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ENERGY RECOVERY FROM SOLID WASTE

Volume 1 - Summary Report

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16. Abstract

A systems analysis of energy recovery from solid waste demonstrates the feasibility of several current processes for converting solid waste to an energy form. The problem is considered from a broad point of view. The social, legal, environmental, and political factors are considered in depth with recommendations made in regard to new legislation and policy. Biodegradation and thermal decomposition are the two areas of disposal that are considered with emphasis on thermal decomposition. A technical and economic evaluation of a number of available and developing energy-recovery processes is given. Based on present technical capabilities, use of prepared solid waste as a fuel supplemental to coal seems to be the most economic process by which to recover energy from solid waste. Markets are considered in detail with suggestions given for improving market conditions and for developing market stability. A decision procedure is given to aid a community in deciding on its options in dealing with solid waste. A new pyrolysis process is suggested. An application of the methods of this study are applied to Houston, Texas.

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INTRODUCTION TO THE SOLID WASTE PROBLEM

It is estimated that the amount of solid waste generated daily in this country averages between 1.18 and 1.81 kilograms (2.6 to 4 pounds) for each person. The exact estimate within this range depends on the authority quoted. Even at the lower estimate, the total mass of material to be handled is overwhelming and the average per person, as well as the total, is increasing. The material comes from many sources and with a great diversity of physical form and chemical composition.

Contributing to the problem is the fact that, concurrent with the steadily increasing mass of solid waste for disposal, traditional methods of disposal are becoming less and less acceptable socially and environmentally, or economically practical. The reasons are many and include a complex interaction of political, environmental, legal, social, economic, and technical considerations.

Disposal of solid waste is one of the most difficult and frustrating problems facing municipal authorities.

Why Energy and Resource Recovery From Solid Waste?

For many decades our concern with solid waste has concentrated on disposal. The attitude has been: Get rid of it -- somehow, somewhere. Only recently have we begun to focus attention on its utilization. A growing awareness is developing that we as a nation are consuming our nonrenewable metal, mineral, and energy resources at a rate faster than population growth. A logical result of this awareness is the realization that solid waste is in itself a resource; we are discarding via the garbage can a high proportion of our primary resources.

The combination of the growing unacceptability of traditional disposal methods along with the need to conserve the nation's resources has spurred efforts to exploit solid waste. Initially, efforts were concerned with recovering materials: ferrous and nonferrous metals, glass, and paper. The current energy shortage helped stimulate a further awareness that the high percentage of organic material including soiled paper in solid waste represents an energy resource. More recent utilization efforts, therefore, have included the development of ways to recover effectively the energy resources inherent in solid waste.

Although it makes good sense to recover energy and materials from solid waste, many problems remain to be solved before such recovery can be practiced widely, efficiently, and economically. The investigation in this report is an attempt to help solve some of these problems.

Parameters of the Study

Emphasis in this study is primarily on energy recovery from solid waste. However, it is virtually impossible to consider energy recovery techniques without also considering the recovery of materials. In many instances, both types of recovery will be necessary for an economically viable process. In general, however, resource recovery is given somewhat less emphasis in this study.

The collection of solid waste is considered to be outside the scope of this study and is not treated in any detail. There are several reasons for this. First, much excellent work already has been done on the collection problem. Second, the need for collection is not unique to energy and resource recovery; it still must be done for traditional disposal practices, and collection methods will not differ too much in either case. Third, as a nation-wide average, the collection of solid waste costs about $45 per ton and represents about 80 percent of the total for present traditional disposal costs. However, current trends in disposal costs are such that collection undoubtedly will represent a much smaller proportion of total solid waste handling costs in the future. The design group concluded, therefore, that it was best to restrict the study efforts to the recovery technologies.

Solid waste, as treated in this study, consists of what generally is known as Mixed Municipal Refuse (MMR). It is what the municipality normally picks up at the curb of residences and from commercial and institutional buildings.

Sewage treatment and the handling of industrial wastes are specifically excluded from this study.

The Approach Followed

In carrying out the study, we have attempted first to identify the various nontechnical aspects of the solid waste problem: political, environmental, legal, social, and economic. It is recognized that the dividing line between nontechnical and technical problems sometimes is vague, and we have attempted to show the interactions between the two.

Insofar as possible, we have tried to identify all of the publicly known techniques or processes for recovering energy or materials products from solid waste. At least 50 processes exist for the conversion and recovery of energy products and these can be categorized broadly as incineration, pyrolysis, or biodegradation processes. Numerous variations are possible within each broad category.

Energy products may be in the form of solids, liquids, or gases -- or energy may be recovered more directly as hot water or steam. Some processes recover combinations of these several types of energy products. The form, or forms, of energy and other products recovered depend on the type of process, its operating conditions, and economic factors.

All levels of technical development are represented by the many different processes available. Some are still in the R & D stage and some are in pilot plant testing. In some instances commercial-scale facilities are under construction, and several commercial-scale units are completed and in operation.

These various levels of development and the different capacities involved make comparative evaluations difficult. However, we have attempted to compare the technical and economic characteristics of the different processes -- including their social, environmental, and related considerations -- on as nearly an equitable basis as possible. Where data do not exist, or are proprietary, we have exercised our best engineering judgment when making estimates.

Along with this activity, a concept for a new pyrolysis process was developed and is suggested for further research.

Various aspects of the marketing situation and other utilization factors relating to the different energy and recovered products are analyzed and discussed.

As the study progressed, it became evident that no single conversion process was superior to all others as an answer to the solid waste problem under all conditions. The choice of appropriate conversion process for energy and resource recovery is highly sensitive to the local situation. The study group therefore developed, and describes in this report, a decision model employing the systems approach. It believes that this model will be helpful to municipal authorities in selecting from among the many alternatives available the best route to follow -- energy recovery, materials recovery, or both -- and the conversion process best suited to their particular local situations.

SOCIAL ASPECTS OF SOLID WASTE MANAGEMENT

The social, political, environmental, and legal aspects of solid waste which we believe would either encourage or discourage the implementation of energy generation and resource recovery are summarized in this chapter.

The social and political factors which encourage or discourage energy and resource recovery are summarized in Table 2-1. Social attitudes and political problems are intimately interrelated and both are closely tied to cost factors. Citizen's attitudes are closely associated with their degree of knowledge of the problem of solid waste (which is in part locality dependent). Ordinarily, citizens do not think much about garbage unless, of course, a collector's strike finds them with a surplus of this commodity. The average citizen's concern with garbage ends at the curb. A nationwide survey of metropolitan housewives revealed that over 30 percent of them did not have any idea what happened to their solid waste after it was collected.

TABLE 2-1
SOCIAL AND POLITICAL FACTORS

ENCOURAGING	DISCOURAGING
1. Energy and resource shortages as a solution to solid waste disposal	1. Citizen attitude toward solid waste problem -- non crisis
2. Concern on part of some citizens regarding limited resources	2. Maintenance of political stability
3. Pressure from environmental groups	3. Lack of comprehensive planning in site selection
	4. Resistance to change in lifestyle source separation, separate collection, disposal bottles, changes in convenience packaging
	5. Reluctance to pay increased costs of alternate disposal systems

Although most citizens now believe that we do have an energy shortage, few are aware that technology exists to recover energy from their own garbage. Wider dissemination of this information could be expected to encourage energy recovery from refuse if the economics of such a procedure are competitive with current practices. Possibly, local environmental groups might serve as a means to disseminate this information. However, any innovative system could be expected to encounter opposition if it poses the threat of additional cost or a change in lifestyle (e. g. source separation, changes in convenience packaging).

Municipal refuse is usually a low priority item with local decision makers; their main concern is also the short-term problem of collection and disposal. In most cities, collection alone is a big enough job. Local officials frequently do not have the time, funding, or manpower for long-range planning unless a local disposal crisis exists. In addition, unless a crisis exists, any change from existing disposal methods may present an immediate political liability to elected officials.

Although insufficient information exists to generalize about local decision makers' attitudes toward energy and resource recovery from refuse, we have found that local decision makers and waste managers do demand certain requirements of any waste disposal system. First, and most important, a disposal system must be reliable and of proven technology. Unproven processes could only be expected to be implemented as pilot plants in areas with acute disposal problems, and then only as supplements to existing methods. Second, any disposal method (including energy recovery systems) must not cost substantially more than current practices.

The environmental factors which encourage or discourage energy and resource recovery are summarized in Table 2-2. Environmental constraints in the form of Federal, state, and local regulations provide a significant and immediate motivating force to clean up our environment. The underlying rationale for most environmental legislation has been a concern for public health. Environmental regulations seek to minimize or eliminate the potential health hazards that have been directly attributed to pollution.

Many past and some current waste disposal practices such as open dumps, open burning, and "unsanitary" sanitary landfills have made significant contributions to air and water pollution. Present and pending regulations and restrictions of these methods, as well as air and water quality standards, all demand change from "dirty" waste disposal practices for municipalities and industrial concerns. The legal constraints to clean up our environment and the realization of a real energy shortage are expected to be factors which will encourage the development and implementation of processes to recover energy from solid waste. Any proposed installation to recover energy from solid waste will have to meet the same state and Federal air and water quality standards for emissions as any other industrial plant. If the energy generating process represents a hybrid between conventional systems and new "energy from refuse technology" it may be subject to additional or unique combinations of existing regulations.

TABLE 2-2
ENVIRONMENTAL FACTORS

ENCOURAGING	DISCOURAGING
1. Present restrictions on landfills	1. Lack of enforcement of present air, water, landfill standards
2. Ocean dumping restrictions--present and pending	2. Citizen attitude of unlimited resources
3. Air and water standards--present and pending	3. Public ignorance of environmental problems
4. Limited nature of resources	
5. Potential public health hazards of current practices	

The legal factors which encourage or discourage energy and resource recovery are summarized in Table 2-3. Among the legal considerations which an energy recovery plant should consider are the problems associated with the ownership, marketing, and freight rates of recycled resources. The economic viability of most proposed processes depends on the extraction of at least some secondary materials. In fact, it may be the credits for these recycled goods that will make an energy recovery system competitive with current waste disposal practices.

