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MARKETS AND TECHNOLOGY FOR RECOVERING ENERGY FROM SOLID WASTE

U.S. ENVIRONMENTAL PROTECTION AGENCY

MARKETS AND TECHNOLOGY

FOR RECOVERING ENERGY FROM SOLID WASTE

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In 1973, energy consumption in the United States grew by 4.8 percent,[1] and experts predicted that energy demand would double between 1970 and 1990.[2] This increasing consumption and the announced goal of achieving independence from foreign energy supplies have created pressures to find new fuel sources.

Municipal solid waste is one raw material currently being discarded that can be "mined" for its energy content. In the United States in 1971, 125 million tons of solid waste from residential and commercial sources were discarded with no attempt to recover energy.[3] Since solid waste has a heat value of approximately 9 million Btu per ton, this represents some 1,100 trillion Btu per year, the energy equivalent of 500,000 barrels of oil per day. Of course, not all of this solid waste would be available for recovery, but some 75 percent of it is concentrated in major metropolitan areas, where processing plants could be large enough to be economically feasible.[4] Industrial, agricultural, and forestry wastes represent the equivalent of an additional 2 million barrels of oil per day,[5] although collection and transportation problems may restrict their use.

Many different approaches to recovering the energy value of refuse are presently being examined. Waterwall incinerators are currently generating steam in a number of U.S. cities. A new waterwall incinerator will be completed in Nashville, Tennessee in mid-1974. In Baltimore, Maryland, a pyrolysis system that will generate steam is nearing completion. St. Louis is currently demonstrating a system that uses the shredded, combustible portion of solid waste as a coal substitute in a utility boiler. Many communities are considering similar systems and extension of the concept of oil-fired boilers, as well as use of wet-pulped and/or pelletized solid waste as a fuel. Pyrolysis systems are being developed to convert solid waste into liquid and gaseous fuels. Two of the most promising of these systems are the Garrett Research and Development County's system for producing oil, which is being demonstrated in San Diego County, California, and Union Carbide's system for producing a gaseous fuel, which is being tested by that company at its plant in South Charleston, West Virginia. The recovery of methane from landfilled solid waste is being practiced in a pilot plant in Los Angeles. Electrical power generation is being explored in a research project conducted by the Combustion Power Company with support from the U.S. Environmental Protection Agency. The demonstration projects in Baltimore, St. Louis, and San Diego are also EPA-supported.

These technologies enable solid waste to be converted into a number of different energy forms, including gaseous, liquid, and solid fuels as well as steam and electricity. The energy recovery system that should be employed in any particularly community depends upon the market for the output product.

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[2], Tables C and E.
[3], p. 3.
[4], p. 11.

The value of a solid waste energy product should be equivalent, on the basis of heat produced to the value of the fuel which it replaces, less any additional costs incurred in its use. The current fuel crisis has significantly increased the value of these products and reduced the need to provide special incentives to enhance their marketability.

To be marketable, though, the solid waste energy products must have qualities acceptable to the user. Steam and electricity produced from solid waste are equivalent to those products from other sources, but fuels produced from solid wastes are physically and chemically different from their fossil fuel counterparts. Characteristics such as ash content, heat value, corrosiveness, viscosity, and moisture content have to be acceptable to the user. For all energy products derived from solid waste, such factors as reliability, quantity, and availability are also important.

This paper reviews the characteristics of the major energy products recoverable from solid waste, the marketability of these products, the potential markets, and the status of the technology for recovery. The first section considers the fuels--solid, liquid, and gaseous--that can be created out of solid waste. The second section examines steam and electricity, two other forms in which the energy from solid waste can be sold. In the final section, the various systems and energy products are compared.

SOLID, LIQUID, AND GASEOUS FUELS FROM SOLID WASTE

Solid, liquid, and gaseous fuels can be producted from solid waste using a number of systems currently under development. These fuels can be used as a supplement to their fossil fuel counterparts: coal, petroleum, and natural gas. (The characteristics and uses of the fossil fuels are discussed in the Appendix.)

Marketability

Fuels derived from municipal solid waste will have physical and chemical properties different from those of conventional fuels and, therefore, will have different handling and combustion characteristics. In order to analyze the potential markets for the solid waste fuels, it is necessary to identify their characteristics and evaluate the constraints they will place on using the fuel products.

There are a number of general characteristics that determine the marketability of fuels derived from solid waste whether they are solid, liquid, or gaseous. These include:

Quantity of fuel produced. Enough of the product must be available to justify any expenses that the user will incur in modifying his facility to accept this new fuel source.

Heating value. The heat value of each fuel must be high enough to minimize the effect of the fuel on boiler or furnace efficiency. Also the costs of transporting, storing and handling the fuel go up as the heat value goes down since a greater quantity of fuel has to be handled in order to obtain the same amount of energy.

Reliability. A high degree of reliability in the supply of the fuel increases its value because the user does not need to maintain standby equipment or fuel.

Quality. The better the product, in terms of handling, stability, aesthetics, etc., the more it is worth because the customer's cost to use the product is reduced.

Solid fuels derived from solid waste are currently being used as a supplement to coal in suspension-fired utility boilers. They are also being considered for use in conjunction with oil-fired units and as a fuel supplement in cement kilns. Some factors that influence the marketability of these solid fuels are:

Particle size. Particles must be small enough to permit complete combustion when burned in suspension. This size will vary with the type of unit used to burn the fuel. Small particle size particularly important if there are no burnout grates at the base of the combustion chamber.

Residue content. Residue should be kept to a minimum in order to prevent errosion of the furnace walls and the fuel firing system. Also high amounts of residue can overload the ash removal system and may restrict the value of the coal ash.

Moisture content. Moisture content will affect the heat value of the fuel. If it is high enough it will reduce the combustion efficiency of the unit.

The Garrett Research and Development Company pyrolysis system is producing a heavy, oil-like liquid fuel from solid waste. This liquid fuel can be used as a supplement to No. 6 fuel oil in large industrial or utility boilers. Factors which will influence its marketability include:

Viscosity. If viscosity is too high the costs of storing and pumping can be excessive. High viscosity can also cause plugging of fuel lines.

Volumetric heating value. The volumetric heat value (Btu per gallon) influences the cost of transporting and storing the fuel.

