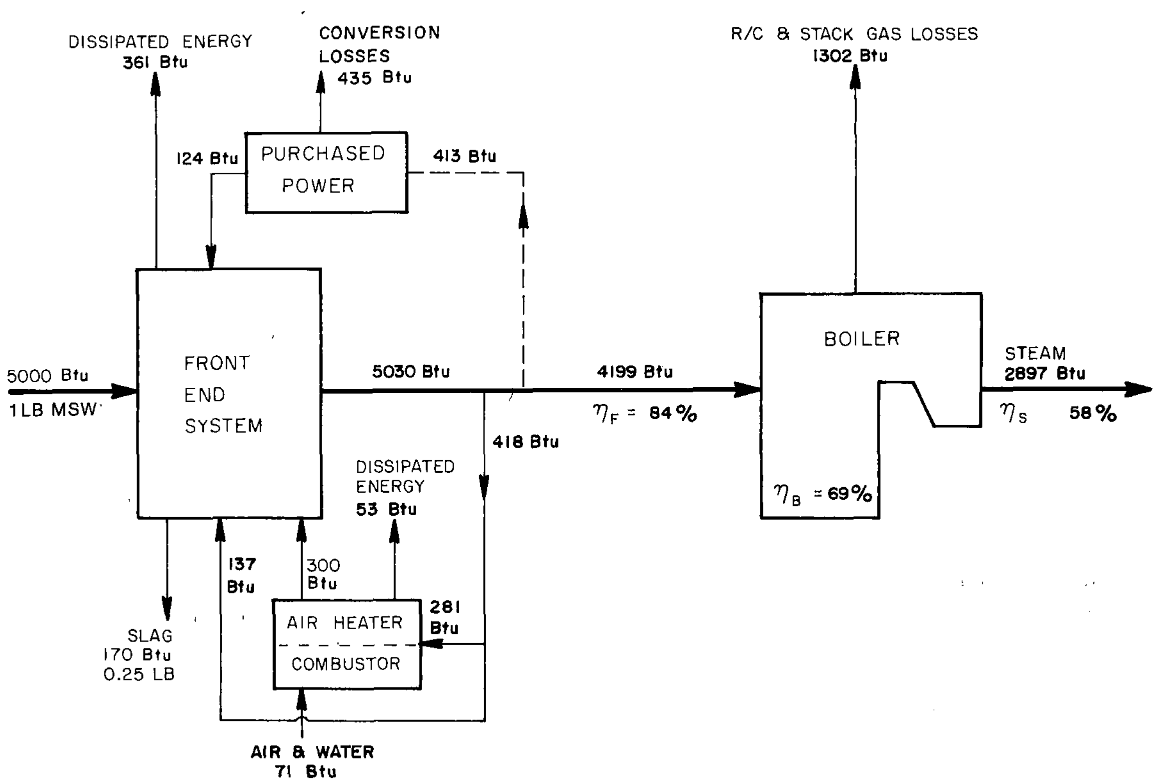

Figure 11. Energy Balance For The Torrax System

*This balance was based upon data obtained from:

Stoia, J. Z., Torrax — A Slagging Pyrolysis System for Converting Solid Waste to Fuel Gas,* Carborundum Environmental Systems, Inc., Solid Waste Conversion Division. Niagara Falls, New York, p. 11-22.

Eerie County — Torrax Solid Waste Demonstration Project, Final Report, May 1974. U. S. Environmental Protection Agency, Office of Solid Waste Management. 46 p.

Legille, E. etal, A Slagging Pyrolysis Solid Waste Conversion System, On Proceedings: Conversion of Refuse to Energy, Montreux, Switzerland, November 3-5, 1975, New York, Institute of Electrical and Electronics Engineers, p. 232-237.

Medium BTU Gas - Union Carbide Purox System

Process Description. The key element of the Purox System is a vertical shaft furnace (Figure 12), wherein shredded solid waste is fed into the top of the reactor through a piston air lock system while oxygen is injected into the bottom of the furnace. The solid waste descends by gravity through the varying temperature zones on its downward passage through the vertical reactor. The oxygen reacting with char material previously formed from refuse in an upper zone of the reactor creates a temperature zone in the range of 3000 F in the lower portion of the reactor. Rising gases cool to approximately 200 F as they move upward thereby providing the energy for pyrolyzing the incoming waste in the upper portion of the reactor. Metals, glass and other materials are transformed into a molten slag by the high temperatures generated in the lower protion of the reactor. The molten slag mixture continuously drains into a water quench tank where a hard granular aggregate material referred to as "frit" is formed.

Product Characteristics. Gases leaving the reactor contain 30 to 40 percent moisture. This is removed in a gas clean up step, along with ash, tars, and other condensable liquids. The remaining gas contains approximately 75 percent CO and H_2 in approximately a two to one ratio; the other 25 percent being comprised of CO_2, CH_4, N_2, and organic compounds. Its heating value is approximately 300 BTU/cu ft.

Status. In 1970, the basic system was assembled in a 5 ton per day pilot plant at Union Carbide's Technology Development Center in Tarrytown, New York. Following evaluation of the pilot plant facility, a 200 ton per day Purox System was completed during 1974 in South Charleston, West Virginia. The West Virginia facility was designed to prove out the corporation's full-scale modular unit, and it was intended that larger plants would obtain greater throughput capacity by incorporating modular additions. Most recently, however, the Union Carbide Corporation has decided to market a 350 ton per day module so that the unit being tested is not the one that will be marketed.

Union Carbide is currently concluding the second portion of a three phase testing and performance evaluation program. The first phase concerned the receiving, feeding, and pyrolytic conversion of mixed municipal solid waste without size reduction or sorting. The second phase involved minimal pre-processing of incoming solid waste, consisting of coarse shredding and magnetic removal of the ferrous fraction prior to introduction into the pyrolysis reactor. The third phase anticipated to commence in 1976, constitutes a co-disposal investigation wherein sewage treatment plant sludges, containing varying moisture contents, will be mixed in varying proportions with shredded solid waste.

Energy Balance. Energy is consumed in the Purox process primarily in the shredding of the waste and in producing the 0.2 lbs. of oxygen that is required for each pound of solid waste burned (Figure 13). Each pound of solid waste processed yields about 11.4 cubic feet of gas having a heating value of about 300 Btu/cu.ft. Because this fuel burns so well, if used directly in a boiler the combustion efficiency would be on the order of 90 percent, with a net system efficiency of about 58 percent.

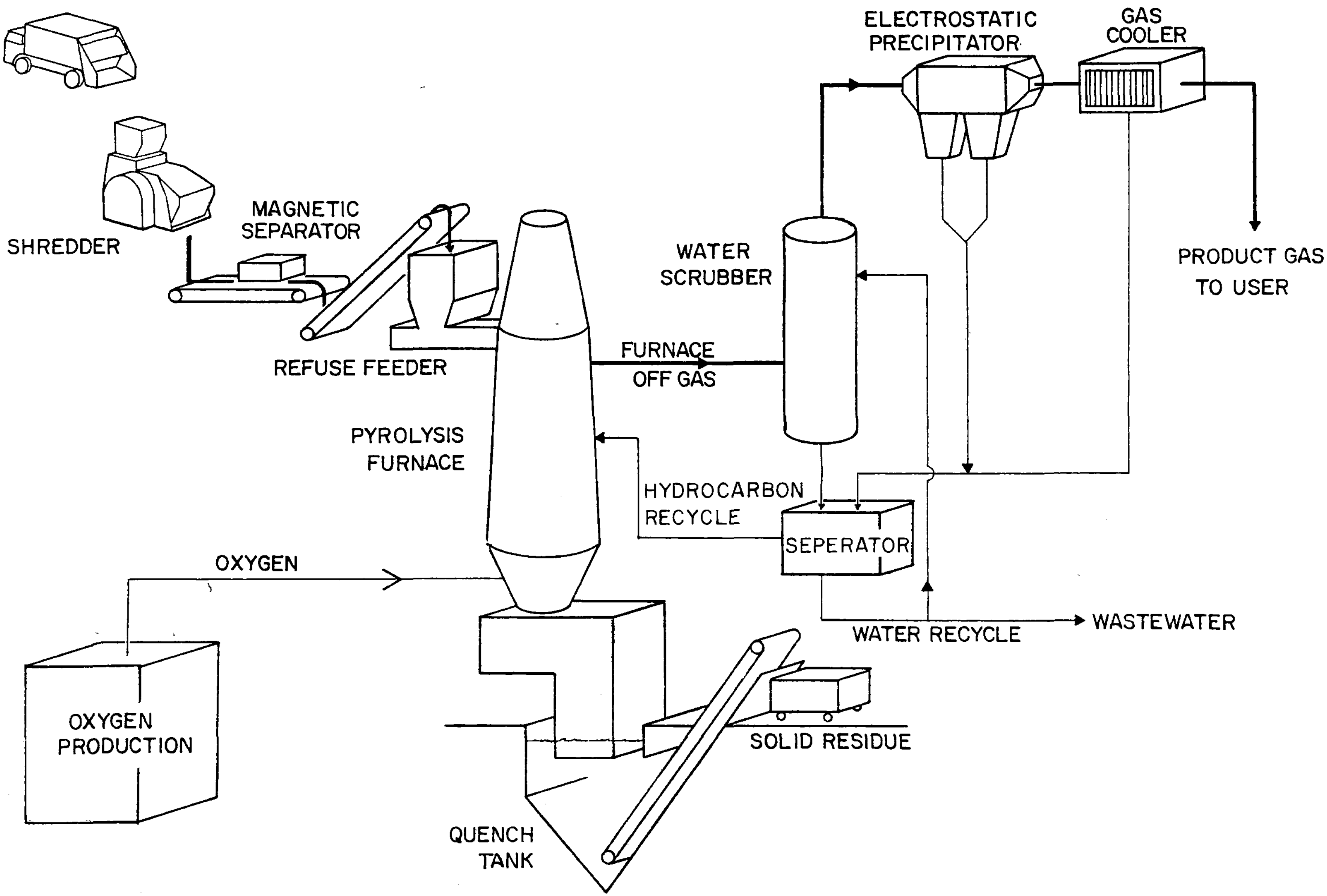

Figure 12. Union Carbide Purox System produces a medium Btu gas for sale to off site users.

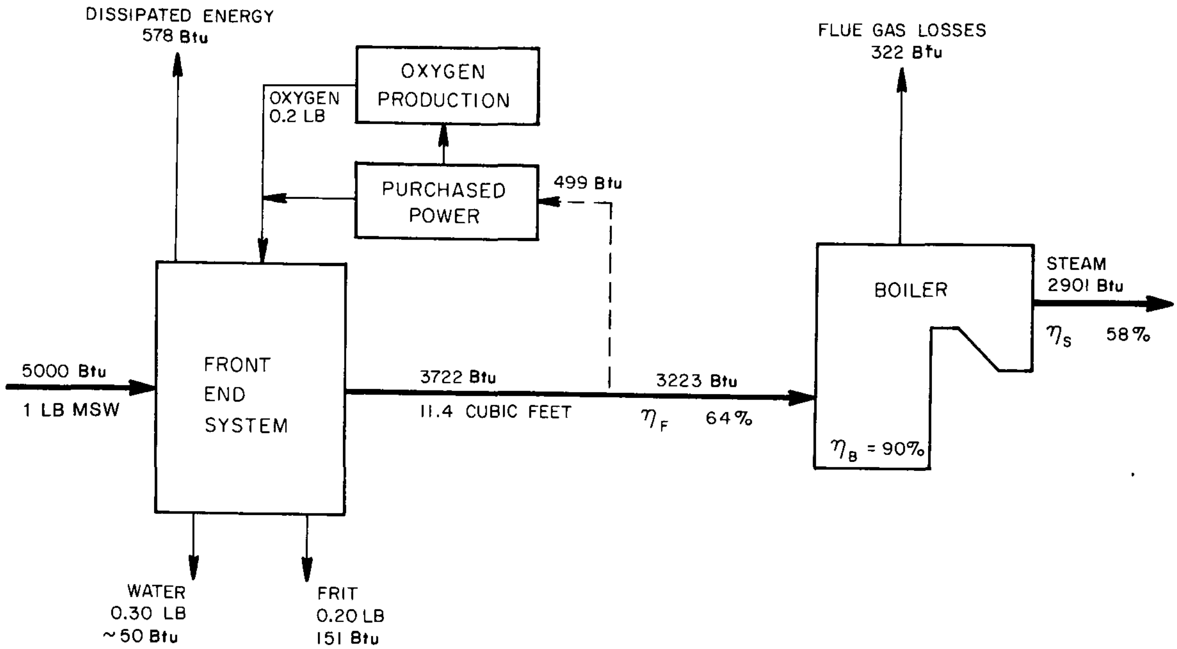

Figure 13. Energy Balance for the Purox Gasifier *

*This balance was based upon data obtained from:

Snyder, N. W., J. J. Brehany, and R. E. Mitchell, East Bay Solid Waste Energy Conversion System, In Proceedings; Conversion of Refuse to Energy, Montreux, Switzerland, November 3-5, 1975. New York, Institute of Electrical and Electronics Engineers, p. 428-433.