Federal interest in energy and resource recovery dates back to the enactment of the Solid Waste Disposal Act of 1965, as amended by the Resource Recovery Act of 1970. These laws establish as national goals the development of better technology for the recovery of secondary materials and energy from solid waste. More importantly, they provide Federal funding for demonstration grants and implement preferential Federal procurement policies for some goods manufactured from recycled resources.

Federal freight rate policies have long been known to discriminate against certain categories of recycled material with respect to virgin materials. These policies are currently under review by the ICC, and those found to discriminate against recycled materials will be considered for change.

TABLE 2-3
LEGAL FACTORS

ENCOURAGING	DISCOURAGING
1. Federal demonstration grants	1. Federal freight rate policies
2. Federal procurement policies	2. Natural gas regulations
3. Federal considerations for policy changes in: A. Freight rates B. Tax policies C. Tax status of bonds D. Product design legislation	3. Federal tax policies
	4. Tax free status of municipal bonds used in public/private systems
	5. Metropolitan area wide disposal systems needed for efficient operation
	6. Short term municipal contracts
	7. Exclusive franchises
	8. Product liability as an unknown
	9. Lack of product design legislation to alter composting of solid waste and encourage resource recovery

The secondary materials industry has begun to lobby for more equitable policies in the areas of depletion allowances and special capital gains treatment which have long been extended to producers of certain nonrenewable virgin resources. Policy changes advantageous to the secondary materials industry in both these areas of major concern, would be expected to stimulate indirectly the implementation of more energy recovery from refuse.

On the other hand, there are a number of Federal governmental factors which tend to discourage energy and resource recovery. The Federally fixed price of interstate natural gas may force any refuse-derived fuel to compete at an unnaturally low price. (State and local fuel price setting may also have this same affect). Federal tax policies which give advantages to virgin raw materials over recycled raw materials will also have a detrimental effect if not changed.

A recent ruling by the Internal Revenue Service that interest from municipal bonds used by public/private partnership systems are not income tax free may make financing of proposed installations more difficult. A number of local policies and laws also discourage energy and resource recovery. Among them are the following:

1. The need to create area-wide

disposal authority systems in order to supply the 453 metric ton per day of refuse required for efficient and economically practical energy recovery systems.

2. Short-term contract limitations (usually 5 years) imposed by many city charters may prevent the long-term arrangements required by many industries.

3. Exclusive franchises already granted by municipalities which may hamper the sale of recovered resources.

4. Unknown legal status of product liability for products produced from refuse may hamper the sales of these products to industry.

To encourage resource and energy recovery from solid waste, we offer the following recommendations for change in existing policies.

1. Eliminate tax and freight rate advantages presently given virgin materials in order to make secondary materials more competitive and help conserve limited natural resources.

2. Subsidize research on resource recovery from solid waste.

3. Impose an excise tax on all virgin resources used to encourage use of secondary materials.

4. Implement governmental standards on product design and product reliability of products.

5. Adopt deposit (Oregon) legislation for the beverage industry.

6. Establish disposability standards for products. All products produced should have a disposal method. For certain products (e. g., automobiles and domestic appliances) it may be necessary to set disposal taxes or bonds which would be included in the original retail price of the product.

7. Provide Federal grants-in-aid to communities to help establish solid waste management systems.

8. Implement all present environmental standards relating to air, water, and landfills. Implementation of these standards would encourage the adoption of energy and resource recovery systems.

The use of solid waste as energy could provide a small percentage of this country's total energy demand. Based on an energy content of solid waste of approximately 1.165 x 10^7 joule/kilogram (5000 Btu/pound) the energy from solid waste could provide a fuel equivalent to 25 percent of our annual consumption of natural gas or about 2 percent of our current fossil fuel consumption (ref. 3-1). On a more local basis, the energy from a community's solid waste could be used to provide up to 20 percent of that community's electrical power requirements. Locally, the recovery of energy from solid waste appears to contribute a significant amount to the total energy picture, but for many communities, the energy recovery will be a secondary advantage. The primary advantage will be the virtual elimination of the solid waste disposal problem.

Energy Recovery Concepts

Energy recovery from solid waste is a relatively new concept, precipitated by the shortage of sanitary landfills in highly populated areas, by public concern over the location and presence of landfills, and to a lesser extent, by the recent energy crisis. The traditional disposal methods are shown schematically in Figure 3-1. The three methods shown are open dumping, sanitary landfill, and incineration. There are many disadvantages associated with each of these alternatives, and many of these have been discussed previously.

Not one of these methods is totally acceptable as a solution to the solid waste problem. Sanitary landfills are generally the cheapest means of disposing of the solid waste. Consequently, systems which recover energy from solid waste are often compared to sanitary landfill costs and will probably have to compete economically with landfill disposal methods to be considered by many communities. The following is a discussion of sanitary landfills and the economics of this waste-disposal method. Incineration costs are discussed in the Midwest Institute Report, (ref. 3-2) and will not be discussed in detail in this report.

Sanitary landfills receive the bulk of the refuse generated in this country. Close-in sites are usually the cheapest means of disposal of Mixed Municipal Refuse (MMR), but land is becoming less available for disposal sites in large metropolitan areas. This means that remote disposal areas must be found. Remote sites make the disposal cost of MMR greater because of increased transportation and time. The economics of both close-in and remote landfills vary with capacity. Expected disposal costs may range from \$3.10/metric ton (\$2.81/ton) for a 227 metric ton/day (250 ton/day) capacity to \$2.65/metric ton (\$2.41/ton) for an 1814 metric ton day (2000 ton/day) capacity, for a close-in disposal site.

The costs for remote landfill (100 miles from the collection area) are considerably higher. The range is from \$6.87/metric ton (\$6.25/ton) to \$6.25/metric ton (\$5.67/ton),

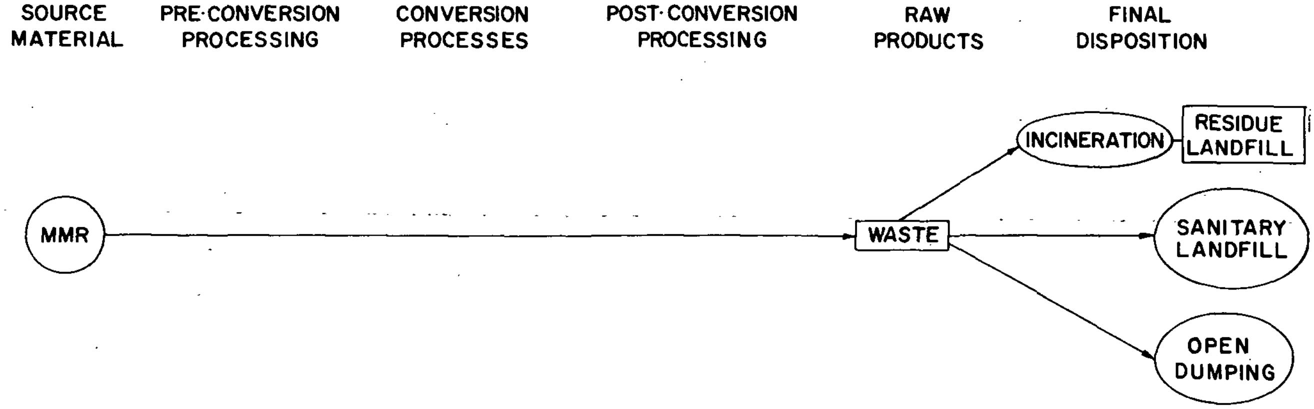

FIGURE 3-1
CONVENTIONAL METHODS OF REFUSE DISPOSAL

for the same capacities given for the close-in landfill. These cost estimates for sanitary landfill disposal are taken from the Midwest Research Institute Report (ref. 3-2) and may be considered as typical costs. Local land, labor, and transportation costs could cause some deviation from these economic data.

As an alternative to landfill or incineration of the raw refuse, some processing could be performed, either for the purpose of materials recovery or simply for the purpose of rendering the refuse more acceptable for sanitary landfill. If additional separation, drying, and grinding steps are performed, a solid fuel could be obtained. These various routes are shown in Figure 3-2.

Resource recovery systems are front-end or pre-conversion process systems which will recover metals, glass, and other useful materials. After recovery, the remaining products in the MMR could either be landfilled or incinerated.

If energy from refuse is desired, several conversion alternatives are available. The broad categories are incineration, pyrolysis, and biodegradation. Each of these methods is discussed in the following sections.

Incineration of refuse in this country, historically, has been plagued with problems. The incinerators polluted the atmosphere with undesirable gases and solid particulates, obnoxious odors, and unburned refuse. They were expensive to operate and were generally not accepted by the public. Only a relatively small number (less than 200) of municipal incinerators were still in operation in the U. S. in 1972 (ref. 3-1).

The newer incineration processes, with energy recovery, are better designed and should improve on all of the above negative characteristics of incinerators. Figure 3-3 is a schematic illustration of the possible incineration routes for energy recovery. In general, they are direct incineration of refuse alone, and the use of refuse as a supplemental fuel. Materials recovery can occur before or after the conversion process, depending on the resources desired. A number of products are possible from the incineration conversion process, the most important probably being steam.

Pyrolysis is defined as destructive distillation, or thermal decomposition, without complete combustion. Figure 3-4 is a schematic illustration of pyrolysis conversion processes. Pyrolysis products may consist of storeable gaseous, liquid, or solid fuels, and resource recovery may occur before or after the conversion process, again depending on the resources desired.

Biodegradation conversion routes are shown schematically in Figure 3-5. The two broad categories are biochemical and biological conversion, and several products are possible, including gases, liquids, and solids.