Chemical stability. If the fuel undergoes chemical change, this will restrict the length of time it can be stored.

Special handling problems. The need to maintain separate storage and firing systems for the solid waste fuel, and to purge the firing systems after the fuel has been burned, places an extra burden on the user which may minish its value.

Most gaseous fuels produced from solid waste have a lower heating value than natural gas because they contain significant quantities of carbon dioxide and, in some systems, nitrogen. The distance they can be transported is limited by the cost of compressing and pumping the gas. As the Btu value goes down this cost becomes prohibitive.

Potential Market Opportunities

Most markets for solid waste fuels would be large utility or industrial users who could blend 20 to 30 percent of solid waste fuel with conventional fuels and still use sufficient quantities of the solid waste fuels to justify the costs of special storage and firing facilities. Steam electric power plants because of their large fuel needs and proximity to urban areas, represent an attractive market opportunity for solid waste fuels. Major industrial operations (such as cement plants, steel mills, and paper mills) and central heating/cooling plants also represent potential market outlets.

Steam Electric Power Plants

Electric utilities operating steam electric plants fired by fossil fuels are the most promising market for solid waste fuels for several reasons: they use very large quantities of fuel; electricity demand is influenced by the same factors that influence solid waste generation--population and industrial and commercial activity; and the utility's generating plants are often located in close proximity to the urban area where the solid waste is generated. Also the quasi-public structure of the electric utility tends to make it more conscious of community problems and more receptive to accepting the costs and risks associated with using these fuels.

Economic gain is the overriding factor influencing a utility's decision to use solid waste fuels. Although savings from using solid waste fuels can amount to only a small fraction of the utility's total fuel costs, other indirect economic gains can be realized through improved community relationships, if local governments build incentives into this means of waste disposal. For instance, a utility may gain approval of a new power plant site more easily if it is part of a solid waste/energy recovery program.

Savings in the cost of a solid waste fuel would be effectively passed on to the utility's customers, since most rate structures include automatic adjustments to reflect changes in the cost of fuel.

Industrial Operations

Many industrial operations are ideal markets for fuel produced from solid waste. Fuel from several hundred tons of solid waste or more a day could be readily utilized in all but the smallest cement plants, papermills, and steelmills, for example.

A typical paperboard mill uses about 25,000 pounds of steam to produce 1 ton of boxboard.[6] A small plant producing 360 tons of boxboard per day would require 400,000 pounds of steam per hour, the equivalent yield of 1,200 tons of solid waste per day.

Most papermills currently burn their own bark and wood waste in boilers as a supplement to conventional fuels. Although this might reduce somewhat the capacity of this market for solid waste fuels, it should ease the marketing task because the industry is already accustomed to burning waste fuels.

Feasibility studies are currently being done to examine the possibility of using solid waste as a fuel in cement manufacturing kilns.[7] The solid waste would supplement the coal or other fuel being used, and any ash remaining would be incorporated into the final product. Cement kilns require about 8 million Btu of fuel per ton of cement produced.

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[6], p.27-1.

Plants range in capacity from 1,000 to 3,000 tons or more per day. Therefore, using refuse as 20 percent of the fuel load, even a small plant could handle the fuel produced from 400 tons of solid waste per day.

Systems for Producing Fuels From Solid Waste

The technology for converting solid waste into fuel is very new and is developing rapidly. All of the systems under consideration today were conceived since 1968. Nevertheless, several full-scale demonstration projects are presently in operation and others soon will be. Furthermore, many communities are proceeding to implement full-scale systems on the basis of these demonstrations.

Prepared solid waste as a supplemental fuel. The city of St. Louis, with demonstration grant assistance from EPA is producing a dry, shredded solid waste fuel which is used to supplement pulverized coal in an existing Union Electric Company suspension-fired boiler.[8] Solid waste fuel provides 10 percent of the energy used in the boiler. At this rate, the 125-megawatt boiler is capable of burning 350 tons of prepared solid waste fuel per day. The project engineers are undertaking experiments to increase the solid waste fuel to 20 percent of the boiler feed.

The process is divided into two distinct operations--preparation and firing. A fuel transportation system is also required in St. Louis because the fuel is prepared 18 miles from the power plant. At the processing plant municipally collected solid waste is shredded in a horizontal hammermill and fed into an air classifier which separates the material into heavy (dense) and light fractions. The heavy fraction is passed over a magnetic belt to remove ferrous metals. The light, mostly combustible material is stored temporarily in a bin and is then transferred to 75-cubic-yard transfer trailers for the trip to the power plant (Figure 1). At the power plant the prepared fuel is transferred to a smaller bin from which it can be pneumatically blown into the boiler (Figure 2).

Similar systems are already being implemented in several other communities, even though the concept is still being tested. The Union Electric Company has announced a 70-million-dollar program to expand its demonstration operation to serve the entire metropolitan St. Louis area.[9] In Ames, Iowa, a prepared fuel will be used in a municipally owned power plant,[10] and in Chicago it will be used by the Commonwealth Edison Company.[11] In East Bridgewater, Massachusetts, Combustion Equipment Associated is preparing a solid waste fuel for use by the Weyerhaeuser Company.[12]

Other studies are investigating other possibilities for solid fuel: using it as a supplemental fuel in oil-fired boilers; preparing it by a wet-pulping method developed by the Black-Clawson Company; and pelletizing it for use in grate-fired boilers.