Bonnet, F. W., Partial Oxydation of Refuse Using the Purox System, given at Conversion of Refuse to Energy Conference, Montreux, Switzerland, November 3-5, 1975, but not in Proceedings.

AWBERC LIBRARY U.S. EPA

Despite the excellent quality of the Purox fuel, some communities in the U.S. that have been considering this system have added at the back end conventional process technology to produce either ammonia (NH_3) or methanol (CH_3OH). Unfortunately, the technical and economic viability of running such a process on this gas stream remains uncertain.

Liquid Fuel - Occidental Flash Pyrolysis System

Process Description. The Occidental Process (Figure 14) utilizes two stages of shredding, air classification, magnetic separation, drying, and screening to produce fluff RDF for the pyrolyser feedstock. Representing about 60 percent of the input solid waste, the fluff RDF is fed along with hot char into a vertical, stainless steel reactor. The hot char, which is actually the solid residue remaining after the pyrolysis reaction, provides the energy needed to pyrolyze the organic material. The material exiting the reactor consists of a mixture of char and ash and the pyrolysis gases. By rapidly cooling the gases before they can completely react, a portion of the gas is condensed into an oil-like liquid fuel. Both the remaining gas and the char are reused within the system.

In going through the elaborate feedstock preparation steps, a by-product residual is left which is high in glass and aluminum. This material is processed by froth flotation to recover a non-color sorted glass cullet and by linear motor-eddy current cement separators to recover the aluminum.

Product Characteristics. The fuel product will be an oil-like, chemically complex, organic fluid. The sulfur content will be a good deal lower than that of even the best residual oils.

The average heating value of the pyrolytic "oil" will be about (10,500 Btu/lb), compared with 18,000 Btu/lb for typical No. 6 fuel oil. The lower heating value is due to the fact that pyrolytic oil is lower in both carbon and hydrogen and containers mcuh more oxygen. A barrel of oil derived from the pyrolysis of municipal waste contains about 76 percent of the heat energy available from No. 6 oil.

Pyrolytic oil will be more viscous than a typical residual oil. However, its fluidity increases more rapidly with temperature than does that of No 6 fuel oil. Hence, although it must be pumped at higher temperatures than are needed to handle heavy fuel oil, it can be atomized and burned quite well at 240 F. This is only about 20 F higher than the atomization temperature for electric utility fuel oils.

The San Diego Gas and Electric Company has agreed to purchase the fuel for use in one of its existing oil-fired steam-electric power plants. However, the fuel will first be put through an extensive testing program to determine its suitability and to determine a price for it.

Status. The first prototype plant is currently under construction in El Cajon, California. It is being built by San Diego County with the financial assistance of a demonstration grant from the U.S. Environmental Protection Agency and a subsidy from Occidental Petroleum. This 200 ton

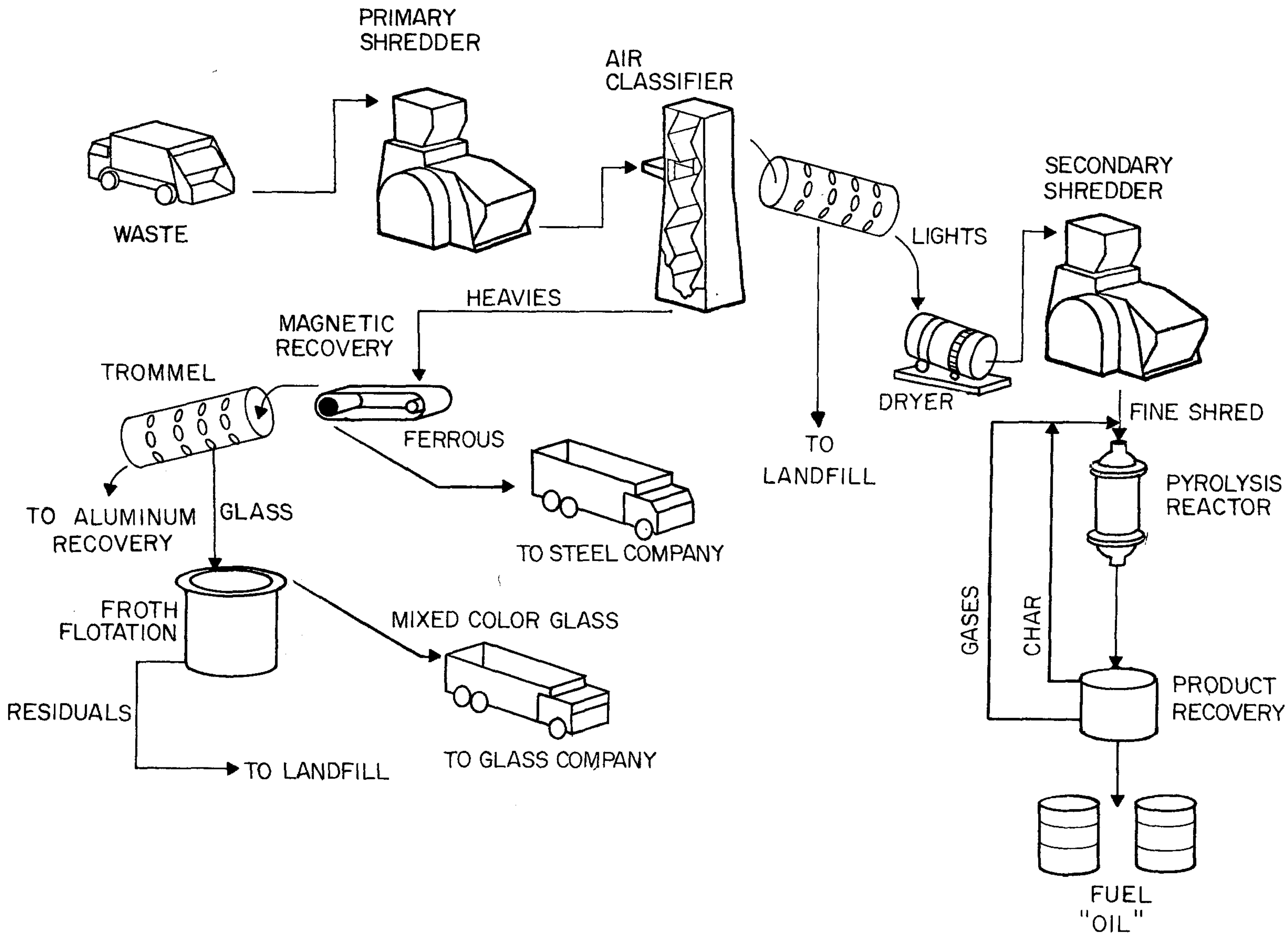

Figure 14. Production of "Oil" from Solid Waste Using the Occidental Process

per day plant was begun in August, 1975 and it is expected that plant start-up will begin in September, 1976. Several months of start-up operations will proceed a one year testing and evaluation program.

Energy Balance. An energy balance for the system is shown in Figure 15. Although electricity and some quench oil is purchased for the facility, it is assumed in this analysis that these energy inputs were produced within the system using normal conversion efficiencies that would result if the pyrolytic fuel product was the prime energy source. From the figure it can be seen that one pound of solid waste having a heat value of 5,000 Btu's yield 2050 Btu's of liquid fuel, with the rest being lost in the residue and char. However, when the 741 Btu's of energy needed to produce the equivalent amount of purchased energy put into the system is subtracted, only 1309 Btu's (or 26 percent of the energy in the original pound of solid waste) of fuel remains available.

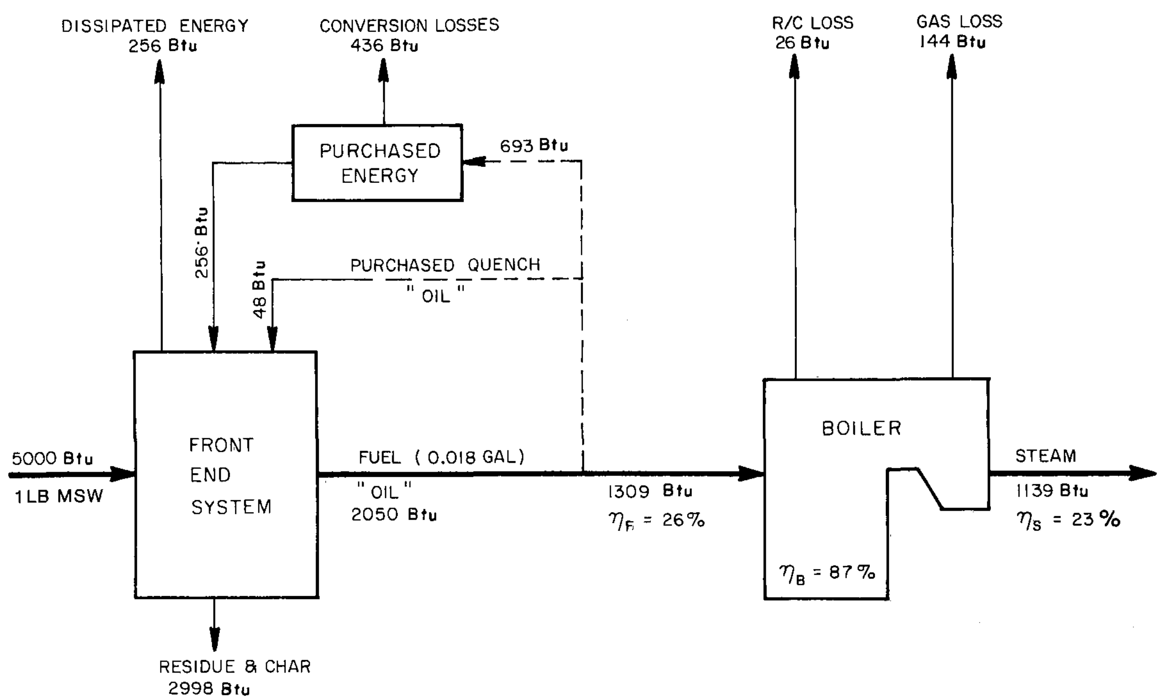

Figure 15. Occidental Petroleum System Energy Balance *

*This balance was based upon data obtained from:

Flanagan, B. J., Pyrolysis of Domestic Refuse with Mineral Recovery, in Proceedings; Conversion of Refuse to Energy, Montreux, Switzerland, November 3-5, 1975. New York, Institute of Electrical and Electronics Engineers, p. 220-225.

Levy, S., The Conversion of Municipal Solid Waste to a Liquid Fuel by Pyrolysis, in Proceedings; Conversion of Refuse to Energy, Montreux, Switzerland, November 3-5, 1975. New York, Institute of Electrical and Electronics Engineers, p. 226-231.

A conventional boiler using this type of fuel will operate at an efficiency of 87 percent, so the net amount of energy available from the original pound of solid waste, once converted to steam is 1139 Btu's or 23 percent.

Biological Gasification Systems

Anaerobic biological digestion of organic materials is a familiar and widely used process. Landfill stabilization, domestic sewage stabilization by septic tanks, or municipal sewage sludge digesters all utilize the same basic process. However, it cannot be said that the process is well understood. Decomposition of organic materials into methane, water, and carbon dioxide is the result of the life process of some bacteria which reside in an obviously complex environment. Some of the effects of variations in that environment on the health and productivity of the bacteria are well known while many others are not. Even so, the level of knowledge and the engineering state of the art are such that the anaerobic digestion of solid waste could be attractive as an energy recovery and waste disposal method for the relatively near future. Recent research has greatly expanded the knowledge about using anaerobic digestion to produce methane from solid waste.