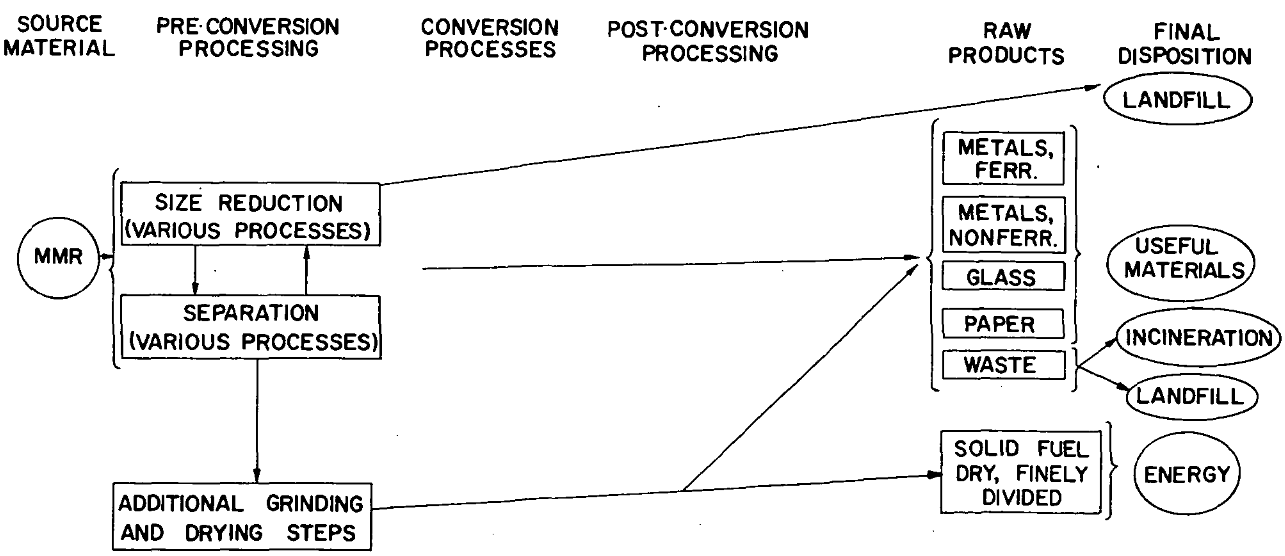

FIGURE 3-2
REFUSE PRE-CONVERSION PROCESSING ROUTES

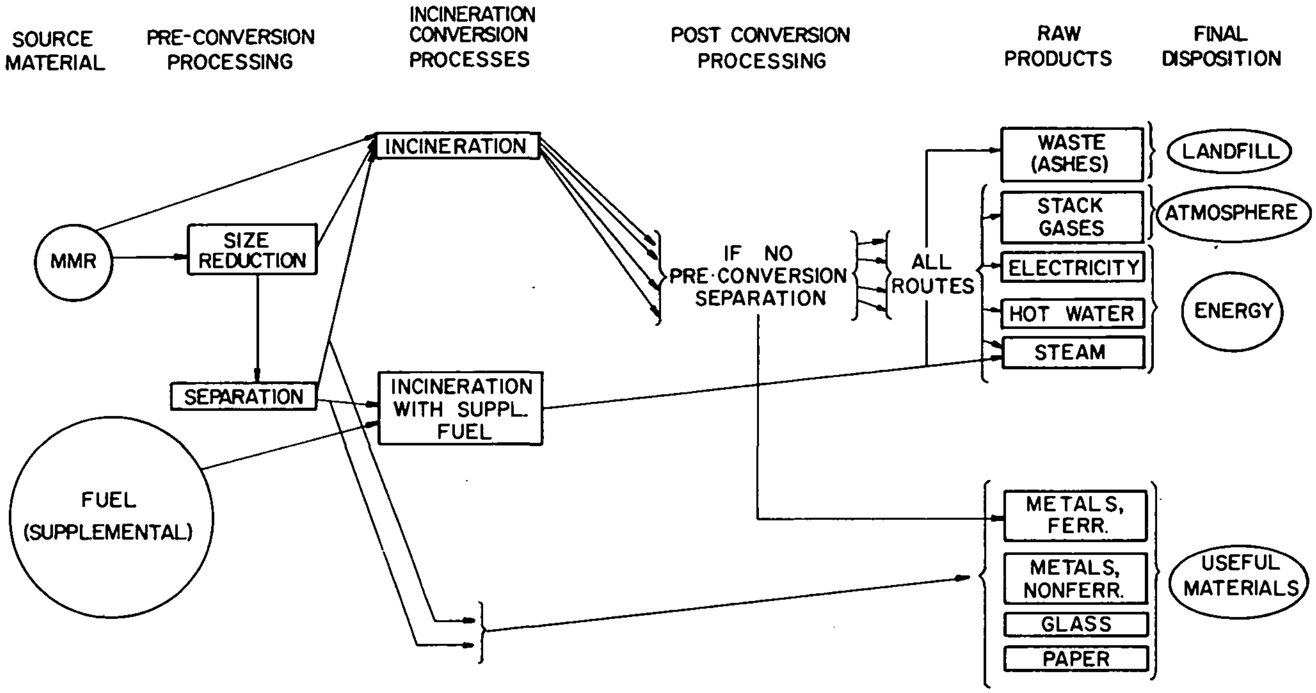

FIGURE 3-3
REFUSE INCINERATION ROUTES WITH ENERGY RECOVERY

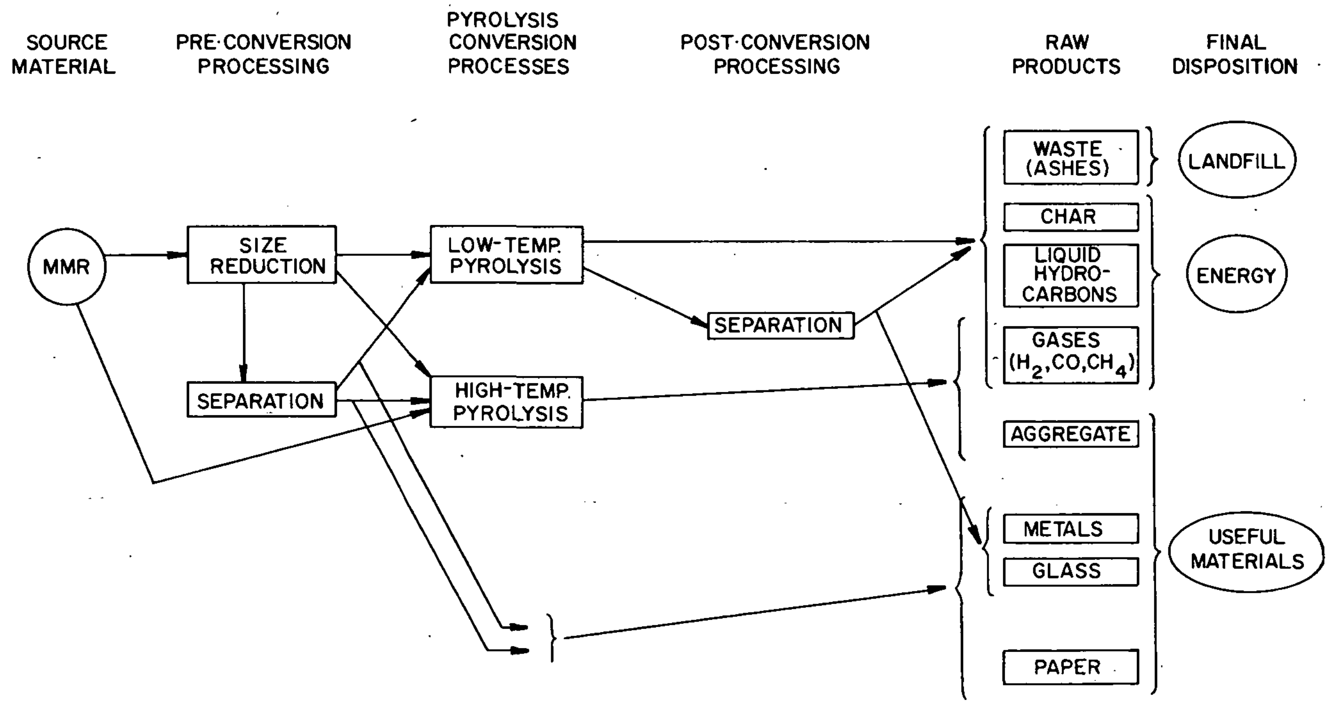

FIGURE 3-4
PYROLYSIS OF REFUSE

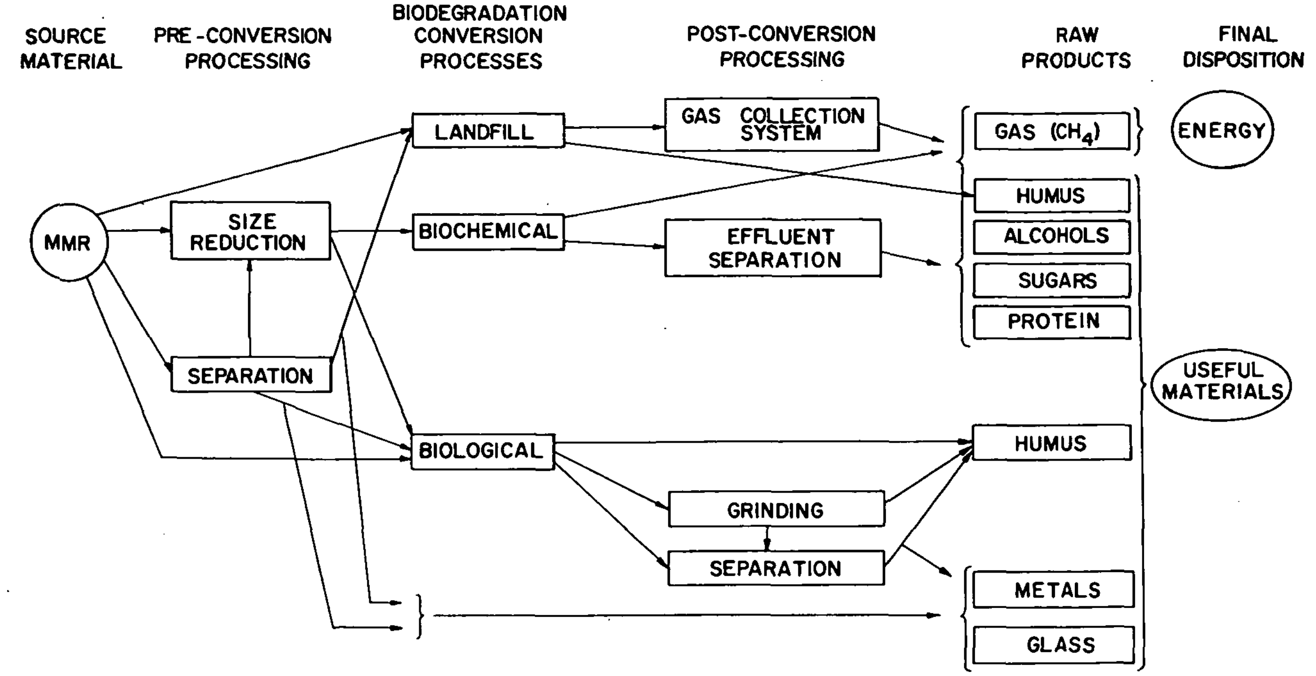

FIGURE 3-5
BIODEGRADATION OF REFUSE

Pre-Processing Techniques

Generally speaking, pre-processing includes all the steps of handling Mixed Municipal Refuse (MMR) from its source up to the stage where it is ready for conversion processing. In this study, however, the collection aspects of MMR were not considered.