PROCESSING PLANT FOR SOLID WASTE, ST. LOUIS PROJECT

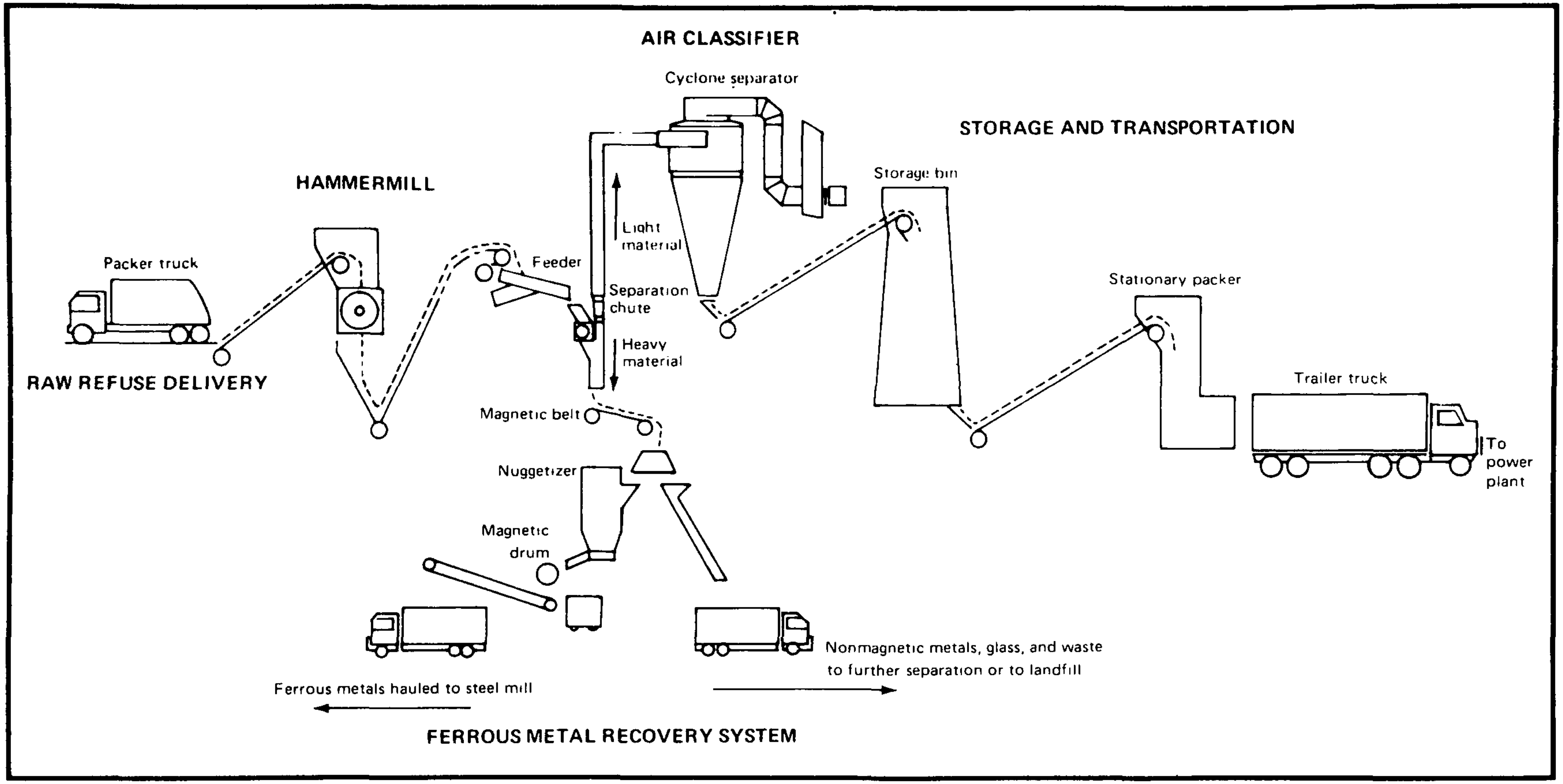

Figure 1. In the system being demonstrated by Union Electric Company in St. Louis, fuel and ferrous metal are recovered from municipal solid waste that has been shredded and air classified.

POWER PLANT USING SOLID WASTE FUEL, ST. LOUIS PROJECT

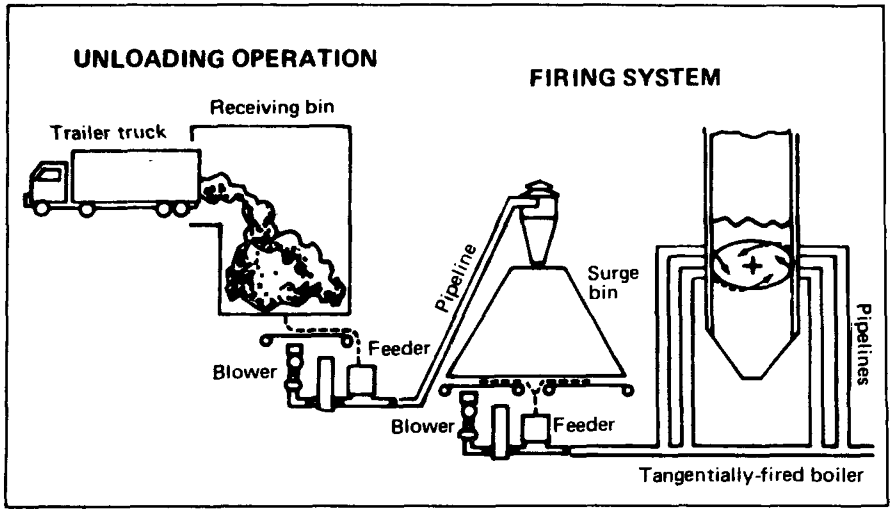

Figure 2. In the St. Louis project, the shredded solid waste fuel is delivered to the power plant, where it is fired pneumatically into boilers as a supplement to coal.

Pyrolysis. Pyrolysis is the thermal decomposition of materials in the absence or near absence of oxygen. The high temperature and the "starved air" situation cause a breakdown of the materials into three parts: (1) a gas consisting primarily of hydrogen, methane, and carbon monoxide; (2) a liquid fuel that includes organic chemicals such as acetic acid, acetone, and methanol; (3) a char consisting of almost pure carbon, plus any glass, metal, or rock that may have been processed. The design of the individual system controls which of these outputs will be the predominant product.[13] Two systems currently under development show promise of producing fuels of sufficient quality and yield to be marketable. The Garrett Research and Development Company's "Flash Pyrolysis" system which is undergoing EPA demonstration in San Diego County, California will produce a liquid fuel.[14] A gaseous fuel will be produced in a Union Carbide System that the company is testing in South Charleston, West Virginia.[15]

Oil Pyrolysis. The demonstration plant for "Flash Pyrolysis" will produce an oil-like liquid which will be used by the San Diego Gas and Electric Company as a supplemental fuel in an existing oil-fired boiler. This fuel, which is produced at the rate of 1 barrel per ton of solid waste, has a heating value of about 94,000 Btu per gallon. This is about 65 percent of the heating value of No. 6 fuel oil, on a volumetric basis. This oil has a higher moisture content and a higher viscosity than No. 6 oil.