Anaerobic digestion of wastes requires the action of two types of bacteria: the acid formers, which are hardy and very resistant to changes in their environment, and the methane formers, which are strictly anaerobic, slow growing, and susceptible to upset. There are two steps in the digestion process: First, the acid formers break down the complex organic materials into organic acids. Second, the methane formers feed on these organic acids to produce methane, carbon dioxide, and water.

These biological reations are used to convert refuse into methane in two different types of systems: landfill gasifiers and biological reactors. Ther former is considered "developmental" as it is being pursued in several prototype operations, but the latter is still "experimental."

Landfill Gasifier

Project Description. In California, several landfill operators are taking advantage of natural phenomena to recover usable methane which is produced naturally by the decomposing solid waste. The system employs a deep (over 200 ft. depth) sanitary landfill with impermeable bottom and gas permeable (porous) daily cover (Figure 16). Cells have been allowed to attain field capacity (saturated with water) and are then capped. Once wet, the micro-organisms begin reducing the cellulose in mixed municipal waste to methane and carbon dioxide. The landfill is equipped with perforated well casings which direct the gas into a gas collection system.

Project Characteristics. Gas is primarily methane and carbon dioxide, but it does contain small amounts of hydrogen sulfide and organic acids, and the gas stream is saturated with moisture. As a result, unless the gas is consumed in equipment specifically designed to utilize digester

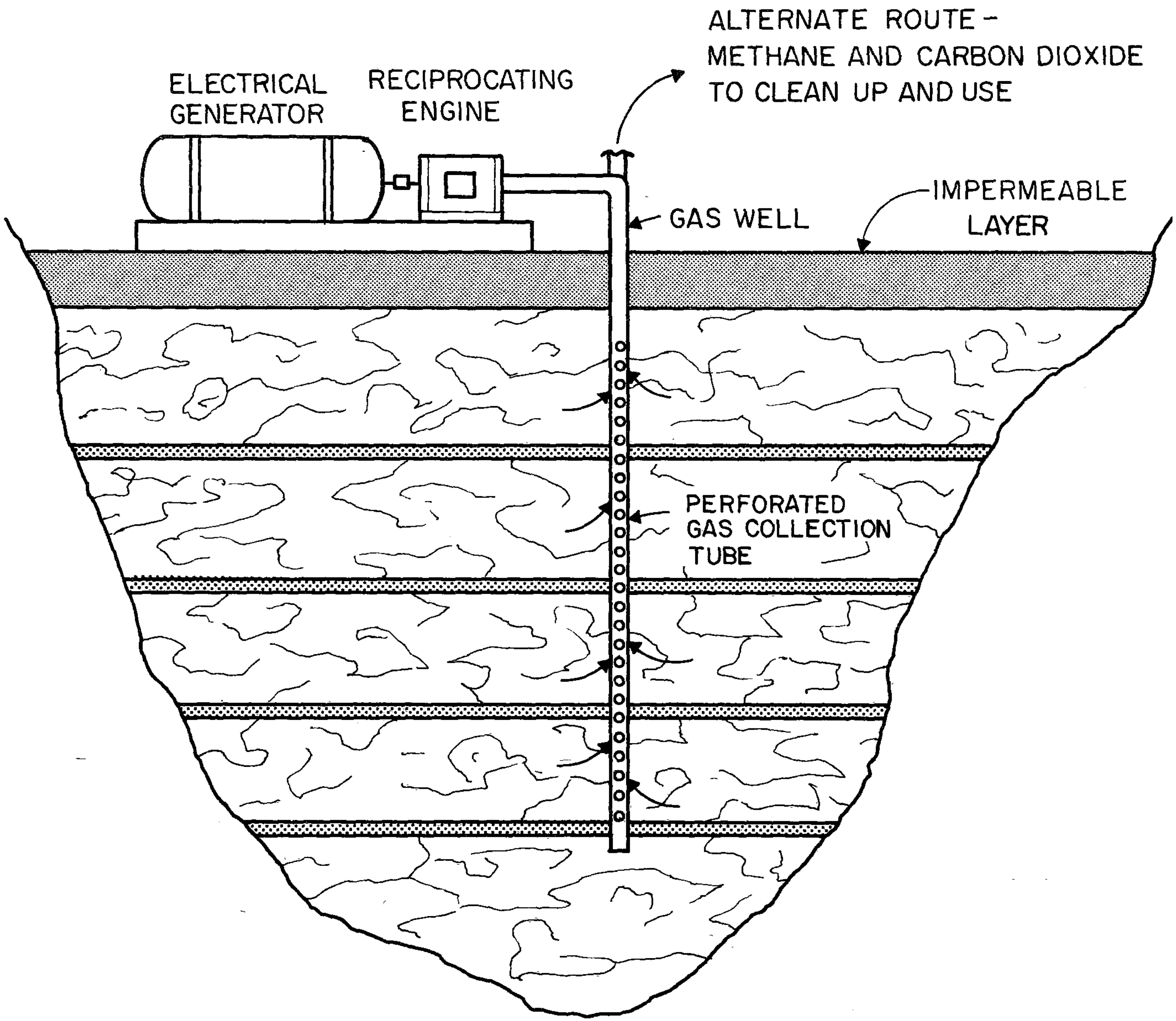

Figure 16. Production of Electricity from Landfill Gas

off-gas (as in sewage treatment plants), it must be dehydrated and "sweetened" (the carbon dioxide is stripped and the acids removed). This method of energy recovery results in a fuel product which can be obtained from an existing landfill and may be compatible with utility boilers and residential fuel requirements.

Status. Pilot or prototype installations are currently recovering methane from two landfills in Los Angeles, California where both direct use in a reciprocating engine-generator set and sweetening to pipeline quality for residential consumption are being practiced. Also, a research study, underway at the landfill in Mountain View, California, is attempting to quantify the various gas recovery parameters so that relaiable technical and economic surveys can be conducted at other potential sites.

Reactor Gasifiers

Process Description. Reactor-based gasification involves the controlled introduction of fluff or wet process RDF and sewage sludge into a heated, well mixed, anaerobic digester where the micro-organisms reduce the cellulose in the solid waste to methane and carbon dioxide (Figure 17). The retention time within the reactor will be 5 to 10 days during which the fastest rate of decomposition takes place. It would not be economical to build reactors large enough to hold the material until it is fully

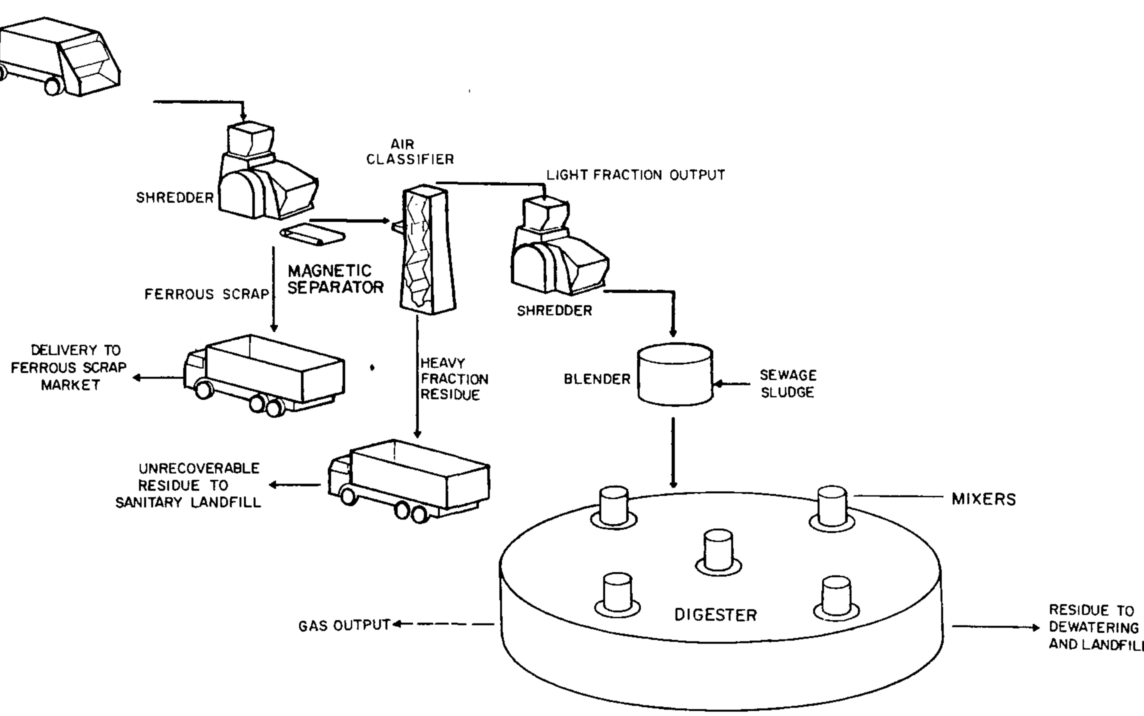

Figure 17. Biological Gasification of Solid Waste in Reactors

digested. Thus, the residue that is removed is not fully digested and represents about 50 percent of the orginal input weight. Results from a pilot plant operated in Franklin, Ohio, indicate that the residue dewaters easily, and that it contains approximately half of the energy potential of the input waste. Using vacuum filters and mecahnical presses, it can probably be dewatered to 55 percent moisture, the same as wet process fuel. The residue could then possible by used as a boiler fuel in specially designed boilers. This use would have to be carefully designed because the residuel is odorous.

Status. The result of laboratory and systems studies indicate that the technology is promising and would be economic when the price of gas rises above $2.00 per million cubic feet. Since the intrastate price of natural gas is above that level in many states today, the process may prove to be eonomical in the near future. However, the technical feasibility has yet to be proven at anything above pilot scale experiments. In addition to the one ton per day gasifier in Franklin, Ohio, Waste Management, Inc. is designing a 50 tpd prototype unit for construc tion in Pompano Beach, Florida, under a contract from the Energy Research and Development Administration.

Among the questions remaining to be answered are: (1) Is the entire process economical? (2) Can the reactors operate on mixed municipal solid waste (people throw out materials such as pesticides which have the capability of upsetting a digester and preventing it from producing gas)? (3) Is the existing equipment for mixing the refuse-sludge slurry in the reactors adequate or is a significant hardware development effort required?

Energy Balance. Figure 18 shows the energy balance for biological gasification of solid waste mixed with sewage sludge in a reactor. It can be seen that only one-third of the energy in the "as received" solid waste is recovered as methane gas. When burned in a boiler having an efficiency of 85 percent, the net yield is 25 percent. In this analysis, it has been assumed that energy required to operate the equipment and heat the digester was obtained by burning the solid residuals recovered from the digester and the front end system. In addition, recovery of these residuals adds an additional 633 BTU's of steam per pound of solid waste, increasing overall system energy yields to 42 percent. If the residuals cannot be used as fuel, and system energy requirements are subtracted from the methane yield, the net energy yield of the system would be reduced to 14 percent.

Product Characterisitics. Reactor gas is predominantly carbon dioxide and methane, in almost equal quantities. The gas has a heat value of about 600 BTU/cu. ft., about 60 percent the value of natural gas.