The content of MMR varies daily in a given location, and even varies in different localities of the country. Refuse generally contains some moisture, and the rainy season drastically increases the total refuse tonnage to be collected. Table 3-1 contains a "typical" composition of MMR, which may be used to determine the amount of potential resources that may be recovered from refuse.(ref. 3-2)

TABLE 3-1
TYPICAL COMPOSITION OF
MIXED MUNICIPAL REFUSE

Waste Component	Percent by Weight
Paper	33.0
Glass	8.0
Ferrous metals	7.6
Plastics, leather, rubber, textiles, wood	6.4
Garbage and yard wastes	15.6
Miscellaneous (ash, dirt, etc.)	1.8
Total Dry Weight	73.0
Moisture	27.0
Total	100.0

It should be noted from Table 3-1 that the refuse typically contains a large amount of moisture. Thus, the amount of resources actually present and recoverable, either in the form of materials or energy, is typically 70 to 80 percent of the as-received tonnage.

The use of size reduction equipment (i.e. hammermills, shredders, grinders, etc.) is gaining acceptance as a preliminary operation in processing solid waste. Two decades of experience and published data concerning the characteristics of shredded refuse are emerging because of the changing economic picture and environmental concerns associated with traditional solid waste disposal philosophy (ref. 3-3).

Benefits of shredding can be realized by almost any kind of followup process whether it is energy recovery, material recovery, or landfill. Initially, shredding of refuse was used as an attempt to increase combustion efficiencies for incineration processes and for the purpose of composting wastes. Although incineration and composting have only obtained limited success, the following advantages of shredding have been noted as a result of these operations:

1. volume reduced by about 50 percent,
2. refuse is more predictable and homogenous,
3. refuse is more rapidly stablized,
4. conveyor movement, magnetic separation, and air classification operations are enhanced,
5. danger from explosives reaching later processes is virtually eliminated,
6. reduces scavenger population (rats, gulls, etc.) at landfill sites,
7. eliminates obnoxious odors usually encountered at dumps,
8. provides more surface area for thermal processes such as pyrolysis or incineration,
9. shredded nonrecognizable waste is con-

sidered more acceptable for land disposal

10. blowing debris is less of a problem because of the dense interlocking characteristics of shredded trash, and
11. fire potential, a definite problem with landfill, is substantially reduced.

There are very definite benefits to be gained from shredding, and the equipment used to accomplish shredding operations include horizontal and vertical shaft hammermills, fail mills, disc mills, grinders, and cage disintegrators, all of which are discussed in more detail in Volume II of this report.

One of the important steps in preparing MMR for any processing is segregation of the MMR according to its main component categories. In most cases an efficient separation process achieves most of the material recovery contemplated in the process. At present, many types of separation processes are in use in various industries. It is only a question of adopting these units for handling MMR. In the last few years many of the manufacturers have tried to adopt their products for this special use. The following (ref. 3-4) are some of the major techniques of separation that are being practiced in the various types of industries:

Hand sorting
Screens
Magnetic separators
Air classifiers
Optical sorting
Inertial separation
Eddy current separation
High-density electrostatic separation.

Hand sorting is the simplest of the above separation methods, and it is effective for removing items such as newspapers and cardboard from the refuse stream. Magnetic separators are highly developed and are in use in quite large numbers of resource recovery plants. Air classifiers are becoming more important in separating out the combustible portion of MMR for use as a solid fuel, and improved air classifiers are currently under development.

The remaining separation methods deal primarily with glass sorting, and with removal of nonferrous metals, especially aluminum, from the refuse stream. Since aluminum is one of the most valuable items in MMR, much developmental work is being done to find an efficient way to separate it from the refuse. To date, however, the separation methods for aluminum and color sorting of glass have not proven economically feasible on a large scale basis.

Most of the energy recovery systems require some pre-processing of the refuse, and these separation and size reduction steps are often referred to as "front-end" systems. It may be, however, that a municipality may not wish to consider the final conversion step, energy recovery, so the pre-processing can be considered as a terminal process in itself. Several system alternatives just involving separation or size reduction are as follows:

1. Size reduction alone - Using currently available shredding techniques, the volume of MMR may be reduced up to 50 percent. This is important for landfill operations, both for the decreased volume and for the greater ease of handling the more homogenous refuse.

2. Size reduction with separation of materials resources - Recovery from the refuse of materials such as glass, iron, newsprint, cardboard, and aluminum would be possible. These materials could be recycled and credits obtained to affect the cost of the recovery system.

An example of a resource recovery system is the Black-Clawson plant in Franklin, Ohio. Fiber is recovered by a wet pulping process, and metals and glass are removed from the refuse stream. The remaining fraction of refuse is then incinerated (ref. 3-5).

3. Size reduction and separation with recovery of materials resources and an energy product - Mixed municipal refuse contains significant amounts of paper, wood, cardboard, and plastic, all of which have a high heating value. Removal of the ferrous metals, glass, aluminum, and inert materials such as a sand and dirt will leave a combustible fraction having a heating value of around 1.62-1.85 x 10^7 joule/kilogram (7000-8000 Btu/pound). This heating value is almost comparable to low grade coal and roughly equivalent to two-thirds the heating value of high-grade coal.

Two systems currently in operation producing a solid fuel from refuse are Combustion Equipment Associates' Eco-Fuel™ II, (ref. 3-6) and the Garrett Corporation's front-end system of their pyrolysis process (ref. 3-7). In both systems the solid fuel can be produced in a fine powder form suitable for combustion in a utility boiler. The fuel may be stored and transported without any special handling.

Incineration Processes

There are a number of incineration processes in existence or under development that will recover energy from municipal refuse. At least two of these systems had their origins in Europe, and this European technology is being applied now in the United States and Canada. The incineration processes to be discussed are:

1. Typical water-wall incinerators for steam generation.
2. The C.P.U. 400 incineration system for electrical power generation.
3. Supplemental fuel systems for electrical power generation.
4. Direct incineration in boilers of prepared refuse for steam generation.

Several water-wall furnaces are listed in Table 3-2. These are not all of the water-walled incineration systems on the North American Continent, but they are typical. There are several chacteristics to note. First, the stokers are of modern European design (ref. 3-8 and 3-9). Both the Martin and VonRoll grates are reciprocating grates, on which the refuse is continuously agitated and turned for more complete combustion. Particulates are generally removed by electrostatic precipitators, although wet scrubbers and dry cyclone methods will be used in the Nashville plant. The usage for the energy product varies from a limited local use in the steam directly to a nearby General Electric power generating facility for the Saugus, Mass. plant. It may be noted from Table 3-2 that the capacities of these plants are as high as 1452 metric ton/day (1600 ton/day).

The CPU-400 energy conversion system has a 63.5 metric ton/day (70 ton/day) pilot plant currently under test (ref. 3-13). The system starts with a rigorous pre-processing system which removes most of the magnetic materials, aluminum, glass, and other non-combustibles. This light fraction is then incinerated in a fluidized-bed combustor. The products of combustion are then cleaned up to remove the particulates and molten aluminum. The cleaned gas stream is then expanded through a two-stage gas turbine/compressor. The first stage of the turbine drives the compressor, providing the pressurization air for the fluidized bed. The second stage expansion drives an electrical generator, producing electrical power.

The firing of refuse as a supplemental fuel in utility boilers is a fairly common practice in Europe, but the only project of this nature in the United States is the St. Louis Horner-Shifren process (ref. 3-14, 3-15). Prepared refuse, shredded to one and one-half inches, is fed pneumatically into a utility boiler where it is burned in suspension with pulverized coal. The air density classifier system has been added recently to improve the burning characteristics of the refuse.

TABLE 3-2
TYPICAL INCINERATION PLANTS WITH ENERGY RECOVERY

LOCATION	DATE OF START UP	STOKER	CAPACITY METRIC TPD / TPD	PARTICLE SEPARATION TECHNIQUE	OUTPUT: FLOW RATE $kg/hr \times 10^{-3}$ / $lb/hr \times 10^{-3}$	OUTPUT: TEMP °C / °F	OUTPUT: PRESSURE $N/m^2 \times 10^{-6}$ / Psig	USAGE	COMMENTS	REFS.
Montreal Canada	1971	Von Roll	4x272 / 4x300	Electric-Static Precipitator	45 / 100	260 / 500	1.55 / 225	Heating & Auxiliary Power	10-15% of input-ash & scrap metal	3-24 3-28
Chicago Northwest Incinerator	1972	Martin	4x363 / 4x400	Electric-Static Precipitator	200 / 440	204 / 400	1.7 / 250	Limited	Recovered Magnetic Metals	3-24 3-28
Harrisburg Pennsylvania	1972	Martin	2x326 / 2x360	Electric-Static Precipitator	63 / 138	232 / 450	1.7 / 250	Auxiliary Power		3-29
Nashville Tennessee	Late 1974	Von Roll	2x226 / 2x360	Wet Scrubbers Dry Cyclone	99 / 218	185 SAT / 365 SAT	1.03 / 150	Auxiliary Coolant, Steam	$16.5 Million	3-30
Saugus Massachusetts	1975	Von Roll	4x272 / 2x360	Electric Static Precipitator	102 / 225	427 / 800	4.3	Power		3-1

Since coal is normally fired in the boilers, bottom ash handling equipment and precipitators for particulate removal already exist. The firing of refuse is not expected to require any additional equipment in these areas.