The Garrett process consists of a complex preparation system followed by a relatively simple pyrolysis reaction (Figure 3). To prepare the solid waste for the reactor it must first be shredded. An air classifier than separates out a light combustible fraction which, after being dried, is shredded again, this time to a particle size of one-sixteenth of an inch. This material, now resembling the material caught in a vacuum cleaner bag, is then introduced into the reactor, where it is mixed with hot glowing char in an inert atmosphere. The material is pyrolyized in less than a second, at a temperature of 900F. The resulting gas is condensed to recover the oil. The process char is recirculated as the energy source to pyrolyze the incoming material.

Gas Pyrolysis. The Linde Division of the Union Carbide Corporation is building a 200-ton-per-day test facility to generate a gaseous fuel product.

The key element of the system is a vertical shaft furnace (Figure 4). Refuse is fed into the top of the furnace. Oxygen entering at the base of the furnace reacts with the char that is one of the end products ultimately formed from the refuse. This reaction generates a temperature high enough to melt and fuse the ash, metal, and glass; this molten material drains continuously into a water-filled tank, where it solidifies as a hard granular material.

OIL PYROLYSIS OF SOLID WASTE

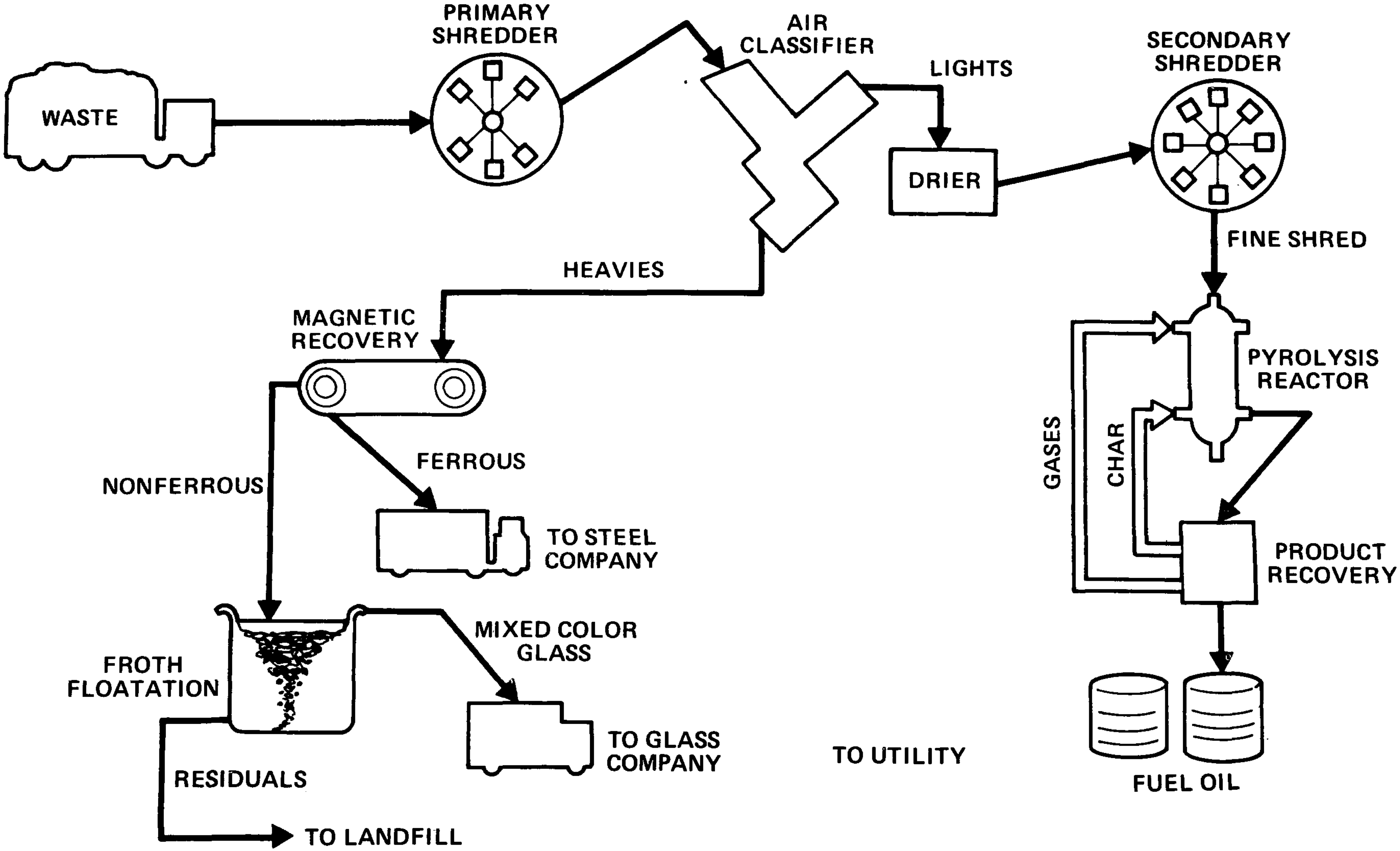

Figure 3. The Garrett process produces an oil-like liquid fuel from solid waste by means of pyrolysis.