Waste-Fired Gas Turbine Systems

In gas turbine systems (Figure 19) high pressure gases resulting from the combustion of solid waste with compressed air are used to drive a gas

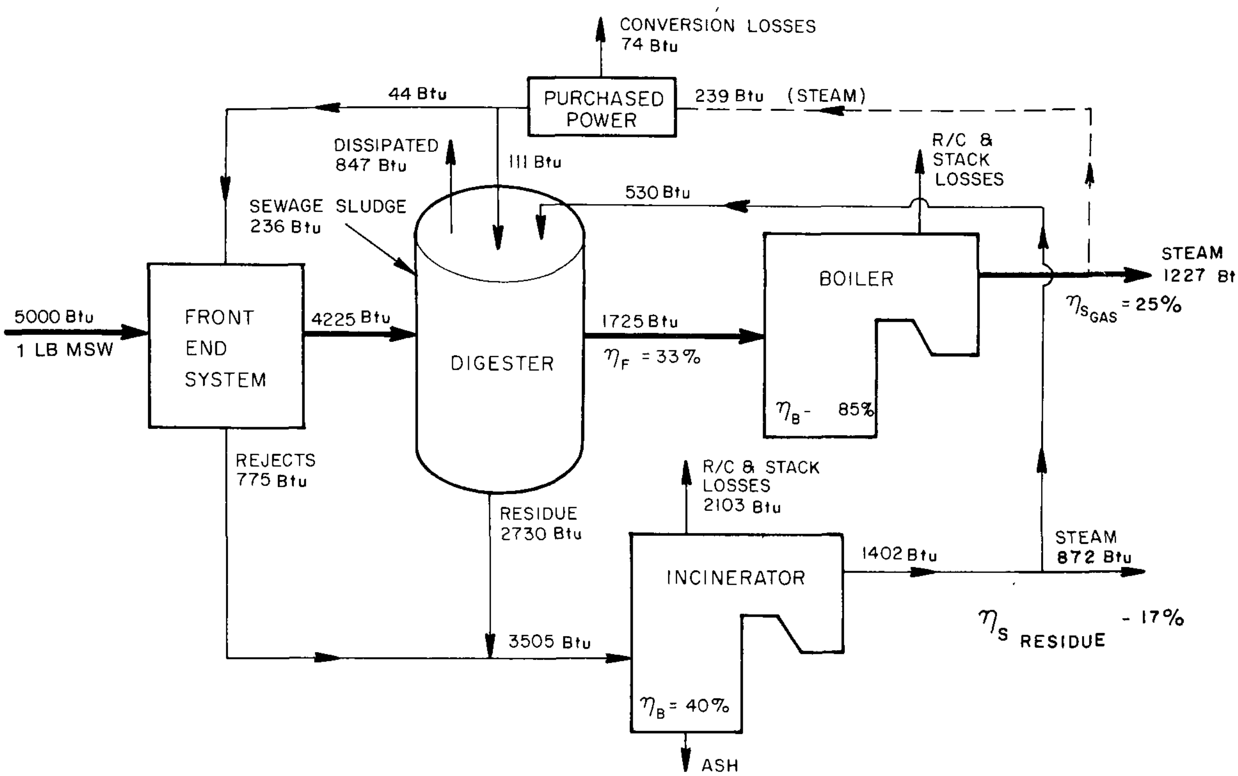

Figure 18. Energy Balance for Biological Gasification *

*This balance was based upon data obtained from:

Pfeffer, J. T., and J. C. Liebman, Biological Conversion of Organic Refuse to Methane, Semi-Annual Progress Report covering period 7/1/74 to 12/31/74, Department of Civil Engineering, University of Illinois at Urbana-Champaign. January 1975. p. 64.

Kispert, R. G., L. C. Anderson, D. H. Walker, S. E. Sadek, and D. L. Wise, Fuel Gas Production from Solid Waste, Semi-Annual Progress Report, Dynatech R/D Company, July 1974. p. 52-58.

turbine. The only example of a waste-fired gas turbine system is the CPU-400 under development by the Combustion Power Company. In this system fluff RDF is burned in a fluidized bed furnace (fuel is burned in an expanded bed of stones) which keeps temperature and excess air low. The resulting gases are cleaned of fly ash using inertial separators and gravel bed filters. The clean gases, at temperatures around 1450 F, are introduced into a gas turbine-generator set to produce electricity.

Status. Severe difficulties have been encountered in high temperature particulate (dust) removal. Additional problems due to condensation of vapor phase "aerosols" in the gases may prove to be inherent. Extensive R&D programs are now ongoing and, until they are successfully completed, the status of the system must be considered as experimental.

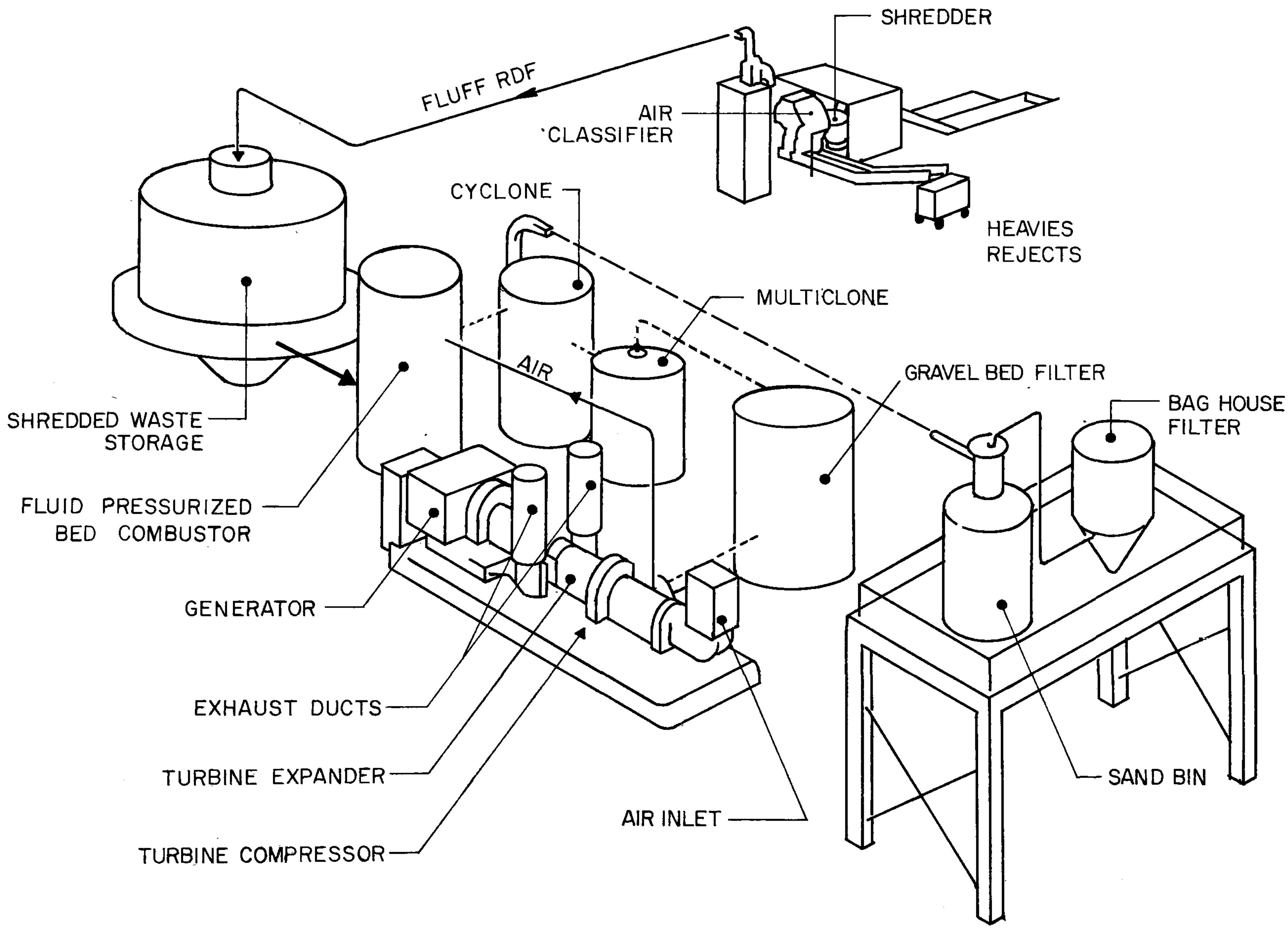

Figure 19. Gas Turbine Generating System Using Refuse as a Fuel (CPU-400)

Energy Balance. The primary energy product in the gas turbine system is electricity (Figure 20). About 12 percent of the original energy is recovered as electricity. This number should not be confused with the yeilds of the other energy recovery systems, which were calculated on the basis of steam recovery, as there is a substantial energy loss in converting steam to electicity. Thus if the steam yield from the Monsanto pyrolysis system, for instance, were converted to electricity, the efficiency would be reduced to about 16 percent, not much better than the yield for this system.

In addition to the electrical energy recovered from the Brayton cycle, there is potentially 19.4 percent more energy which can be recovered as steam. This would require the use of a waste heat boiler to recover energy from the gases after they pass through the turbine.

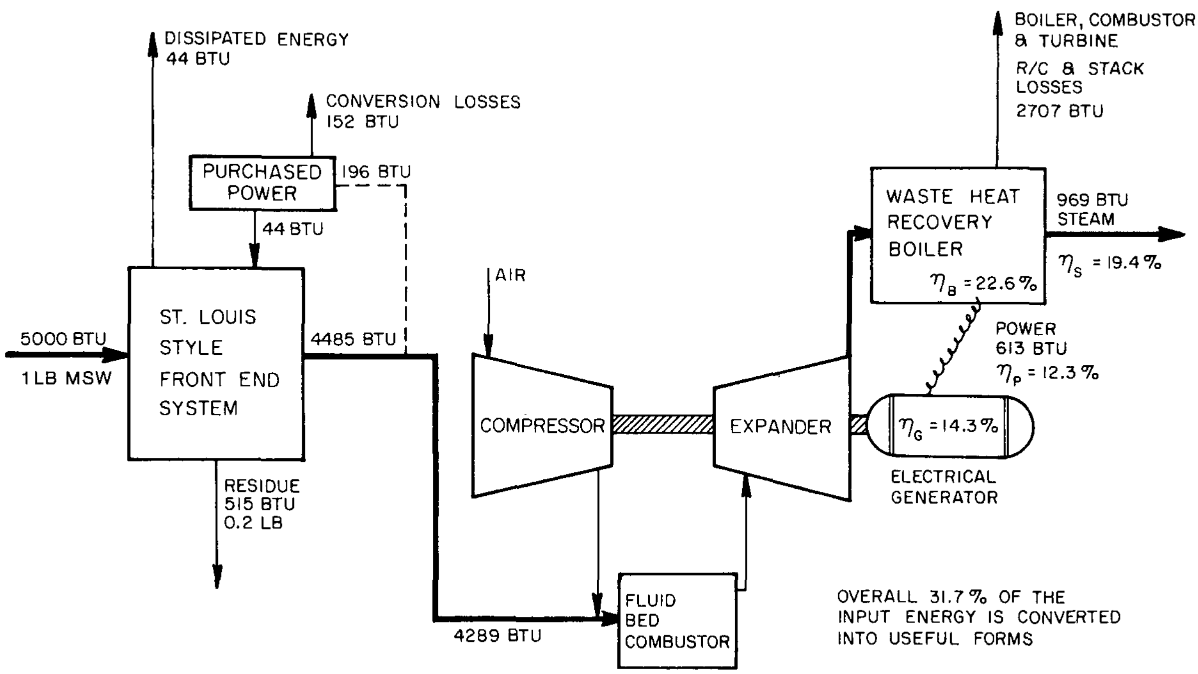

Figure 20. Gas Turbine Energy Balance *

*This balance was based upon data obtained from:

CPU-400 Systems Studies and Preliminary Design, Combustion Power Company, Inc., U. S. Environmental Protection Agency, Office of Research and Development, Cincinnati, Ohio. 72 p.

SECTION IV

MATERIALS RECOVERY SYSTEMS

Materials recovery encompasses methods and procedures for extracting useful materials from solid waste for return to the economy. The prime objectives in the development of materials recovery systems are: (1) to conserve natural resources and energy; (2) to reduce land requirements for disposal; (3) to facilitate the preparation of refuse derived fuels for energy recovery systems.

Materials can be recovered through source separation, hand sorting, or mechanical separation. This report addresses only mechanical separation. Mechanical separation methods capable of segregating solid waste into valuable components have developed, based on techniques use in the mining and paper industries. These methods are aimed at minimizing the level of impurities in recovered products so that maximum dollar value can be obtained for the recovered material. Material recovery systems have concentrated on the reclamation of fiber or paper (the most abundant component in solid waste); magnetic metals (the most easily extractable); aluminum (the most highly valued); and glass (the most difficult to extract).

Material recovery components are often combined with energy recovery systems. These systems are designed to serve as total recovery plants. Section III of this report describes systems which convert part of the solid waste into a fuel product. The following subsections describe some of the subsystems used in these solid waste disposal/energy recovery systems to recover valuable resources.

Paper Fiber Recovery

Paper fiber recovery processes use either wet or dry primary separation of fibers from mixed municipal waste. The initial separation steps are similar to those employed in dry and wet RDF production facilities. In fact, it may be practical in some situations to establish both a fuel and a fiber market for the paper so that the actual end use of the product can change in response to changes in market demand (value).

Wet Processing Concept - Fiber Recovery

The major components of a wet processing system are described in Section III. The fiber recovery portion of the facility is described here.