Supplemental fuel incineration is the most cost effective energy recovery system considered in this study (see Vol. II for the economic data), and a number of communities are considering projects similar to the St. Louis project. They include: Ames, Iowa; Albany, New York; Monroe County, New York; New York City; Wilmington, Delaware; and Memphis, Tennessee (ref. 3-16). The state of Connecticut has already contracted for a supplemental fuel project using the Garrett front-end system. The system is expected to be completed in 1976 (ref. 3-17).

As discussed in section 3.2.4, prepared refuse can have a heating value approaching that of low grade coal. Combustion Equipment Associates (C.E.A) has a contract with the state of Connecticut to build a resource recovery system and to prepare Eco-Fuel™ II from refuse (ref. 3-17). The solid fuel will be burned in a utility boiler for steam generation. Tests will be conducted to determine the optimum particle size and combustion characteristics when firing refuse in their double vortex boilers. The plant is expected to be operational in 1976.

Pyrolysis Processes

Pyrolysis is defined as thermal decomposition without complete combustion. If a storable fuel is desired, either gaseous, liquid, or solid, pyrolysis offers a viable option with a minimum amount of landfill and pollution control problems. The process technology, however, has not been widely demonstrated on a commercial basis; thus there is considerable confusion regarding vendor technical and economic claims.

The cellulose portion of the refuse may be represented by an emperical formula (ref. 3-18), $C_{30}H_{48}O_{19}N_{0.5}S_{0.05}$. The decomposition starts to occur at about 180°C (360°F), producing a mixture of solids, liquids, and gases. The proportions and composition of each phase depends on the reactor conditions. Several different types of reactors are available. They include horizontal and vertical shaft reactors, rotary kilns, and fluidized bed reactors.

Vertical shaft reactors are probably the simplest of the reactor types. Refuse is fed into the top of the shaft, and the high temperature zone is at the bottom. Pyrolyzed gases flow up the shaft, heating the incoming refuse. Horizontal shaft reactors require some sort of conveyor system to move the refuse through the reactor. Continuous feeding is thus possible with this type of system.

Rotary kilns are long cylinders rotated upon suitable bearings and usually inclined at a slight angle to the horizontal. Typical length/diameter ratios are 4 to 10. Refuse is fed into the top, and it moves down toward the opposite end where it is discharged. The motion of the kiln provides better mixing of the refuse than in the shaft reactors.

The fluidized-bed reactor consists of a bed of solid particles such as sand suspended by an upward flowing gas stream. The particles are heated, and the refuse is pyrolyzed when it comes in contact with the particles. The fluidized bed yields a very high heat transfer rate, but sometimes presents problems in cleanup and transport of the solid particles in the bed.

Most pyrolysis reactions are considered endothermic, and require a heat source. Two distinctly different types of heating methods are available, direct and indirect. Direct heating implies that heat is supplied to the reaction mixture by partial combustion of refuse and/or supplementary fuel within the reactor. Oxygen (pure or in air) must be supplied or be available for this reaction. Indirect heating implies that the primary heating zone is separated from the pyrolysis vessel. The separation may be by the wall of the reactor, or by transfer of a medium from the combustion zone to the pyrolysis zone, as in the case of a fluidized bed. Indirect heating methods avoid the presence of oxygen in the pyrolysis zone (and thus reduce SO_x and NO_x in the gas stream), but are generally less efficient than direct methods.

Variables such as time, temperature, and particle size of the feed are best illustrated in Figure 3-6. Gases, for instance, would tend to be produced from a short residence time at high temperatures with a finely shredded refuse. Solids, on the other hand, would tend to be produced for long residence times, low temperatures, and large particle sizes.

Table 3-3 lists 15 processes classified according to reactor type and heating method. Twenty-four different pyrolysis systems or concepts were investigated in this study. These 24 are included in Tables 3-4a and 3-4b. The additional nine systems were not sufficiently developed or did not have enough information available about them to classify them according to the reactor and heating method in Table 3-3. Note in Table 3-4 that six systems have pilot plants or commercial plants with a capacity in excess of 91 metric ton/day (100 ton/day). They are Union Carbide, Garrett Corporation, Urban Research

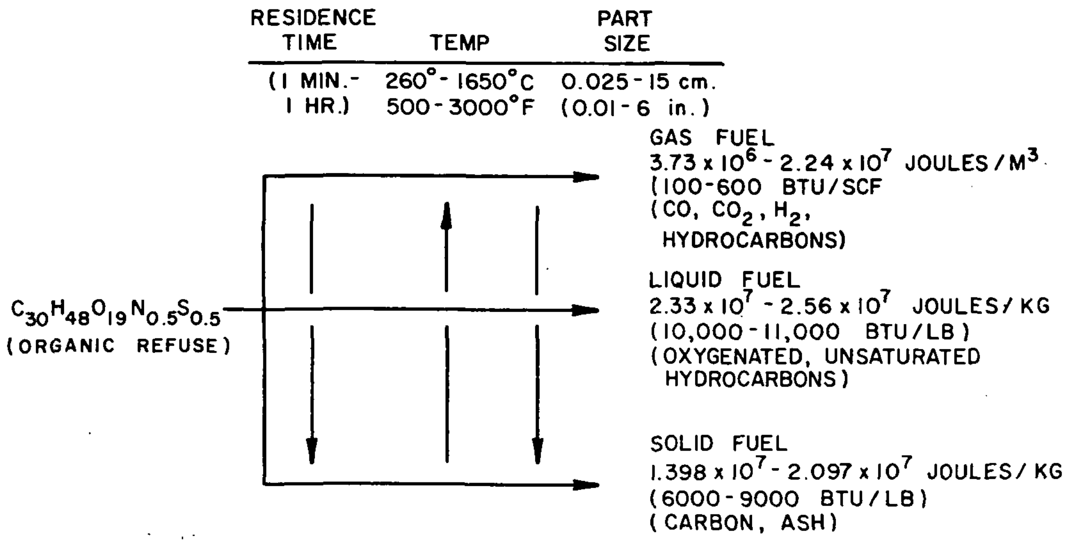

FIGURE 3-6
EFFECTS OF TIME, TEMPERATURE AND PARTICLE SIZE ON PYROLYSIS PRODUCT DISTRIBUTIONS

TABLE 3-3
PYROLYSIS PROCESS GROUPING

REACTOR TYPE	DIRECT HEATING		INDIRECT HEATING (nonslagging)	
	NONSLAGGING	SLAGGING	WALL TRANSFER	CIRC. MEDIUM
Vert. Shaft	Ga. Tech. Battelle	URDC Torrax Un. Carbide		Garrett
Horizon. Shaft			Kemp	Barber-Colman
Rotary Kiln	Monsanto Devco		Rust Pan. Am. Res.	
Fluid. Bed	Coors			West Va. Univ. A. D. Little

TABLE 3-4A
PYROLYSIS REACTOR CLASSIFICATIONS (METRIC UNITS)

PROCESS	HEATING METHOD DIR.	HEATING METHOD INDIR.	PRODUCT DISTRIBUTION SOLID Joules/ kgx10^{-7}	PRODUCT DISTRIBUTION LIQUID Joules/ kgx10^{-7}	PRODUCT DISTRIBUTION GAS Joules/ m^3	FEED CONDITIONS RAW	FEED CONDITIONS SIZE RED.	FEED CONDITIONS SEP-ARA-TION	REACTOR TEMP °C	STATUS RES.	STATUS Metric Pilot Plant	STATUS Tons/Day Comm	REFERENCES
VERTICAL SHAFT													
Garrett		X	2.20	2.44	2.04		X	X	482		3.6	180	3-18,-21,-22,-28 -47,-50,-51
Battelle	X				.64		X		982		1.8		3-22,-28,-47,-54 -55
Ga. Tech.	X		2.32	3.02	.74		X		399		23		3-53
URDC	X				.56	X			1427		109		3-26,-47,-48
Torrax	X				.56	X			1650		68		3-26,-28,-47,-48 -52
Union Carbide	X				1.113	X			1650		4.6	180	3-28,-47,-48,-49
HORIZONTAL SHAFT													
Kemp		X	X	X	X		X		593		4.6		3-47
Barber-Colman		X			1.86		X	X	649		.91		3-56
ROTARY KILN													
Monsanto	X		0.57		.48		X		982		32	907	3-21,-22,-28,-47 -60,-61,-62
Devco	X		X		X		X	X	538		109	1360	Priv. Comm.
Rust Eng		X			1.68				677			236	3-57,-58,-59
Pan Am Res.		X					X		1093	X			3-8,-63,-64
FLUID. BED													
W. Virginia		X			1.68		X	X	760	X			3-65,-66,-67,-68
A.D. Little		X			X		X	X		X			3-70
Coors	X				.56		X	X	760		.91		3-69
OTHER													
Battelle		X							982	X			3-71
Hercules			X							X			3-28,-72
Bur. Mines		X			1.86		X	X	982	X			3-22,-28,-73,-74 -75
NYU		X							927	X			3-76,-77
USC		X								X			Priv. Comm.
Anti. Poll. Syst										X			3-78
Univ. Calif.		X					X			X			3-79
Wallace-Atkins		X	.70	3.71	1.86				871	X			3-80
Res. Sci.		X					X		982		1.8		3-47

TABLE 3-4B
PYROLYSIS REACTOR CLASSIFICATIONS (ENGLISH UNITS)