GAS PYROLYSIS

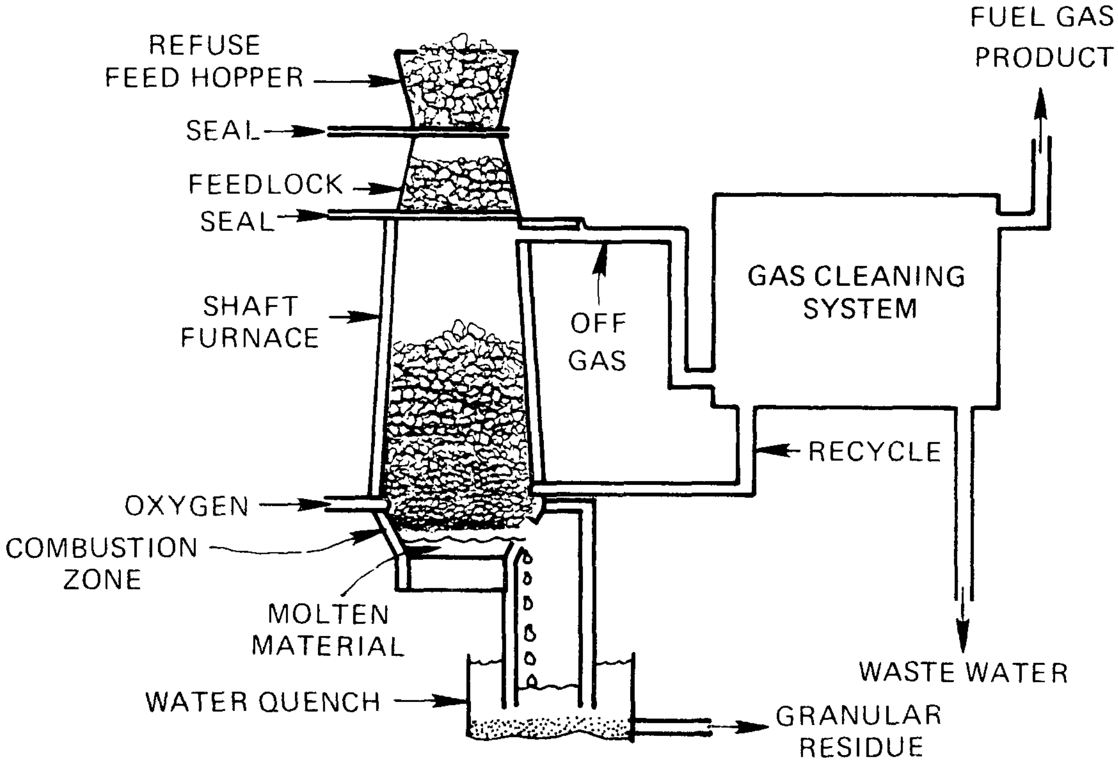

Figure 4. The key element of the Union Carbide pyrolysis process is a vertical shaft furnace.

The hot gases formed by reaction of the oxygen and char rise up through the column of refuse and pyrolyze the refuse, transforming it to gas and char. In the upper portion of the furnace, the hot gas also dries the incoming refuse. The gases produced from the pyrolyzed refuse exit the furnace at a temperature of about 200F. This exhaust gas contains considerable water vapor, some oil mist, and minor amounts of other undesirable constituents, which are removed in a gas-cleaning system.

The resultant gas is a clean-burning fuel comparable to natural gas in combustion characteristics, but with a heating value of about 300 Btu per cubic foot which is 30 percent of the value of natural gas. It is essentially free of sulphur compounds and nitrogen oxides and burns at approximately the same temperature as natural gas. This gas can be substituted for natural gas in an existing facility; the only plant modification necessary would be to enlarge the burner nozzle so that the volumetric flow rate could be increased.

One limitation on use of this gas is the cost of compressing it for storage and shipment. Since a larger quantity of this gas is required to yield the same amount of energy as natural gas, compression costs per million Btu will be 3.1 times greater than for natural gas. As a result, markets for this gas will have to be within 2 miles of the producing facility and only short-term storage can be contemplated.

Methane Production. When solid waste decomposes in an anaerobic (oxygen-free) environment, it produces methane and carbon dioxide. Programs are currently underway to recover the methane that is produced by the natural decomposition of solid waste in a sanitary landfill[16, 17] and by the accelerated decomposition of solid waste in a mechanical digestor used to digest sewage sludge.

In the sanitary landfill recovery program, a well is drilled through the fill and lined with perforated pipe. The gases are pumped out of the fill and the carbon dioxide is removed using membrane filtration or cryogenic separation techniques. The NRG NuFuel Company is installing gas recovery systems in landfills operated by the County of Los Angeles and the City of Phoenix. Both of these sites possess very specific characteristics which are necessary for the process to be feasible, and any potential site must be examined to determine whether this process is practicable there.

The National Science Foundation is currently supporting a research effort by the Dynatech Corporation to examine the feasibility of combining solid waste with sewage sludge for digestion in a mechanical digestor.[18] Pipeline quality gas, with a heat value of 900 Btu per cubic foot, would be recovered at the rate of 3,700 cubic feet per ton of waste.

STEAM AND ELECTRICITY

Steam can be thought of as the medium of transportation in an energy network, in the sense that chemical energy of the fuel is transported by the steam as thermal energy to the user, who may convert it to other forms of energy. Steam can be sold for use in three basic energy forms: (1) it can be used to transmit heat directly, for example, to heat buildings in a district heating system; (2) it can be mechanically converted into electricity by the use of steam turbines, which is what happens in a steam electric power plant; (3) its mechanical energy can be used to drive machinery in various industrial processes, or to operate a condensing unit in a district cooling system. A municipality may elect to produce the steam from its solid waste and sell it to a utility, or it may take the process one step further, converting the steam to electricity and selling it in that form.

In a steam electric power plant, the furnace is lined with tubes filled with water. The fuel burned in the furnace releases heat and converts the water to steam. The steam is then piped to a turbine where it gives up its heat energy by driving a generator that produces electricity. Due to practical limitations on the efficiency with which heat can be transferred to the steam and can later be extracted from it, about 10,000 Btu of fuel energy are required to produce one kilowatt-hour (kwh) of electricity, which is equal to only 3,412 Btu of energy.[19]

Steam temperatures generally range from 250F to 1,050F and pressures range from 150 pounds per square inch (psi) to 3,500 psi. The strength of the materials used to construct the system places limitations on temperature and pressure. In electric power plants the greatest efficiency is achieved at the highest temperatures and pressures. In steam distribution systems, however, temperatures are kept as low as possible to minimize heat loss in the delivery system, and pressures are kept as low as possible to reduce the cost of the system and minimize danger from bursting pipes.

In system that use solid waste as the sole or primary fuel, the steam is usually produced at 600 psi or less in order to minimize slagging and corrosion of the boiler tubes. The steam can be further processed in separate units to bring it to the pressure at which it will be used.

Marketability of Steam

Unlike fuels derived from solid waste, steam produced from solid waste is indistinguishable from steam from any other source.

To be marketable this steam must meet the specific needs of the user. When designing a solid waste disposal/steam recovery system some factors which must be considered are:

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[19], p. IV-19.

Proximity to Customer. The facility must be close enough to economically serve the steam market. Steam can be transported only about 2 miles, and in congested areas expensive pipeline installation problems may further restrict this distance.