Process Description. Figure 21 is a flow chart of the components of the fiber recovery subsystem. The feedstock to the fiber recovery process is the same material as taken to the dewatering presses in a wet fuel processing system. The hydrapulped solid waste is

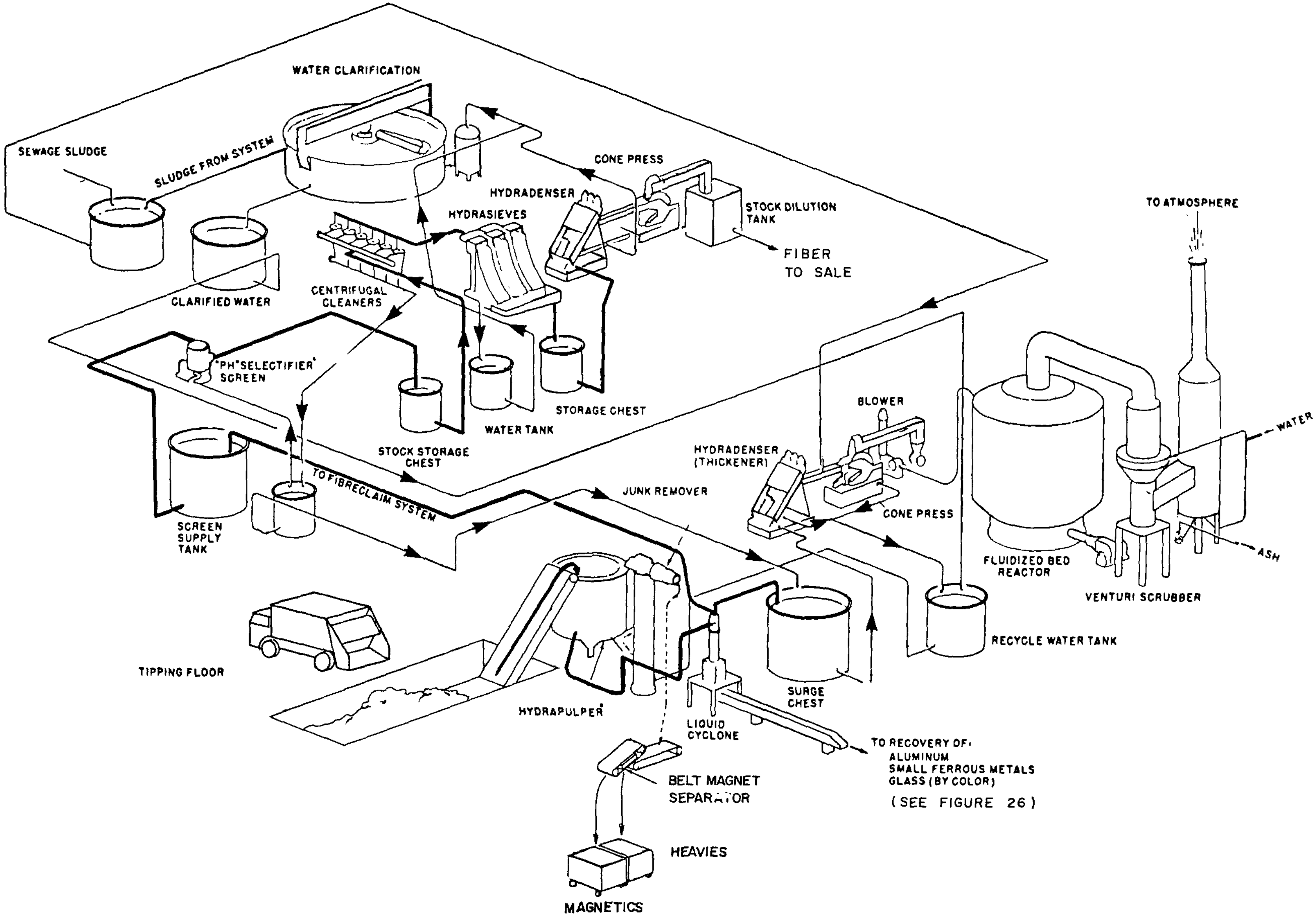

Figure 21. Wet Process Fiber Recovery System

centrifugally separated and light fraction taken to fiber recovery. The first step in the beneficiation process is to remove all large particles from the slurry. This is accomplished by screening. All particles greater than 1/16 inch diameter, including the plastic films, are removed. The fibrous slurry is then passed through a series of high efficiency centrifugal cleaners and screens which remove grit. The material exiting the cleaners and screens is recovered fiber. This material can be washed and dewatered prior to shipment for use in a manufacturing process or for further upgrading (cleaning and removal of shorter fibers).

The economic viability of fiber upgrading processes is determined by the market for the recovered products. Generally, long-term contracts must be secured and the price of the upgraded fiber must be sufficiently higher than unbeneficiated fiber to warrant the extra expense.

Figure 22 presents a mass balance for the recovery of paper fiber using wet processing. About 20 percent by weight (dry) of the incoming municipal solid waste is recovered as marketable fiber. This represents approximately 50 percent of the paper fiber content of the solid waste on a dry weight basis.

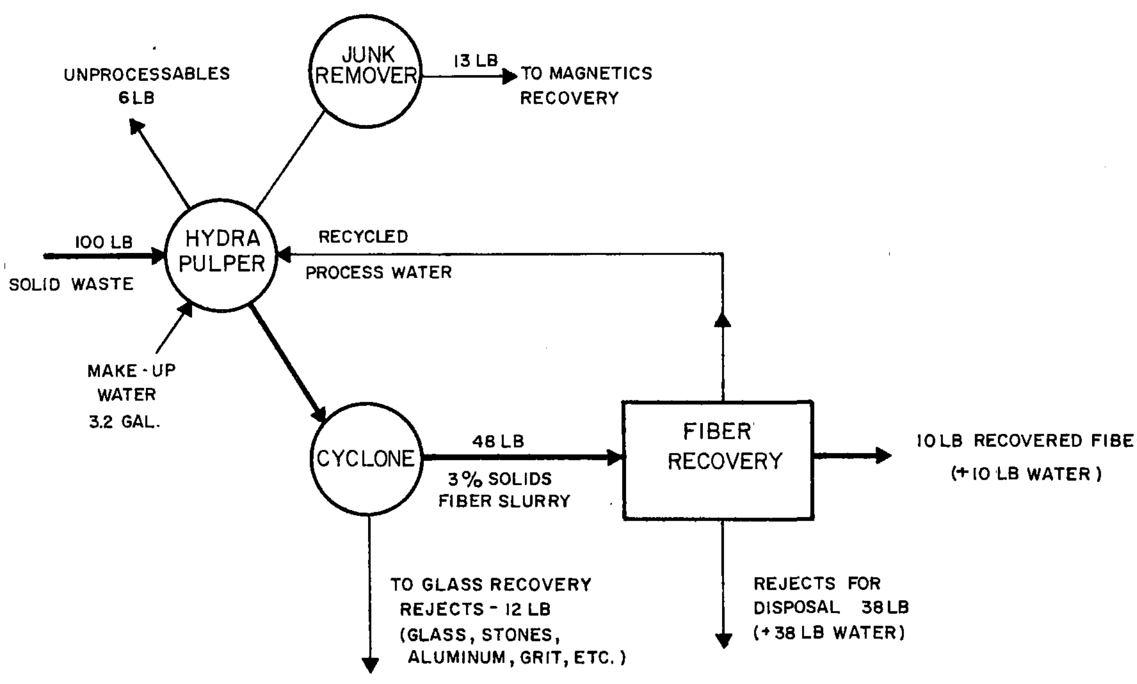

Figure 22. Mass Balance for Wet Process Fiber Recovery *

*This balance was based upon data obtained from:

Wittmann, T. J., et. al., A Technical, Environmental and Economic Evaluation of the "Wet Processing System for the Recovery and Disposal of Municipal Solid Waste", Final Report SW-109c, U. S. Environmental Protection Agency, 1975. 217 p.

Status. The fiber recovery process was developed by the Black-Clawson Company and has been demonstrated with a 150 ton per day plant built in Franklin, Ohio. This plant has been in continuous operation since 1971. Fiber recovered at the plant is currently being sold to a manufacturer of asphalt impregnated roofing shingles. However, recent combustion tests have established a market for the fiber as a fuel and henceforth the fiber will be sold to the most lucrative of the two markets.

Although the wet fiber recovery process has been successfully demonstrated, the large fluctuation which occurs in the paper fiber market, and the fact that the fiber is suitable for only low grade uses has limited the systems economic viability. In fact, as discussed in Section III Black-Clawson is currently promoting the use of its wet pulped fuel recovery system instead of its fiber recovery system.

Product Characteristics. The paper fiber recovery at Franklin is of fairly low quality. It is shipped to its market via a short pipeline as a slurry containing 4 percent solids. The major contaminent impacting on its quality is oil and grease. Microbial organisms which survive the pulping and recovery processes are also a problem in that they severely restrict the "shelf-life" of the fibre and require that its end use include a heat treating step where the organisms are killed.

Dry Processing Concept - Paper Recovery

Process Description. Another technique for paper recovery is displayed in Figure 23. The concept involves the recovery of paper using a series of air classifiers and rotary screens to remove and upgrade the paper fraction from shredded solid waste. The paper fraction removed by air classification is baled and either marketed in this form or further processed using a wet processing system similar to the wet process fiber recovery system.

As illustrated in Figure 23, the solid waste is first shredded followed by the removal of magnetics. An air classifier separates the paper and plastic from the remaining stream. Further air classifying removes the plastic fraction from the paper/plastic stream.

When wet processing is used as the final clean up step, the paper/plastic fraction is charged into hydrapulpers and converted into a paper-water slurry. Plastics float on the surface of the hydrapulper and are removed at regular intervals. Heavy foreign matter and more plastics are removed by screening.

The fiber-rich pulp is discharged from the pulper to a hydracyclone to remove small particulate matter (grit). The cleaned slurry is pumped to a prethickener where a large portion of the water is removed for recycling to the pulper. This thickened material is conveyed to a

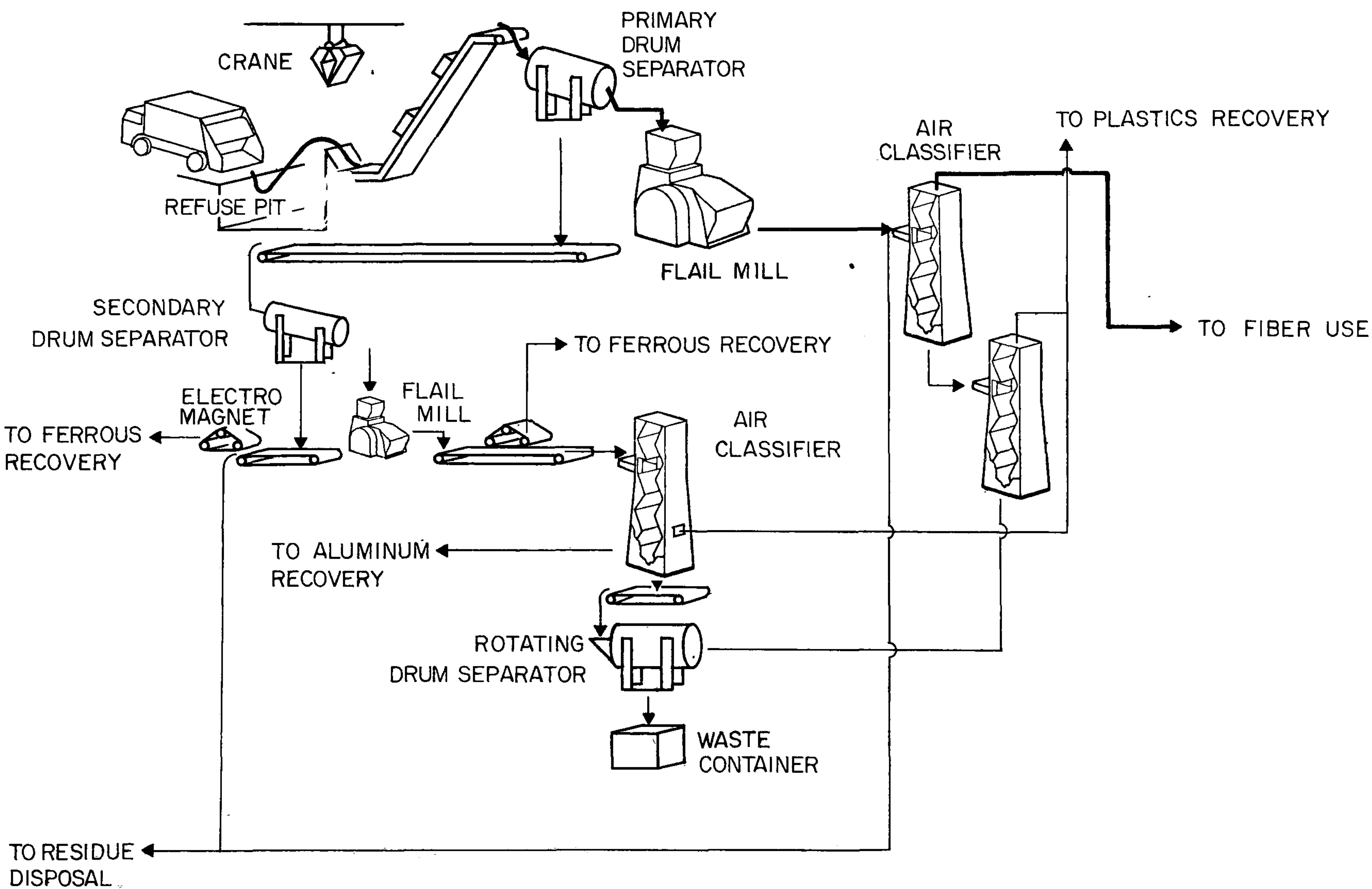

Figure 23. Dry Process Paper and Materials Recovery

dewatering press where the material is concentrated to approximately 38 percent solids and additional water is recycled to the pulper. The fibrous material is then processed in a refiner (mixing, grinding, and steaming steps) to remove unwanted paraffins and tar residues from the fiber product.