	HEATING METHOD DIR.	HEATING METHOD INDIR.	PRODUCT DISTRIBUTION SOLID (BTU/ lb)	PRODUCT DISTRIBUTION LIQUID (BTU/ lb)	PRODUCT DISTRIBUTION GAS (BTU/ ft^3)	FEED CONDITIONS RAW	FEED CONDITIONS SIZE RED.	FEED CONDITIONS SEP-ARA-TION	REACTOR TEMP °F	STATUS RES.	STATUS PILOT PLT (TPD)	STATUS COMM (TPD)	REFERENCES
VERTICAL SHAFT													
Garrett		X	9,700	10,500	550		X	X	900		4	200	3-18,-21,-22,-28,-47,-50,-51
Battelle	X	X			170		X		1800		2		3-22,-28,-47,-54,-55
Ga. Tech.	X		10,000	13,000	200		X		750		25		3-53
URDC	X				150	X			2600		120		3-26,-47,-48
Torrax	X				150	X			3000		75		3-26,-28,-47,-48,-52
Union Carbide	X				300	X			3000		5	200	3-28,-47,-48,-49
HORIZONTAL SHAFT													
Kemp		X	X	X	X		X		1100		5		3-47
Barber-Colman		X			500		X	X	1200		1		3-56
ROTARY KILN													
Monsanto	X		2,500		130		X		1800		35	1000	3-21,-22,-28,-47,-60,-61,-62
Devco	X		X		X		X	X	1000		120	1500	Priv. Comm.
Rust Eng		X			450				1250			260	3-57,-58,-59
Pan Am Res.		X					X		200	X			3-8,-63,-64
FLUID. BED													
W. Virginia		X			450		X	X	1400	X			3-65,-66,-67,-68
A. D. Little		X			X		X	X		X			3-70
Coors	X				150		X	X	1400		1		3-69
OTHER													
Battelle		X							1800	X			3-71
Hercules			X							X			3-28,-72
Bur. Mines		X			500		X	X	1800	X			3-22,-28,-73,-74,-75
NYU		X							1700	X			3-76,-77
USC		X								X			Priv. Comm.
Anti Poll. Syst.										X			3-78
Univ. Calif.		X					X			X			3-79
Wallace-Atkins		X	3,000	16,000	500				1600	X			3-80
Res. Sci.		X					X		1800		2		3-47

and Development Corporation (URDC), Rust Engineering, Monsanto, and Devco. Only two of the plants (Monsanto and Devco) have capacities of 907 metric ton/day (1000 ton/day) or greater, and both are under construction.

A complete technical description of each of these processes in included in Vol. II.

A new pyrolysis concept evolved from the energy recovery study from MMR. The principal equipment in the process consists of two rotary kilns, one serving as a pyrolyzer and the other as a combustor. A continuous stream of dolomite circulates between the two. As a system, dubbed the NAAS process, it would fall into the rotary kiln, indirect heating column of Table 3-3, under circulating medium. The system combines the good features of several systems, i.e., operational simplicity of the rotary kiln, high heat transfer rate of dolomite particles, and a lack of air in the pyrolysis zone to decrease the concentration of undesirable gases such as NO_x. The NAAS process is described fully in Chapter 3 and in Appendix A of Volume II.

Biodegradation Processes

Biodegradation of refuse can be defined as reduction by the use of organic methods. Organic methods may be further subdivided into two categories - biological degradation, which includes aerobic and anaerobic conversion, and biochemical reduction. The applicability of biodegradation processes to solid waste is limited; however, some processes, such as composting, have met with some small degree of success and will be briefly discussed.

In aerobic degradation processes, the organic materials are oxidized to give a humus product commonly called compost. This compost can be used as a fertilizer. Since the process involves a decay of the organic materials such as garbage, leaves, manure, dried blood, etc. in refuse, considerable time is usually involved. In a small-scale operation the refuse is placed in a pile or heap. Since oxygen is required in the process, the refuse must be turned periodically to allow all parts to be exposed to air. The time required for the decay depends on the pH value of the pile and the amount of nutrients, (sewage sludge can be added to enrich the mixture), with the total time generally about four to six weeks. The volume reduction in a composting process can be about 50 percent, which does reduce the ultimate amount of MMR to be landfilled.

Commercial composting plants in the United States have had very little success. Reference 3-56 discusses the status of 18 municipal composting plants, and Volume II updates that status. Of the 18 plants discussed, 16 have been closed for varying reasons. Only one, the Fairfield-Hardy plant in Altoona, Pa., has been operated successfully for a number of years. The Fairfield-Hardy plant has a capacity of 41 metric ton/day (45 ton/day), but normally processes about 23 metric tons (25 tons) of refuse a day. The process employs both primary and secondary grinding, a hydropulper where sewage sludge is added, and a mechanical digester where the initial oxidation is accelerated. After approximately 5 days in the digester the compost is removed, and cured an additional 3 weeks. After curing, the compost is granulated, dried, screened and bagged. A large scale composting plant would require many acres for the final curing stage.

Anaerobic digestion processes applied to refuse could lead to a highly marketable product, methane gas. The first step in the process would be a breakdown of the complex organic materials in MMR into organic acids and CO_2. The second step would be to have bacteria known as methane formers act on the organic acids to produce CH_4 and CO_2. Small scale methane production plants are discussed in references 3-57, 3-58, 3-59, 3-60, 3-61, and 3-62. A large scale methane production plant has been suggested by Pfeffer, ref. 3-63, and Wise, et.al, ref. 3-64, and is called the Pfeffer-Dynatech Anaerobic digestion process. More details of the process can also be found in Volume II.

Summary

A large number of options for energy recovery from refuse are available to the community. The most proven technology is water-wall incinerators, but this system usually involves a high capital cost, and reliable markets must be found for the steam produced. Supplemental fuel incineration and the use of prepared refuse as a solid fuel look very promising, but only the St. Louis supplemental fuel plant is in operation on a large-scale basis. Pyrolysis systems offer the greatest versatility, and enough large-scale plants are under construction that very reliable data on these processes should be available within two years. At this time it does not appear that composting and other biological processes will have any significant impact on the solid-waste disposal problem

Despite the lack of technical data on many of the systems, it does appear that viable energy recovery options will be available for a community within 2 years. The increasing volume of solid waste generated, the filling-up of available landfill sites and the high cost of land, plus the increase in the cost of energy could make the energy recovered from solid waste an important part of our nation's energy needs.

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Since market considerations are the primary determinants of the economic viability of energy and resource recovery systems, it is imperative that a community carefully negotiate the sale of process outputs. Process outputs are very dissimilar and it is not enough to be assured that all output products can be sold. Demand and price fluctuate, and daily changes can be noted in the secondary material markets. A fact finding group may evaluate the cost of a disposal system based on a current price of $17/metric ton for recovered ferrous metal, only to discover that the price has dropped to $5/metric ton by the time the plant is built and on line. The extreme fluctuation in the price of recycled newspaper is another good example of the uncertainty which must be considered when trying to estimate credits in the economics analysis. Finding product markets and negotiating guaranteed prices may be the key to keeping incineration and pyrolysis costs within acceptable limits.

There are numerous products which might be available either from pre- or post-processing activities or from energy recovery itself. The following list of products is representative of those that can be reclaimed prior to any conversion:

- ferrous metals
- glass
- paper products (newsprint, cardboard)
- plastics
- nonferrous metals (aluminum, zinc, lead, copper)

Products derived from energy recovery processes appear in varying amounts and qualities depending on the process, and include:

- fuel gas
- fuel oil
- solid fuel
- char
- methane
- power
  - electric
  - steam

Ideally there would be no pollutants and no residue to be landfilled after the solid waste had been processed. Currently research is being conducted to see if byproducts can be used in construction materials or soil conditioners. Typical of conversion byproducts are:

- frit
- fiber and humus
- fly ash
- CO_2
- compost
- slag, glass stone, dirt
- residue

There are a number of Federal laws and regulations or policies that discourage the sale of energy and resources recovered from municipal solid waste. Examples of these policies are freight rates for secondary materials, depletion allowances and rules of capital amortization, and Federal policies fixing the price of natural gas.

Policies and Attitudes

While it is not currently possible to demonstrate that the higher freight rates cause an actual decrease in the amount of secondary materials recycled, it can be demonstrated that certain secondary materials cost more to ship than virgin materials.

Several Federal tax policies give benefits to industries engaged in the recovery of virgin materials. At the present time, such Federal tax policies apply only to recovery of natural or virgin resources and not to the same material recovered from secondary sources.

The Federal Power Commission regulates the transportation of natural gas in interstate commerce as well as "the sale in interstate commerce of natural gas for resale for ultimate public consumption for domestic, commercial, industrial, or any other use, and natural gas companies engaged in such transportation or sale. Thus, if a pyrolysis plant produced a gas which was sold to an electrical generating system which comes under the jurisdiction of the FPC, that pyrolysis plant might also be subject to FPC regulations and be forced to price its gas at an artificially low price. This would naturally reduce the financial attractiveness of energy recovery through pyrolysis.

Even if the pyrolysis plant were not under FPC jurisdiction, it could be forced to sell its gas at a low price in order to compete with natural gas priced according to FPC regulations. Many industries may accept a higher priced pyrolysis gas in place of the lower priced, but unavailable, natural gas. An additional competitive advantage of pyrolysis gas is the possibility of contractually guaranteed supply. If a shortage of natural gas occurs, FPC policy requires utilities to give priority to residential customers and service to industrial customers may be curtailed. Pyrolysis gas, as an intrastate commodity, is not subject to this constraint.

One of the largest problems to overcome in recycling is that of market uncertainty. Since the Federal government is the single largest consumer of many products, it has been suggested that Federal procurement of recycled materials could be used to establish a stable market for products manufactured from secondary materials. This has been done with paper products and automobile and truck tires. The EPA has concluded, however, that while the Federal government is the single largest consumer of many products, it does not constitute, by itself, a sufficient demand to create a stable market for recycled materials. State and local governments and other consumers must join the Federal government in the effort to create a market for recovered resources.

The social attitudes of consumers also have a great influence on the marketability of recovered resources. These attitudes, which are discussed in detail in Chapter 2, are briefly summarized here. The first of these is reluctance of consumers to undertake separation of disposable items at the household level. If source separation were practiced, front end systems would be unnecessary, and resource recovery would be much less expensive. Second, consumers tend to avoid purchasing products made from nonvirgin material. A prime example of this is the reluctance to use table napkins made from recycled paper taken from garbage.

Resource recovery is recognized as an important aspect of solid waste management and the recovery process can be structured so that resources can be recovered before, during, or after the actual processing of the solid waste. The nature of the products recovered is dependent on the stage in the process at which recovery takes place. Many products which are immediately saleable are recovered before processing.

Marketable Products

Although approximately a quarter of the tonnage of paper, major metals, glass, textiles and rubber consumed in recent years in the U. S. has been acquired through recycling operations, most of it has been salvaged from manufacturers and businesses, where large amounts of relatively clean and homogeneous wastes accumulate. Very little is currently being salvaged from municipal refuse.