Value. The cost at which the steam is delivered must be competitive with the costs of the customers alternate energy sources.

Quantity. The amount of steam supplied must be compatible with the customer's needs. If peak loadings cannot be supplied entirely by burning refuse then standby, fuel-fired boilers will be needed.

Operating Schedule. The steam-producing facility must be set up on an operating basis that satisfies the operating schedule of the steam customer.

Availability of Refuse. The municipality must insure that it has enough refuse to meet its steam output commitments.

Steam Quality. The temperature and pressure at which the steam is produced must be a function of both the optimal performance of the unit and the limits acceptable to the customer.

Reliability. The system must include sufficient backup facilities to meet the level of reliability of supply agreed upon. This may include contingency plans to burn fossil fuels when the solid waste unit is out of service. The cost of building and operating these facilities must be considered in the economic evaluation of the system.

Excess Steam. The facility must be designed to serve the community's disposal needs, even if there is an interruption to the steam market. Condensing units or a backup sanitary landfill may be necessary.

Timing. The steam must be available when it is needed. Unanticipated delays in construction of the facility could force a steam customer to find another source of steam.

Steam can be marketed in two ways: as a guaranteed supply, or as a limited supply that requires a backup system. In the first case, the municipality provides a complete and reliable supply, and assumes the responsibility of providing steam from other sources if there is an interruption in the production of steam from solid waste. If the municipality is supplying steam which the customer does not otherwise have the capability of producing, then the municipality must guarantee the reliability of the supply. Although the municipality's costs go up, the value of the steam also goes up, for this steam has a value equivalent to what the customer would have to spend to produce it himself. In the second case, the utility buys all of the steam the municipality produces from solid waste, but the customer carries the burden of producing additional steam in the event that this supply is interrupted or is not adequate to meet its demand. In this case, the value of the steam is lower (it is limited to the value of the fuel saved by the customer) but the municipality assumes less risk and responsibility.

Market Opportunities for Steam

Most metropolitan areas have one or more major outlets for steam. Yet, despite the fact that proven technology exists for generating steam from municipal solid waste, constraints on its use have made the marketing of steam very difficult.

District Heating and Cooling Systems. There are about 450 commercial and campus district steam heating systems operating in this country.[20] Many of these systems also distribute chilled water for cooling buildings during warm weather. A number of cities have steam systems serving their central business or industrial areas (Table 1). The fuel crisis has encouraged other cities to consider such systems in an effort to make more efficient use of limited and increasingly costly fuels.

TABLE 1

SELECTED CITIES WITH DISTRICT HEATING/COOLING SYSTEMS*

Akron, Ohio	Hartford, Conn.
Allentown, Pa.	Houston, Tex.
Atlanta, Ga.	Indianapolis, Ind.
Baltimore, Md.	Los Angeles, Calif.
Birmingham, Ala.	St. Paul, Minn.
Boston, Mass.	Nashville, Tenn.
Cheyenne, Wyo.	New York, N.Y.
Cleveland, Ohio	Oklahoma City, Okla.
Dayton, Ohio	Omaha, Nebr.
Denver, Colo.	Philadelphia, Pa.
Detroit, Mich.	Pittsburg, Pa.
Eugene, Oreg.	San Diego, Calif.
Grand Rapids, Mich.	Seattle, Wash.
Harrisburg, Pa.	Tulsa. Okla.

* International District Heating Association, 1973 Rate Reference Book. Pittsburg, 1973. 15 p.

In these systems, steam is distributed at a low pressure, generally in the neighborhood of 250 psi, which can be easily provided by a solid waste disposal facility. Unlike the demand for electricity, which has certain peak periods, steam demand is fairly constant throughout the day and from day to day. Seasonal variations can be significant, but if the utility also distributes chilled water it can operate its chilling plant with a steam-driven turbine. In any event, the demand for steam can be sufficient to accommodate a constant amount of steam produced in an energy recovery plant during most, if not all, of the year.

Because steam cannot be transported for more than about 2 miles, the solid waste plant must be located close to the steam users; usually this will mean in or near the central part of the city. Although land costs may be higher, solid waste hauling costs will probably be minimized, because of the proximity of the plant to the waste generators.

When the steam produced in a solid waste disposal facility is sold to a district heating utility, its value is equivalent to the price the utility would pay for the fuel needed to produce the steam. However, if by purchasing this steam, the utility is able to expand its service to customers whom it previously lacked the capacity to serve, then the steam would have a higher value equivalent to the utility's own total cost for producing steam.

In a city where no steam distribution network exists, the municipality can consider installing a complete solid waste steam-generating incinerator and a steam distribution network. To minimize the costs, this might be tied to a major urban renewal project or to the construction of a large industrial park or complex. Although the municipality would then be able to sell the steam at a much higher price, it would also be responsible for a much higher capital investment. Because it would be the only source of supply for its customers, it would also have to assume the responsibility for total reliability. A backup system would be needed to provide steam when the incinerator was out of service or if there were an interruption in the delivery of refuse to the facility.

Two systems currently under construction will produce steam for utility distribution. The first system, being built in Baltimore with grant assistance from EPA, will produce steam for sale to the local utility.[21] The utility will use the steam in its existing steam distribution loop. Revenue from the sale of steam will amount to at least $3.50 per ton of refuse.

In the second project, the city of Nashville, Tennessee, created an independent, non-profit authority that will sell steam and chilled water to commercial and government office buildings in downtown Nashville, using refuse-fired waterwall incinerators as the primary steam source.[20] Fossil-fuel-fired backup boilers will also be available. Steam revenues will amount to $10 per ton of refuse. This price, nearly three times the price paid for Baltimore's steam, reflects the construction cost of the complete steam generation and distribution system. Chilled water, which is sold at a much higher price, will provide an even greater amount of revenue about $25 per ton of refuse.

Industrial Plants. Large industrial facilities such as papermills, food processors and major manufacturing plants are also steam customers. Industrial customers who operate their facilities 24 hours a day are preferred because a waterwall incinerator is designed for round-the-clock operation. Some industrial users may specify the quantities of steam to be delivered at certain given times, and then will most likely specify the temperature and pressure. These factors must be identified and incorporated in the design of the incinerator.

Although it is impossible to predict the long-term effect of the energy shortages on industrial needs, fuel shortages should improve the marketability of a reliable steam supply.