Status. This process has been developed by the Cecchini Company of Rome, Italy. Cecchini presently operates three plants in Italy. Paper from these plants is used, along with straw, to make a low grade paperboard. No tests have been conducted to determine if such a product would be marketable in this country.

Product Characteristics. Like the wet recovery system fiber, the paper recovered in the dry separation system is of low quality, and as a result, has limited marketability. It's major contaminant is plastics. Product yields are lower in this process as substantial amounts of paper are lost in the air classifying and screening operations. It is estimated that approximately 23 percent of the input paper is recovered as marketable fiber.

Composting

Composting of municipal refuse is a method of converting the organic portion of mixed solid waste into a soil conditioner. This conversion is accomplished by a well known biological process called aerobic digestion, the decomposition of organic materials by microorganisms which require air to live. The humus which results from composted refuse can improve the tilth and moisture retention characteristics of poor soils. Clays are only temporarily improved by the addition of humus, but sandy soils can benefit substantially, especially in dry climates. Composting of municipal refuse has been practiced in Europe where intensive agriculture by speciality farmers and other small landholders is carried out close to large towns and cities.

Three basic methods of composting are distinguishable: windrowing - digesting of the material in open stacks laid on the ground; tilling the undigested organics into soil containing mature compost; and completely mechanized industrial composting plants.

The first two processes require large amounts of land, a condition which rarely exists near today's American cities. The third requires mechanical equipment. The windrowing process can require as much as 30 days to achieve a mature compost, while the mechanical process can go to completion in two to ten days. (In most of the United States, 10 days are required because of the high paper fraction in mixed municipal waste.)

Composting processes require moisture addition and mixing to provide adequate aeration of the material. In addition, efficient composting requires that the organic components in the solid waste be reduced to small particle sizes and that as much as possible of the inert materials be removed from the waste stream prior to processing. The size reduction and inerts cleanup requirements for composting are almost identical to the processing requirements for production of fluff RDF. The same equipment can be used for both.

Since similar processing is required for the preparation of refuse for composting and RDF, and since RDF is expected to be more readily marketable than compost in an urban economy (near the waste generation centers), it is unlikely that composting will be able to compete with energy recovery as a solid waste management tool. Furthermore, composted refuse is a very low grade fertilizer which cannot compete with available chemical fertilizers on American farms. Finally, the soil in very few areas of the United States is in need of the type of soil conditioning offered by humus. The high processing costs (whether in terms of land or equipment) and the lack of a suitable market indicates that the composting of municipal solid waste is not a promising method of urban solid waste management. The possible exception is its use in sections of the country where sandy soils exist, solid fuel combustion is economically prohibitive, and a strong, long-term market for humus exists.

Ferrous Metals Recovery

Process Description. Ferrous metal reclamation is a subsystem which can be incorporated into almost all energy and materials recovery systems. The technology for extracting ferrous metals is based on magnetic attraction of ferrous materials and is readily available.

Magnetic separation of ferrous metals from municipal solid waste generally follows the first stage of shredding. In many sophisticated resource recovery systems, magnetic separators are also employed later in the system to recover any ferrous metal that was initially missed. Particle size does not appear to be critical since existing equipment can easily remove most ferrous objects which appear in urban solid waste. Bulky items such as appliances can be either manually sorted or shredded prior to magnetic separation. Heavy ferrous objects, such as motor casings, are generally manually separated in order to protect the size reduction equipment.

Two broad classes of magnetic separators are used in solid waste processing (Figure 24): suspended types and head pully types. Suspended type separators, positioned over solid waste feed conveyors, are used to remove ferrous metals from solid waste which may or may not have been shredded. The recovered ferrous metal is contaminated with paper so that air scalping or secondary magnetic separation is needed to produce a marketable fraction. Head pully type separators are generally employed as a means of secondary ferrous separation.

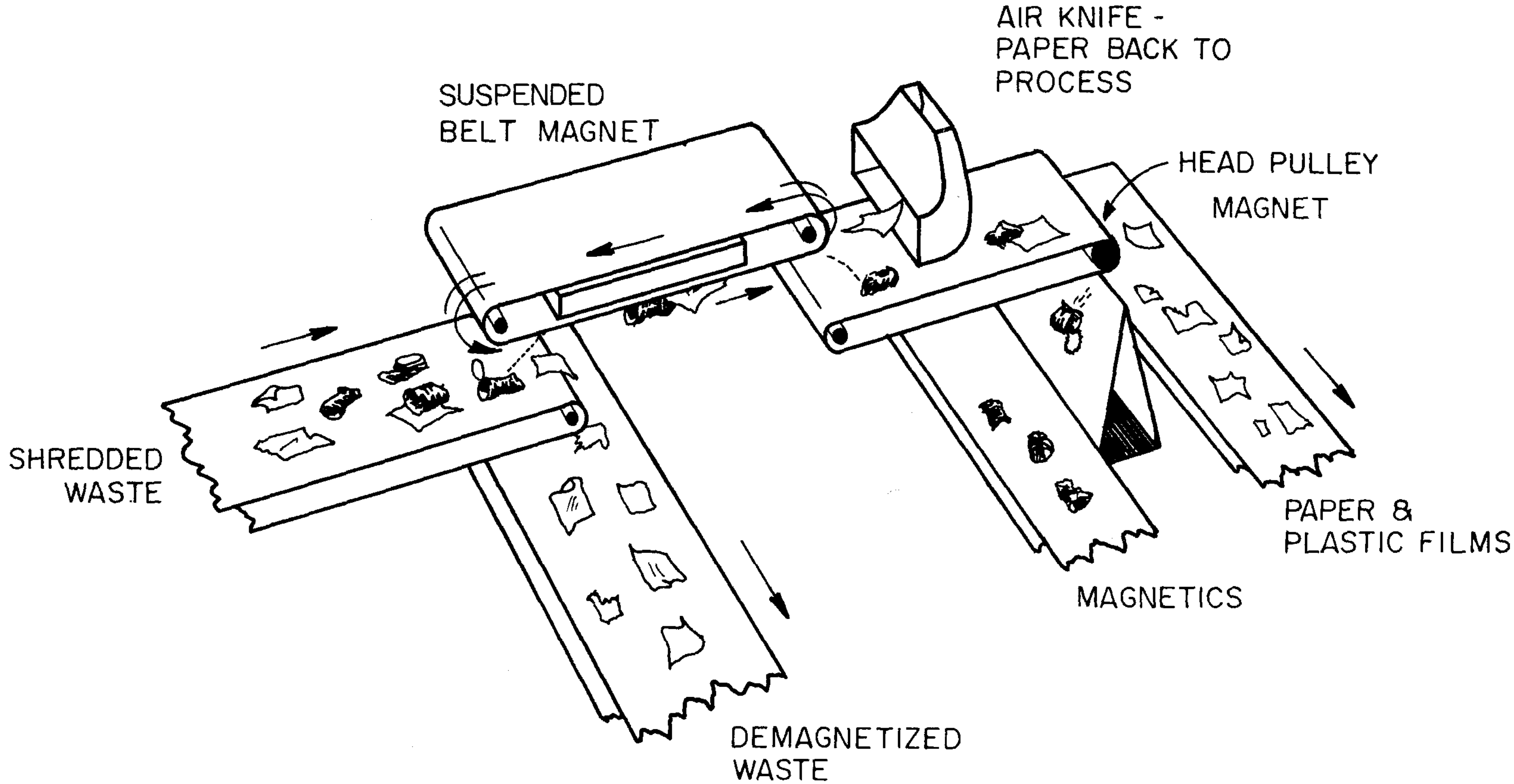

Figure 24. Magnetic Separator Configuration

The suspended magnetic separator lifts ferrous metals from the waste and deposits them on a separate belt. The head pully causes ferrous metals to follow the conveyor around the head and drop behind the solid waste stream.

Product Considerations. There are three principal uses of ferrous scrap in the United States today: detinning, steel production, copper precipitation. Each of these industries have different physical requirements and contaminant restrictions for ferrous scrap. These markets are discussed in the Markets section of this guide (SW-157.3). The actual, or most likely market for ferrous metal recovered from a proposed plant should be determined before the plant is designed so that the plant can be designed to produce a ferrous product that will meet the specifications of the market.

Recovery rates of 90 to 97 percent of the ferrous material in the waste stream are possible.

Status. The technology of ferrous metals separation and reclamation is proven and has been demonstrated in numerous areas. Magnetic separation is being used in almost all operating and proposed energy and material recovery systems.

Glass and Aluminum Recovery Systems

Recovery of glass and aluminum from mixed municipal solid waste would occur after the waste has been processed to remove the bulk of the organic or combustible waste and ferrous metals. Thus, equipment to recover glass or aluminum would normally be preceded by one or more stages of shredding, air classification, magnetic separation and screening. Thus, glass and aluminum recovery can be viewed as a supplement to other processing and recovery systems. The separation equipment receives a mostly nonorganic concentrate containing primarily glass, aluminum, and nonferrous metals, as well as stones and some leftover ferrous metals. This stream is often referred to as "heavies". Some residual organics including food, paper, rubber, plastic, and leather are still in the feed.

Since separation of one of the desired components (e.g. aluminum) leaves a component with a heavy concentration of the other (e.g. glass), glass and aluminum recovery are often viewed as joint recovery operations. However, recovery of only one or the other of the components is clearly possible.

Aluminum is difficult to extract because it has no unique physical characteristic which can be used to easily isolate it from the waste stream, and because it is a minor constituent (generally less than one percent of municipal solid waste). It's high value as scrap (approximately 300 per ton) however, makes it a potential recovery target.

Glass, on the other hand, has a relatively low scrap value but because it represents a much larger percentage of the waste stream (about 9 percent) the value of the glass and the aluminum in a ton of solid waste are nearly equal. The major problem in recovering glass is that stones and ceramics are not readily separable from glass and these materials are a major contaminant in the manufacture of glass. Thus, producing a product which can meet the rigid quality standards specified by the glass industry is difficult.

Before describing the glass and aluminum recovery systems presently under development it will be helpful to review some of the unit processes which are used in these systems.

- Heavy Media Separation. In this process a water suspension of finely divided particles of heavy minerals (e.g. magnetite or ferrosilicon) is used to create a fluid having a specific density which will cause the material being fed to it to split into "sink" and "float" fractions depending upon the specific gravities of the particles in the feed. Multiple separations can be made by using several stages or cells, each at different specific gravities.

- Eddy Current Separation. This is a dry process for separating aluminum and other nonferrous metal conductors from non-conducting materials. In these devices an electrical current is imposed on a fixed linear motor located beneath a moving belt. Metal conductors passing through the magnetic field created by the linear motors are subject to an induced (Eddy) current which opposes the field created by the linear motor. The opposing force is strong enough to knock the conductor off the belt. Non-conductors pass over the linear motors unaffected.