The technical feasibility of recovering various materials from the municipal waste stream has been well demonstrated in the past, even though the reclamation of salvage material becomes more difficult when it is mixed with garbage and other refuse. Ferrous metals account for roughly 7 percent of the municipal waste stream. After the large bulky items have been removed and after the rest of the incoming refuse has been shredded, the ferrous metal is usually extracted magnetically.

Paper, the largest single component of solid waste, is one of the most important manufactured materials in the United States. Waste paper, which can be used as a raw material in the same way as wood pulp, is classified as either bulk or high grades. Bulk grades are used in sizeable quantities in paperboard and construction products. High grades are high quality fibers which can be directly substituted for wood pulp.

Glass makes up about 10 percent by weight of municipal solid refuse. Glass scrap, which is called cullet, is a desirable input material for the glass industry because it liquefies at a lower temperature than the other raw materials. The use of cullet in the glass industry has the effect of reducing fuel consumption and air pollution emissions, and it helps to extend the life of furnace linings. Technology currently exists for extracting and color-sorting glass from municipal solid waste, but it is not yet in large scale use.

Plastics is one of the most difficult materials to extract from municipal solid waste, and no plastic recovery now takes place from municipal solid waste. The heat content of plastics is approximately that of coal, and consequently plastics have great heating value in energy recovery systems. Unfortunately, burning plastics in the presence of moisture produces hydrochloric acid vapors. These vapors are very corrosive and pose an equipment maintenance problem as well as an air pollution problem.

Most of the rubber in mixed municipal refuse is either in the form of tires or such products as soles and heels on footwear. Reclamation of rubber from mixed refuse appears impractical at this time, especially because of the technical limitations in its recovery.

Most large aluminum companies in this country are now involved in aluminum can recycling. These recovery programs have been mostly based on voluntary citizen collection and delivery to a specific site.

The establishment of many aluminum can reclamation centers throughout the country, coupled with the high prices currently being paid for this metal scrap, explains why aluminum recovery is being considered in most of the recovery systems currently under development.

One of the most common products resulting from a pyrolysis process is fuel oil. The major marketing obstacle is the reluctance of the petrochemical industry to use gases or liquids produced by a waste disposal system as a feedstock. Discussions with representatives of the petrochemical industry indicate that privately owned chemical companies are not interested because of impurities and fluctuation in chemical composition.

Since there has not yet been a major attempt to produce and market these products, this judgement is conjectural. It is also worth noting that even if this conjecture is correct, it does not rule out the sale of combustible liquids or gases to chemical companies for use as a fuel.

FUTURE MARKETS

In addition to industrial demand, other factors play a role in secondary material markets. The secondary materials industry is inadequately capitalized and poorly organized. An influx of new capital technology, and managerial skills is needed to improve the productivity of the secondary materials industry.

Many Federal tax and transportation rate policies work to the disadvantage of secondary material dealers. Changes in these policies are long overdue, and would have an important revitalizing influence on the entire industry. Finally, procurement policies at all levels of government, which give preferential treatment to products utilizing secondary materials, would help to stabilize secondary materials markets and promote resource recovery. These factors should facilitate a more positive cycle where stable demand encourages the kind of investment in resource recovery which will ensure a stable supply of secondary material. The general availability of supplies of secondary materials will in turn encourage new industrial utilization of these resources.

A fuel derived from MMR may be utilized by electric utilities which can either use the fuel directly, or use steam generated at the disposal plant. The possibility of supplying steam to a district heating network also exists. An important consideration when selling steam is the distance the steam must be piped. Low energy content can place severe limitations on this distance.

A major impedement to the direct marketing of the fuel gases produced by many pyrolysis processes is their low Btu content. In the case of the liquid fuel produced by the Garrett process, a major drawback is its high viscosity and potentially corrosive nature which can greatly increase its handling expense.

There are two basic approaches to marketing products:

1. try to capture a share of existing markets from similar type products, or

2. create a need for an available product where none currently exists.

The gas and oils produced from the pyrolytic process, for instance, are products which must compete for a share of the energy market. On the other hand, research conducted at the University of Missouri at Rolla, indicates that a market might be developed for recycled glass in the production of glasphalt.

There are numerous marketing problems to be solved in both methods if a successful solution is expected in the solid waste handling problem.

At the present time there is no reliable market for many products produced from solid waste. However, future developments may lead to improved markets for such products. For example, energy prices have increased in the past few years, and substantial evidence exists to indicate that they will continue to increase as the world demand for energy increases. Research and development for new products utilizing solid waste materials is presently being conducted and encouraged by Federal government grants. Proposed legislation in the form of the Hazardous Waste Disposal Act and increasing landfill costs, may make landfills impossible in many cities. This should encourage trends toward energy and resource recovery. Additional legislative proposals are being formulated to study the effects of Federal policies such as freight rate and tax incentives for virgin materials on the secondary materials markets. If legislation is forthcoming to provide tax incentives for secondary materials recovery, this should encourage the development of markets. Legislation on air standards for incinerators is closing this option for many cities and encouraging resource recovery systems.

Additional use of energy conversion systems would increase confidence in these processes, and this confidence would encourage a supply/demand cycle which enhances rather than hinders the development of steady markets for the products of energy conversion systems.

A DECISION PROCEDURE

A brief examination of the history of solid waste disposal practices illustrates the need for an interdisciplinary approach to decision making in this area.

Until the 1960's, most communities, using only a least cost criterion for waste disposal practiced open dumping. Enough people, environmentally concerned in the 1960's, encouraged legislation prohibiting open dumps. Examples of such laws are Michigan Public Law 87 (1965) and the Texas Refuse Dumping Law (1963).

Many communities then turned to either incineration to reduce the amount of residue going to a landfill or used the sanitary landfill alone. Many of the incinerators, however, were shut down because they could not economically meet Federal clean air standards.

Also, to compound the difficulty for municipal officials there arose problems with sanitary landfills. These problems were not economic or environmental but social and political in nature. People living near proposed sites protested.

Many cities, dissatisfied with landfills and incineration turned to composting as a socially and environmentally acceptable alternative. However, when the compost market disappeared, most of the operations in the United States closed down.

The conclusion from this brief historical sketch is that regions still concerned with cost must now integrate into their decision process social, political, environmental, legal, and market considerations.

Philosophy

The philosophy of the decision process developed is that any technical option considered by a community must be compatible with all the aspects of that community. Solutions that do not account for community markets, culture, political institutions, and other pertinent characteristics will ultimately fail.

Outline of Procedure

A schematic diagram of the decision procedure is given in Figure 5-1. At the very start in seeking a waste disposal solution, a community is confronted with a wide range of technical options including those for energy and resource recovery. An initial screening process is proposed to eliminate those options not feasible in a local community. The tool for screening is a set of criteria set up by the municipal officials related to refuse handling, legal considerations, social acceptance, economics, and environmental regulations. Each process is then considered in light of these criteria. If a process is judged feasible it becomes a candidate for a more detailed analysis. The detailed analysis is to find the optimum solution among those judged feasible. This analysis is basically done in two parts. A detailed economic analysis is made. Also a desirability analysis is made concerning qualatative items. The results are put together in a useful form and given to those who must make a final decision.

Selection Criteria

An outline of various factors is presented. These have been shown to be important in considering solid waste disposal solutions in a community. They can be used to develop both the preliminary selection criteria and the desirability factors.

REFUSE FACTORS

- type
- amount
- composition
- seasonal variability
- special wastes
- waste generation locations
- growth rate of generation

SOCIAL, LEGAL, ENVIRONMENTAL, AND POLITICAL FACTORS

- public acceptance
    - credibility
    - existence of need
    - aesthetics
    - pest control
    - odor control
    - past history
    - culture
    - tax needs
- OSHA regulations
- EPA regulations
- local pollution standards
- resource and energy recovery
- political institutions

MARKETS AND ECONOMIC FACTORS

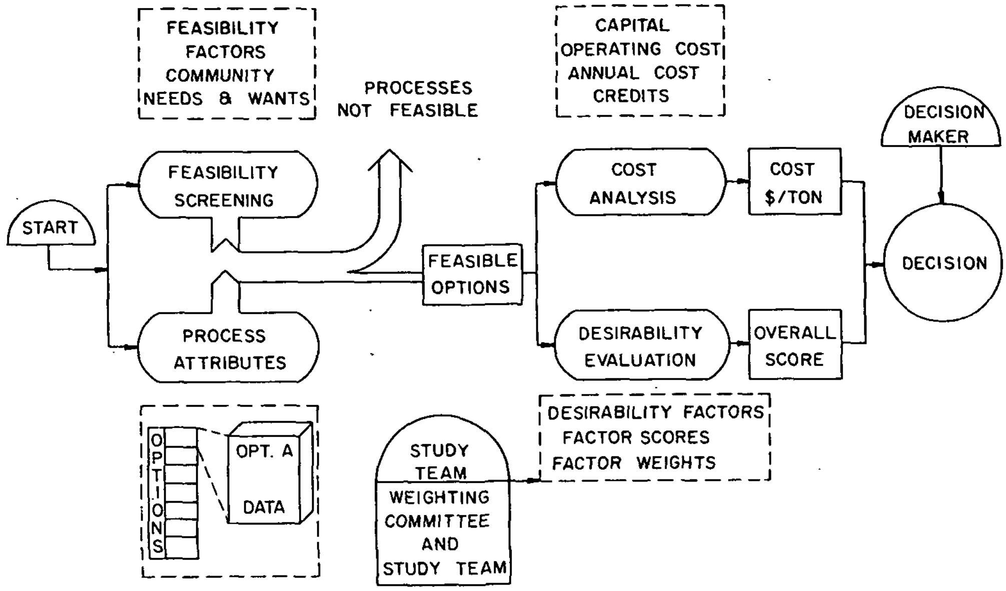

FIGURE 5-1
DECISION PROCEDURE

capital investment
operating costs
maintenance costs
markets for energy and recovered resource
- availability
- energy form
- reliability of supply and demand
- potential markets
- transportation
- market prices
- contracts
- location of plant
- market price fluctuations

PHYSICAL AND TECHNICAL FACTORS

residue disposal
installation and start-up time
adaptability
- capacity needs
- legal changes
- market changes
- political and social changes
- technical developments

labor requirements
plant siting
- land availability
- hydrology
- topography
- geology
- weather
- wind
- traffic
- neighborhood
- historical problems

reliability
maintainability
repairability

There are relationships between the different factors mentioned which suggest that to increase a system's desirability in one might be to decrease it in another. An obvious example is the relationship between capital cost and maintenance costs. Often, if one is higher, the other is lower. Built in redundancy, flexibility, and short installation time are desirable features which could increase capital costs but lower operating costs.