Many cities have single industries large enough to utilize all the steam that a large solid waste facility can produce. In Saugus, Massachusetts, a 1,700-ton-per-day waterwall incinerator is being built that will handle 1,700 tons of refuse per day. All of the steam produced in this plant (about 350,000 pounds per hour) will be used in an adjacent General Electric Company plant for heating and cooling, electric power generation and a variety of manufacturing and testing operations.[22]

Steam Electric Power Plants. Although steam electric power plants use tremendous quantities of steam it may be difficult to develop satisfactory marketing arrangements in this sector.

One problem is that the cost of accommodating an outside steam source may exceed the value of the expected fuel savings. Modification of the pressurized components of the power plant could involve costly construction operations and could require that the power plant be kept out of service for a long time. Also, using supplementary steam may cause a boiler to operate at a lower efficiency so that additional fuel will be needed to obtain the same energy output.

Another marketing problem results from the fact that the total demand, or the amount of electricity that a utility must produce, varies considerably throughout the day and from day to day. The utility's most efficient plants are used continuously to supply the minimum demand (baseload), while the less efficient or otherwise more costly plants are used during peak demands. Thus each power plant within a utility system, and in fact each boiler within a plant, will have a different rate of utilization (or load factor) depending on its relative operating efficiency. The utility would be able to buy steam only when the boiler which has been modified to accept outside steam is operating. This would be 75 percent or more of the year for a baseload unit, but it could be 25 percent or less for a peakload unit.

One way to overcome the problems of retrofitting an existing unit would be to build a new baseload turbine and generator unit especially to take steam produced in the solid waste facility. The Florida Power and Light Company suggested such an arrangement as part of a plan to buy energy from a proposed solid waste processing facility in Dade County.[23] According to their proposal, the company building the solid waste facility would also build the generating facility. Florida Power and Light would then buy the steam, and also buy the generating facility, paying for it on the basis of the units of electricity produced. This arrangement requires that the municipality provide the capital investment, and the municipality, rather than the utility, assumes the financial risk since reimbursement is tied to production.

Systems for Producing Steam

Systems available for the generation of steam from solid waste include waste heat boilers, waterwall incinerators, and refuse-fired support boilers.

Waste-heat boilers. A waste heat boiler package is one that is placed in the flue following the secondary combustion chamber of a conventional refractory-lined, mechanical grate incinerator. In addition to being used in many industrial processes, waste-heat boilers were used in the early design of heat recovery incinerators in this country. The poor operating characteristics of refractory-lined incinerators have made this approach obsolete.[24]

A waste heat boiler is employed quite effectively, however, as part of the new pyrolysis system being built in Baltimore. The plant, designed by Monsanto, has the boiler following a pyrolysis kiln (Figure 5). Heat cannot be recovered from the kiln directly because it is used to accomplish the pyrolysis of the solid waste. Once the pyrolysis gases are formed they are combusted in a separate afterburner and the heat that is released is then recovered as steam using a package type, waste heat boiler. Two hundred thousand pounds per hour of steam will be recovered from processing 1,000 tons of solid waste per day. The steam will be transmitted by pipeline three-fourths of a mile to an existing steam distribution system which is operated by the local utility.

COMBINED PYROLYSIS AND STEAM RECOVERY SYSTEM

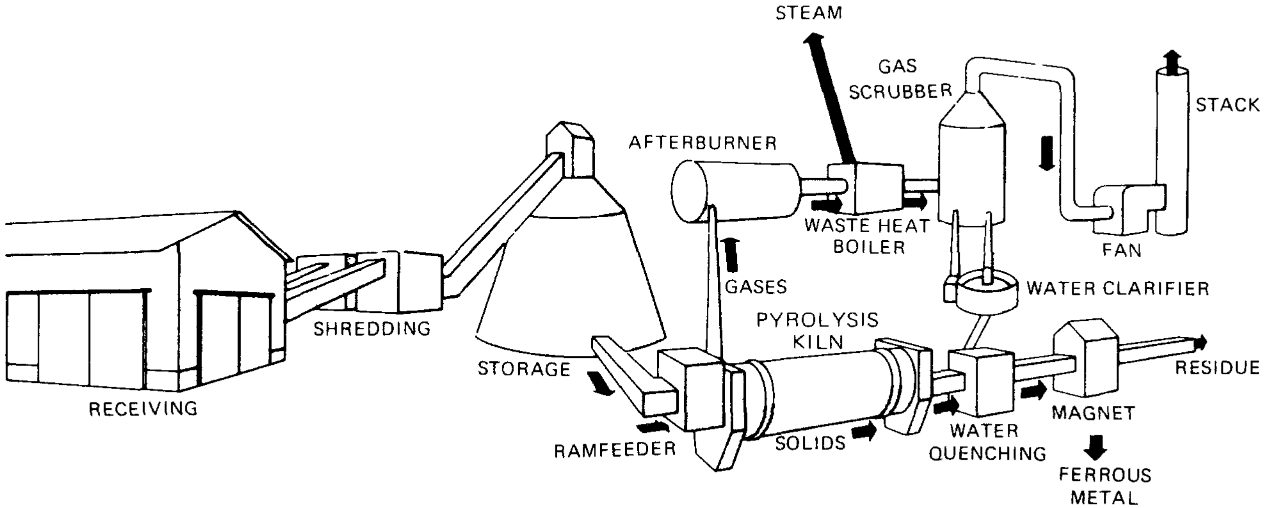

Figure 5. This schematic drawing of the main components of the Monsanto system in Baltimore shows how it recovers steam with a waste heat boiler following the pyrolysis of municipal solid waste.

Waterwall incinerators. Waterwall furnaces have almost entirely replaced refractory-lined combustion chambers in current incinerator design. In this type of construction, the furnace walls are constructed of vertically arranged metal tubes joined side-to-side with metal fins. Radiant energy from the burning of refuse is absorbed by water passing through the tubes. Additional boiler packages, located in the flue, control the conversion of this water to steam of a specified temperature and pressure.

This construction is also advantageous because it acts as an efficient method of controlling the temperature of the unit. The heat released by combustion is transferred to the water, so less air is needed to keep the operating temperature of the incinerator at an acceptably low level. This in turn reduces the size of the combustion unit and its air pollution control equipment. In fact, the volume of gas entering the air pollution control equipment will be only about 25 percent that of an air-cooled, refractory unit. So effective is this means of temperature control that this type of construction has become standard even in incinerators not designed for every recovery.