  Combustion Power Company of Menlo Park, California, and Occidental Research (formally Garrett Research) of La Verne, California, and the Raytheon Company have developed prototype aluminum spearation systems using eddy currents. Systems of this type are reportedly under development that will include the separation of other nonferrous metals from aluminum.

- Jigging. This mineral processing technique, is used to separate materials of different densities. Water is pulsed through a screen causing material fed onto the screen to separate. The lighter, material is floated off leaving the heavier material at the base of the jig. Jigs have been used in laboratory and pilot scale trials for separation of aluminum from mixed nonferrous metals.

- Electrostatic Separation. This method for dry nonferrous metal separation is based on differences in the conductivity of materials. As feed material enter on electrostatic field, particles become charged and fall on a rotating drum. Conductors immediately lose their charge on the grounded drum and fall from it while non-conductors retain a surface charge and adhere to the drum.

- Optical Sorting. Electronic sorting machines are used to optically separate 1/4 inch to 3/4 inch diameter glass by color. Glass cullet is fed from a hopper onto a vibrating feeder (Figure 25). A uniform feed of particles is led to a grooved belt conveyor which transports pieces in single file to a separation chamber. Here two photo cells (one on each side) view the glass. A color plate is situated opposite the photocell to provide a standard against which deviations in reflectivity of the glass are measured. Those particles within a certain range of reflectivity cause a voltage change in the photocells which in turn triggers a short blast of compressed air which deflects the particle from the main stream. This equipment can be set up to separate transparent particles (glass) from opaque particles (stones and ceramics), to separate clear glass from colored glass (amber and green), or possibly, to separate green glass from amber glass.

- Froth Flotation. This is a standard mineral processing technique being adapted to glass separation. Froth flotation is accomplished when an air bubble is attached to a selected particle having hydrophobic surface characteristics. This desirable surface property is usually achieved by "conditioning" the particle using a reagent prior to entering the flotation circuit.

  Following air bubble attachment, the floatable glass particles are buoyed to the surface to form a froth which can then be removed by skimmers. Rotors are used to circulate the glass rich slurry and to provide good air-solids mixing. To achieve the required residence time, flotation cells are usually arranged in series with adjacent cells separated by baffles to reduce "pulp short circuiting."

There are a number of possible configuarations of these unit processes in combination with grinding and screening to make up a complete recovery module. Two such systems are described below.

Black Clawson System

Process Description. The first flow scheme is in operation in Franklin, Ohio, at the Black Clawson fiber recovery plant. The feed

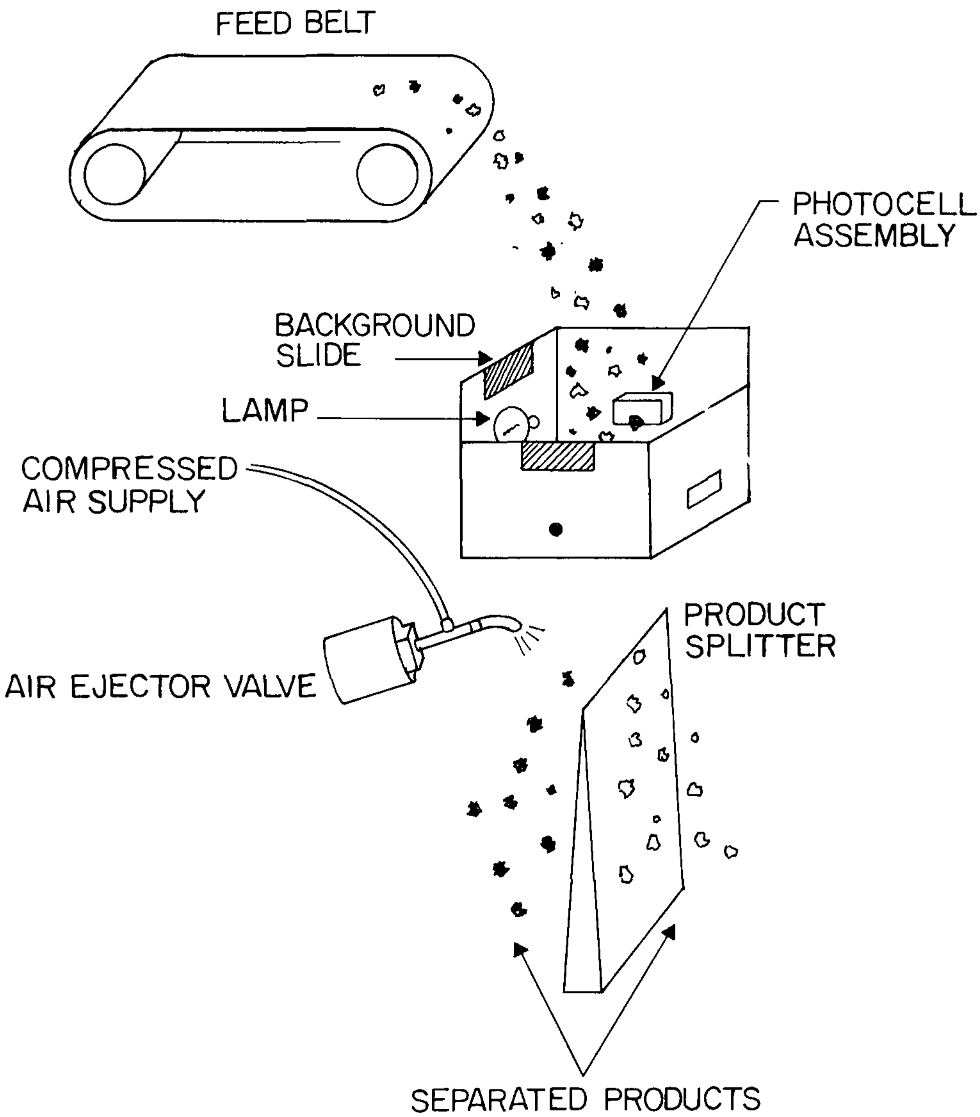

Figure 25. The Sortex optical sorter is used to color sort glass particles.

to this system is the heavy inorganic fraction (glass, nonferrous metals, stones and small amounts of ferrous metals and organics) which drops out of the wet cyclone (see Figure 21). The system as it is currently laid out is shown in Figure 26. Heavy material from the cyclone is mechanically dewatered prior to entering the surge storage bin. From the bin the material is placed on a vibrating screen and the fines and

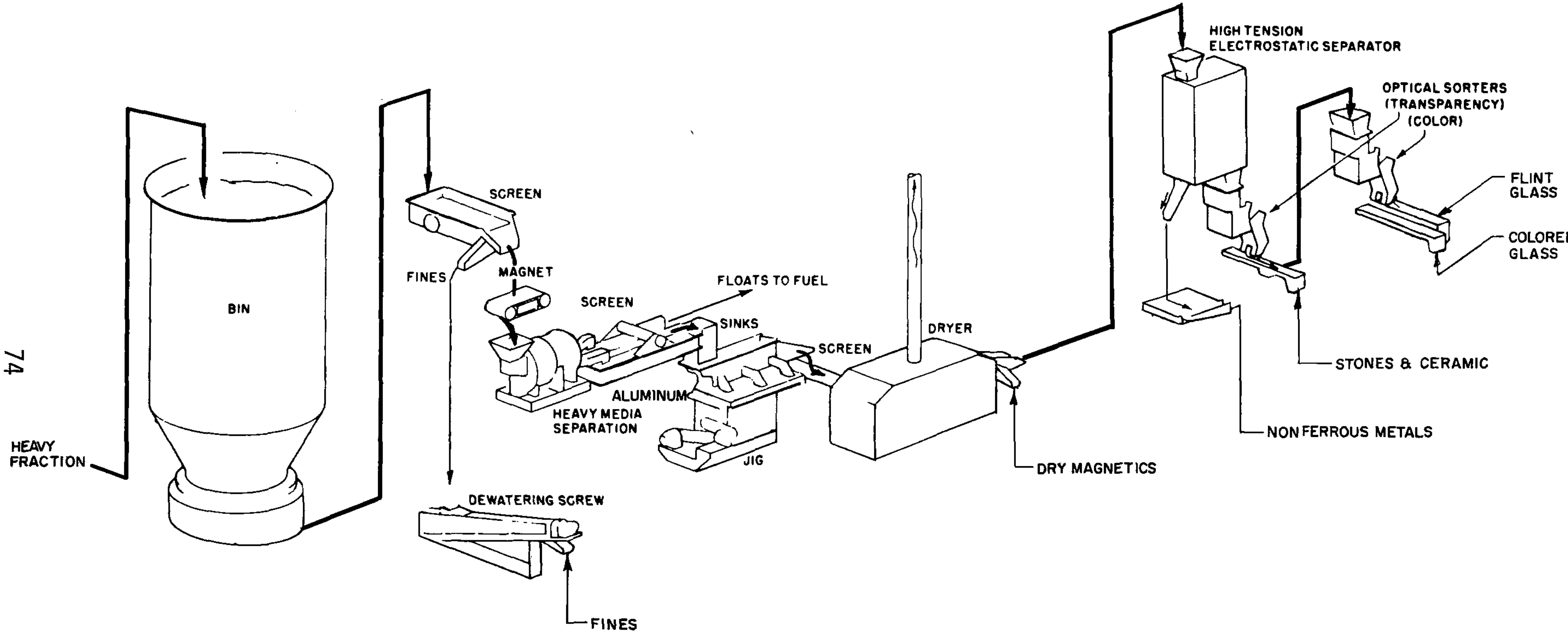

Figure 26. Wet Processs Glass Recovery System

and some dirt with organic residue is washed off; the fines being arbitrarily defined as anything less than 1/4 inch. This undersize material will not be color sorted or recovered in any way, and it is sent to the landfill.

After the screening, the material is magnetically scalped to remove ferrous metals, and is then conveyed to the heavy media separation unit. The heavy media separation unit is held at a specific gravity of 2.0 in order to remove any heavy organic materials, specifically plastics, that have slipped through the liquid cyclone in the main system. All the floated material is returned to the main plant to be burned (it would be used as a fuel in a fuel recovery system). The sink material, that is, the material that has a specific gravity greater than 2.0, is sent on to the jigging operation for separation of glass from nonferrous metals - mainly aluminum.

The jigging operation, as set up at the Franklin site, has three output streams - the lightweight, mostly aluminum can-type stock; the medium fraction which is mostly glass; and a very heavy fraction, composed generally of cast metals, such as brass keys, coins, cast aluminum, cast zinc, or lead-form material. With the feed material held for the proper residence time within the jigging operation, good concentrates of aluminum, glass and heavy metal fractions can be obtained. The glass fraction is conveyed from the jigging operation to the rotary kiln dryer to get rid of the excess surface water.

The glass fraction is then carried by a conveyor to the electrostatic separation unit for removal of any remaining metals.

Material which can be made to carry a charge is pulled out of the glass rich stream. Some natural stone, residual cast metal materials and any residual aluminum can stock is thus removed. The use of this particular device has proved to be very effective for handling materials ranging in size from 1/4 inch to 1 inch.

The glass fraction coming from the high tension electrostatic device is then transported by bucket elevators into hoppers which feed v-shaped belts for the separation of stones and ceramics from the glass fraction by use of a transparency device. The transparency device is a relatively new addition to the processing line at Franklin and is based on the need to remove an extremely high incedence of ceramic or refractory materials found in the glass fraction. These refractory materials are unacceptable in the manufacture of glass containers since their presence causes imperfections in the glass container which destroy the integrity of the jar or bottle. The material, once it has been transparency sorted, is then passed on to a color sorter.

Status and Product Characteristics. In a previous study at Franklin, the glass composition was segregated into flint, amber and green glass. However, experimentation within the industry determined that a triple color sorting was not necessary, and that a flint, non-flint, (amber and green) separation would be sufficient.

While the process appears to satisfactorily sort the glass by color, achieving high recovery rates and an acceptable product appear to be contradictory goals. Specifications commonly used by the glass industry require that the cullet contain a maximum of two stones per 100 pounds of cullet. As presently operating, the pilot plant is producing a much lower quality product. Extensive modifications and tests are being undertaken to remedy the problem. However, at the present times, color sorting is "developmental" technology.