SELECTION OF FEASIBLE OPTIONS

To screen for feasibility all the technical options available, a set of selection criteria are developed by officials from the factor categories above.

An example set for a hypothetical community are given below.

1. Because of a long term contract already held with the city, the system must handle the oily waste from Acey Industry.

2. System must handle 1000 metric tons of MMR per day at the time of installation and be expandable to 2000 metric tons per day by 1985.

3. System must meet all EPA standards thru 1985 as to air, land, and water pollution.

4. Major breakdowns should occur no more than twice a year. When the plant shuts down, operation should be restored

within 24 hours.

5. The net operating cost per metric ton of MMR must not exceed $8.50 assuming public financing at 8 percent interest.

6. System should recover at time of installation 90 percent of the tin cans and 50 percent of the aluminum - the only markets available at this time.

7. Total landfill requirements must not exceed 20,000 square meters per year at depths determined by a geological survey in each potential area.

8. To reduce collection costs, system should be installed in two modules in different geographical locations.

9. Sites should be within 18 kilometers of the city center and be agreed upon by citizen referendum within a radius of 4 kilometers.

10. System should have had running experience for 2 years at a capacity of at least 500 metric tons per day.

The technical options are then matched against these criteria. Those that meet these are added to a list of feasible options to be further evaluated.

Analysis of Systems Judged Feasible

This process is outlined in Figure 5-1 to the right of the Feasible Option block. The analysis contains two parts. The first is an economic analysis. The second is a desirability analysis. The latter is an attempt to evaluate each feasible process in light of its desirability for the community.

Economic Analysis

Sound estimates of both the initial capital expenditures and the yearly operating costs and revenues provide the foundation for a valid economic analysis. The net annual cost for a given system can be determined by adding the annual capital cost to the annual operating cost and subtracting the annual credits or revenues from the sale of any energy or recovered resources. This dollar amount is divided by the metric tons per year handled to obtain a dollar per metric ton cost. To obtain the annual capital cost the interest rate and economic life period must be established.

If operating costs and revenues can be estimated over the period of operation years, standard Engineering Economy analyses can be made such as a Present Worth Analysis or an Equivalent Annual Cost Analysis.

The results of this economic analysis coupled with the desirability score of the next section is a useful guide to the decision maker.

Desirability Analysis

This analysis is done by two separate groups or committees. The first committee - the Weighting Committee - should be composed of individuals very knowledgeable about the local community. They should be attuned to the political, social, and economic character of their locale. Local technical expertise is also needed.

Their task is to determine the desirability factors. An example set is given in Table 5-1. When these are agreed upon, the committee must determine which are more important than others in their community. Standard weighting techniques are used to arrive at this ranking.

A second committee - Study Team Analysts - should be composed of people knowledgeable about the feasible technical options to be analyzed. Their task is to judge the desirability of each process in light of the factors chosen by the Weighting Committee. An example scoring sheet for the Public Acceptance Factor is given in Figure 5-2. This technique takes into account the factor over a selected number of periods into the future.

A computer program can then be used to combine the results of both committees into an overall desirability score - usually a number between 0 and 1.

Analysis Presentation

A possible combination of economic and desirability factors is presented in Figure 5-3. The net cost per metric ton is plotted versus the overall score of desirability for a set of hypothetical systems. The cost variability is due to the uncertainty of market prices for energy and recovered resources. It is readily seen that at least processes C and F should probably be eliminated from further consideration. Process C has a very large cost range, an indication of market uncertainty. Process F may be certain as to markets, but has a combination of high cost and low desirability.

Final Decision

The responsibility for waste disposal

TABLE 5-1
DESIRABILITY FACTORS

	FACTOR	MOST DESIRABLE	LEAST DESIRABLE
1.	market of recovered energy	guaranteed by contract	new market needs to be created
2.	market of by-products	guaranteed by contract	new market needs to be created
3.	residue disposal	none	50% or more and/or special disposal
4.	environment	no pollutants	may not meet some standards
5.	health & safety	completely safe	potential hazards in plant, to public
6.	installation time	will meet schedule	likely to delay beyond required date
7.	capital investment	minimal and/or easily financed	almost impossible to finance
8.	operating cost	low	high
9.	management	simple or sub-contracted	difficult to manage plants and labor
10.	adaptability	adaptable to any new technology	can not be modified
11.	public acceptance	attractive to public	strong resistance from public
12.	capacity expansion	fully expandable	no room for expansion
13.	input requirement	any composition of refuse/fuel	operation stops if input is inadequate
14.	labor requirement	few and unskilled	many and highly skilled
15.	plant siting	no restrictions	only one possible site
16.	conversion technology	well developed and commercialized	experimental
17.	maintainability & repairability	done without stopping production	prolonged shutdowns frequently
18.	resource and energy recovery	complete recovery of energy and resources	low thermal eff. & nothing recovered
19.	back-up and storage	continuous operation assured	no back-up, no storage
20.	market price fluctuations	minimal affect	extremely sensitive

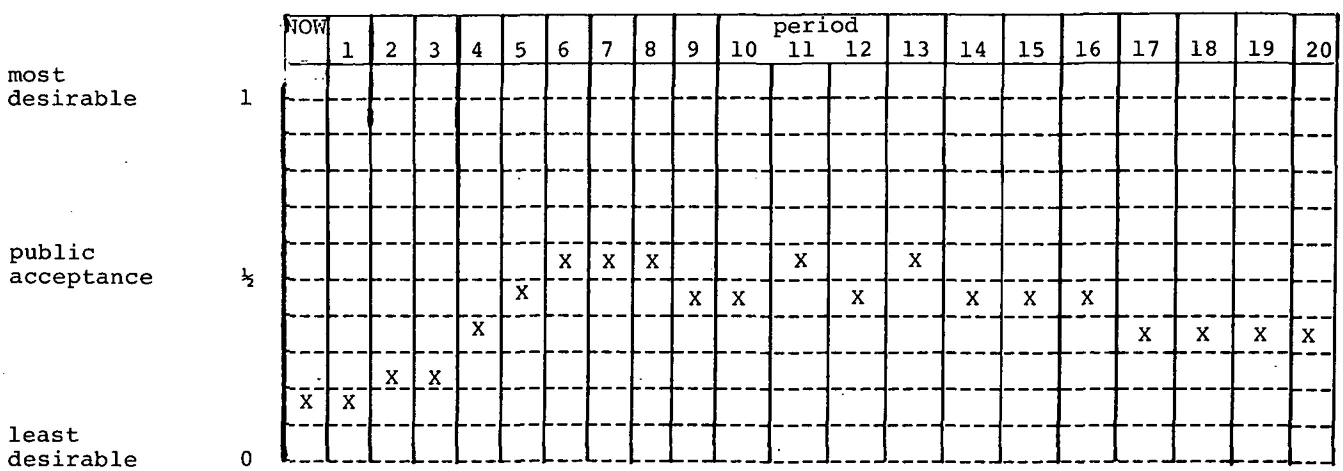

FIGURE 5-2
DESIRABILITY SCORING EXAMPLE

OPTION	DESIRA-BILITY SCORE	$/METRIC TON	COST RANGE
A	.62	5.25	4.00 6.00
B	.41	3.90	3.00 5.50
C	.79	8.40	6.00 10.50
D	.82	6.80	5.50 7.50
E	.73	6.10	5.00 6.50
F	.57	7.00	6.20 7.50

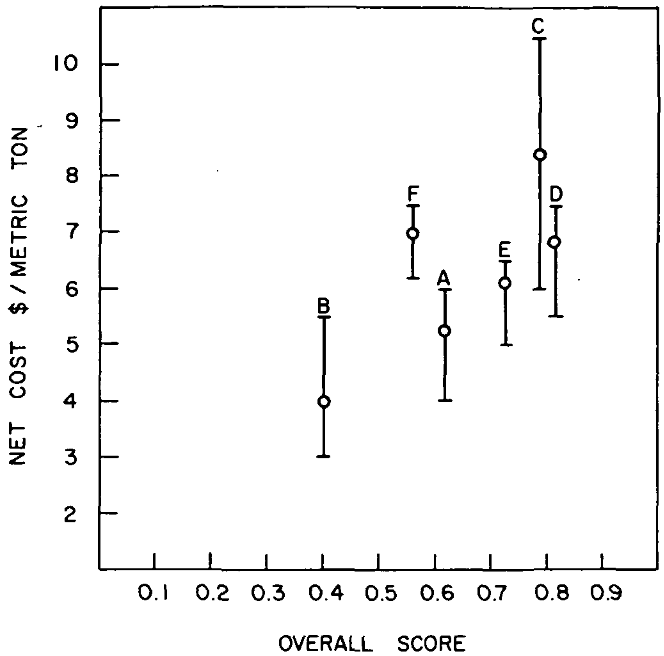

FIGURE 5-3
OVERALL SYSTEMS EVALUATION EXAMPLE

falls on the governmental units responsible for overall public health. The ultimate responsibility however, lies with the general public who, in producing the waste, must not only allow it to be picked up but must also assure that it is properly put down.

To carry out disposal decisions, governments have set up various regional authorities. These range in size from entire states to one or more counties to cities themselves.

It is hoped that these agencies can utilize information such as given in Figure 5-3 in making better waste disposal decisions tailored to their particular situation.

A note of caution should be given regarding the decision procedure. Even though the various factors are considered independent, in reality they are not. To include these relationships in a decision model is difficult indeed. The decision makers must keep this in mind when using the procedure. Also, the overall perspective must be maintained. For example, a particular process may not be screened out even though it does not meet some preliminary criteria but yet has other characteristics which will yield a high desirability score. It is assumed that the "human" aspect of the decision process will be concerned with factor relationships and an overall perspective not obvious in the procedure itself.

The decision procedure, used intelligently, should help insure more viable waste disposal solutions in given communities.

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NASA-Langley, 1975

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