The Occidental Research Corporation System

Process Description. The Occidental Research Corporation (ORC) has constructed a pilot glass and aluminum recovery plant which incorporates froth floatation for glass recovery and eddy current separation of aluminum (Figure 27).

The material fed to this plant consists of municipal solid waste that has been shredded to a particle size of 1 inch. The material, after shredding, has had most of the magnetic metals removed and much of the organic matter has been removed by air classification. As a result of this pre-processing, the feed material largely consists of glass, aluminum, rocks bones, dirt, some magnetic metals, some heavy organics and other inorganic matter.

The material entering the system flows into a trommel which is a large rotating cylindrical screen. The large material, which contains much of the aluminum, passes through the trommel, is conveyed to a magnetic separate for "tramp" ferrous metal recovery, and then to the aluminum separator. Here, a linear induction motor, powered by an alternator generates a force field which acts upon the pieces of aluminum. The aluminum is very rapidly deflected to the side of the conveyor belt and is collected.

The small material stream which falls through the trommel screen openings and is composed of small dense particles, largely glass, is conveyed to a wet type spiral, classifier. Here the material receives its first cleaning and the few light organics are removed. The partially cleansed material then flows by gravity into a rod mill for size reduction. This sized fraction is pumped through a cyclone and screen where the large-sized non-glass material (rubber, plastic, etc.) is removed. The contaminated glass is sized to greater than 200 mesh in a classifier then flows to a conditioning tank where a proprietary ORC reagent called "SiLECT" is added. The "conditioned" glass is then sent to a series of flotation cells called "roughers", "cleaners" and "recleaners". In the froth flotation cells, the pure glass selectively attaches to bubbles. and floats to the top of the cells where it is skimmed off, collected, and sent to a final dewatering classifier. The product glass is then dried and shipped to market. Rejects from the "roughers" are passed through "scavengers," dewatered, and then discharged as tailings.

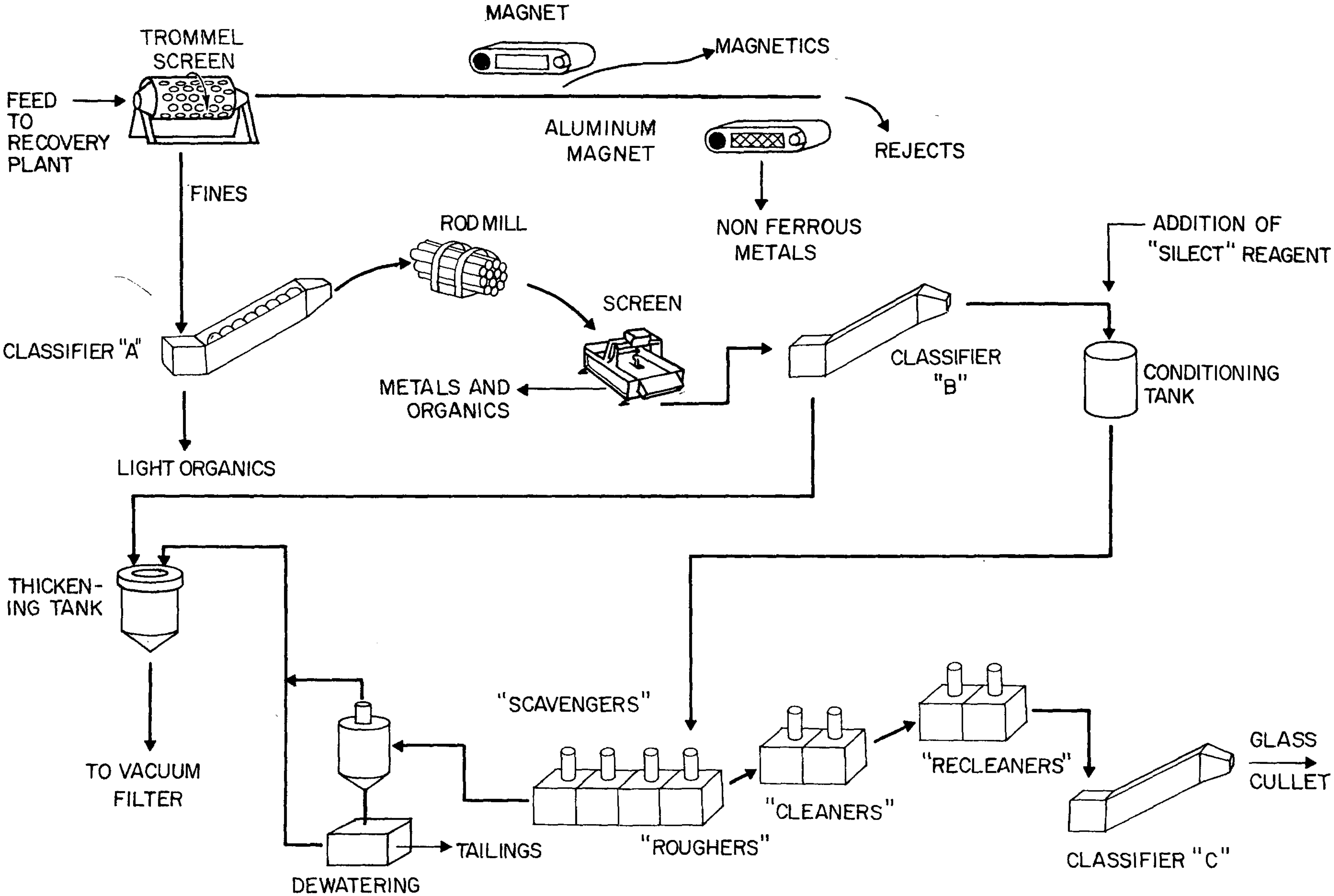

Figure 27. The Occidential Research Corporation has set up a glass and aluminum recovery pilot plant in LaVerne, California utilizing this flow scheme.

Undersize material from the classifier is further processed in a cyclone and screen, thickener tank and vacuum filter. Water used in the process is filtered and treated for reuse.

Status. The first full-scale test of this system will be incorporated in the Occidental Flash Pyrolysis plant now under construction in San Diego County, California. Until full scale, continuous operational experience is obtained and market acceptance of the non-color-sorted cullet has been demonstrated, froth flotation must be classified as "developmental."

SECTION V

READING LIST

Overview

*McEwen, L. B. A nationwide survey of resource recovery activities. Environmental Protection Publication SW-142.1. Washington, U.S. Environmental Protection Agency. (In press.)

*U.S. Environmental Protection Agency, Office of Solid Waste Management Programs. Resource recovery and waste reduction; third report to Congress. Environmental Protection Publication SW-161. Washington, U.S. Government Printing Office, 1975. 96 p.

*U.S. Environmental Protection Agency, Office of Solid Waste Management Programs. Decision-makers guide in solid waste management. Environmental Protection Publication SW-500. Washington, U.S. Government Printing Office, 1976. 158 p.

*Smith, F. A. Comparative estimates of post-consumer solid waste. Environmental Protection Publication SW-148. Washington, U.S. Environmental Protection Agency, May 1975. 18 p.

Parkhurst, J. D. Report on status of technology in recovery of resources from solid wastes. [Whittier], County Sanitation Districts of Los Angeles, California, January 13, 1976. 198 p., app.

Energy Recovery

Conference papers; CRE, Conversion of Refuse to Energy; 1st International Conference and Technical Exhibition, Montreux, Switzerland, Nov. 3-5, 1975. IEEE catalog no. 75CH1008-2 CRE. [Piscataway, N. J.], Institute of Electrical and Electronics Engineers. 615p.

From Waste to Resource Through Processing; Proceedings; 1976 National Waste Processing Conference, Boston, May 23-26, 1976. New York, American Society of Mechanical Engineers. 585 p.

*McEwen, L. B., and S. J. Levy. Can Nashville's story be placed in perspective? <u>Solid Wastes Management/Refuse Removal Journal</u>, 19(8): 24, 28-39, 58, 60, August 1976.

Roberts, R. M., et. al. [Envirogenics Company]. Systems evaluation of refuse as a low sulfur fuel. Washington, U.S. Environmental Protection Agency, 1971. 2 v. (Distributed by National Technical Information Service, Springfield, VA, as PB-209 271 - PB-209 272.)

+Levy, S. J. A review of the status of pyrolysis as a means of recovering energy from municipal solid waste. Presented at 3d U.S. - Japan Conference on Solid Waste Management, Tokyo, May 12-14, 1976. Washington, U.S Environmental Protection Agency, Office of Solid Waste Management Programs. 29 p.

*Sussman, D. B. Baltimore demonstrates gas pyrolysis; resource recovery from solid waste. Environmental Protection Publication SW-75d.i. Washington, U.S. Government Printing Office, 1975. 24 p.

Davidson, P. E. Slagging pyrolysis solid waste conversion. Engineering Digest, 21(7):31-34, August 1975.

Anderson, J. E. The oxygen refuse converter - a system for producing fuel gas, oil, molten metal and slag from refuse. In Resource Recovery Thru Incineration; Proceedings; 1974 National Incinerator Conference, Miami, Florida, May 12-15, 1974. New York, American Society of Mechanical Engineers. p. 337-357.

*Levy, S. J. San Diego County demonstrates pyrolysis of solid waste to recover liquid fuel, metals, and glass. Environmental Protection Publication SW-80d.2. Washington, U.S. Government Printing Office, 1975, 27 p.

Preston, G. T. Resource recovery and flash pyrolysis of municipal refuse. In Clean Fuels from Biomass, Sewage, Urban, Refuse and Agricultural Wastes Symposium, Orlando, Florida, Jan. 27-30, 1976. Chicago, Institute of Gas Technology. p. 89-114.

*Hitte, S. J. Anaerobic digestion of solid waste and sewage sludge to methane. Environmental Protection Publication SW-159. [Washington], U.S. Environmental Protection Agency, July 1975. 13 p.

Pfeffer, J. T. University of Illinois, Department of Civil Engineering. Reclamation of energy from organic waste. Washington, U.S. Environmental Protection Agency, March 1974. 143 p. (Distributed by National Technical Information Service, Springfield, VA, as PB-231 176.)

Materials Recovery

*Arella, D. G. Recovering resources from solid waste using wet-processing; EPA's Franklin, Ohio, demonstration project. Environmental Protection Publication SW-74d. Washington, U.S. Government Printing Office, 1974. 26 p.

Systems Technology Corporation. A technical, environmental and economic evaluation of the "wet processing system for the recovery and disposal of municipal solid waste." Environmental Protection Publication SW-109c. U.S. Environmental Protection Agency, 1975. 223 p. (Distributed by National Technical Information Service, Springfield, VA, as PB-245 674).

+Levy, S. J. Materials recovery from post-consumer solid waste. Presented at 3d U.S.-Japan Conference on Solid Waste Management, Tokyo, May 12-14, 1976. Washington, U.S. Environmental Protection Agency. 29 p.

Morey, B., J. P. Cummings, and T. D. Griffin. Recovery of small metal particles from nonmetals using an eddy current separator - experience at Franklin, Ohio. Presented at 104th Annual Meeting. American Institute of Mining, Metallurgical and Petroleum Engineers, New York City, February 16-20, 1975. 11 p.

Campbell, J. A. Electromagnetic separation of aluminum and nonferrous metals. Presented at 103d Annual meeting, American Institute of Mining, Matallurgical and Petroleum Engineers, Dallas, February 24-28, 1974. 17 p.

Non-ferrous metals recovery...conserving a valuable resource. NCRR Bulletin, 5(3):67-72, Summer 1975.

McChesney, R., and V. R. Degner. Hydraulic, heavy media, and froth flotation processes applied to reocvery of metals and glass from municipal solid waste streams. Presented at 78th National Meeting, American Institute of Chemical Engineers, Salt Lake City, August 18-21, 1974. 27 p.

Samtur, H. R. Glass recycling and reuse. IES Report 17. Madison, University of Wisconsin, Institute for Environmental Studies, March 1974. 100 p.

Cummings, J. P. Glass and non-ferrous metal recovery subsystem at Franklin, Ohio - final report. In Proceedings; 5th Mineral Waste Utilization Symposium, Chicago, April 13-14, 1976. Chicago IIT Research Institute. p. 175-183.

---

*Available from: Solid Waste Information Control Section, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

+Available from: Resource Recovery Division, Office of Solid Waste Management Porgrams, U.S. Environmental Protection Agency, Washington, D.C. 20460.