Refuse-fired support boilers. In Europe many municipalities combine waterwall refuse units with separate fossil-fired boilers in one facility.[25] Steam from the two separate units is integrated to drive one turbine/generator system.

One reason this concept is widely used in Eurpoe but not used at all in this country is that many European municipal governments unlike their American counterparts are responsible for solid waste disposal but also for power generation, distribution of steam for district heating, and the operation of electrically powered transportation systems.

Markets for Electricity

Like steam, electricity produced from solid waste is indistinguishable from electricity produced by any conventional method. The problem in marketing electricity, though, is that it usually can be sold only to the electric utility serving the area, because within that service area the utility is generally exempt from competition. The only exception are municipally owned utilities but these account for only 10 percent of the nation's generating capacity.[19]

The price that a utility will pay for electricity depends on whether it is used to satisfy baseload or peakload demand. Although peakload marketing commands a much higher price, a municipality needs to sell electricity on a continuous basis (i.e., as baseload) in order to maintain a continuous solid waste disposal operation.

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[19], p.III-4.

A municipality considering the sale of electricity to a utility should seek to establish a floating price for the electricity, whereby the price per kilowatt-hour rises as the demand on the utility increases. Thus, the price would be a function of the incremental direct costs the utility incurs in producing the electricity needed to meet increased demand.

Systems for Producing Electricity

The systems for producing fuel and steam discussed above can be extended to include power generation. An economic analysis would have to be undertaken to determine whether the revenue produced from the sale of the electricity would be enough to offset the additional capital and operating costs of the equipment needed to produce it.

The direct generation of electricity from solid waste combustion is being explored through a research project funded by EPA.[26] The Combustion Power Company has developed a completely integrated solid waste combustion-power generation system (Figure 6). A 100-ton-per-day pilot plant is currently in the shakedown phase.

Incoming municipal refuse is shredded and air classified to remove noncombustibles. Metal and glass are further separated for recovery. The combustible fraction is pneumatically transported to an intermediate storage facility and from there into a pressurized fluid bed combustor. The hot, high-pressure gases from the combustor pass through several stages of air cleaning equipment (separators) to remove particulates. The cleaned gases are then passed through a gas turbine that drives a 1,000-kilowatt generator. Although the pilot plant operates at only 45 pounds per square inch guage (psig), commercial plants would operate at pressures in excess of 100 psig.

Performance problems have caused accelerated deterioration of the turbine blades and have thus slowed the development of this process. This deterioration and other problems must be solved before this is a technically and economically feasible system for energy recovery.

ANALYSIS AND CONCLUSIONS

The key to successful implementation of a solid waste energy recovery program is to select a system which is compatible with the energy market as well as the community's solid waste disposal requirements. Once a suitable market has been identified, an appropriate system can be designed which will convert the solid waste energy potential into a marketable form.

DIRECT GENERATION OF ELECTRICITY FROM SOLID WASTE

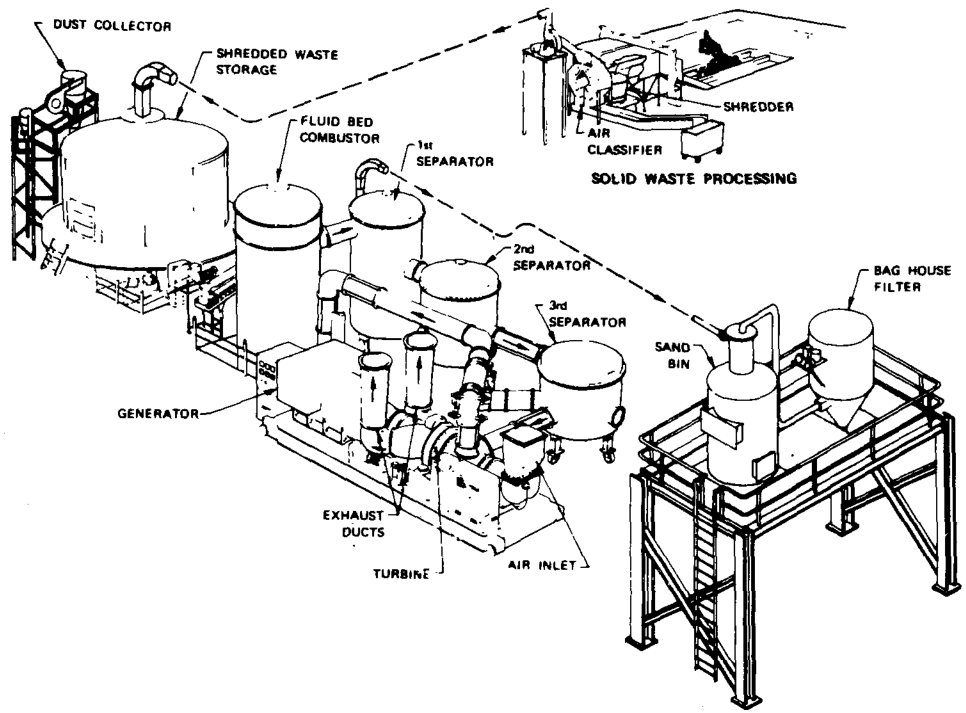

Figure 6. The CPU-400 system, being developed by the Combustion Power Company, produces electricity from the combustion of solid waste in a high-pressure fluidized bed.

Comparison of Market Opportunities. It is most important that the market for fuels and energy produced from solid waste be large and favorably located. The size of the market is very important because the customer may have to absorb the cost of process changes needed to accommodate the new energy source. This is particularly true with regard to producing an oil or a solid prepared fuel because special storage and firing facilities are needed and these fuels are fired only as a small percentage of the total fuel load.

Steam and gas can be transported only very short distances and although the dry and liquid fuels can be transported farther, transportation costs should be minimized wherever possible. Therefore, the preferred market would be a facility located near the point of solid waste generation.

Steam electric power plants are the most promising market. The fact that most utility systems consist of several power plants increases the probability that an acceptable market can be found. The potential energy value of all solid waste generated amounts to between 5 and 10 percent of the total of fossil fuels used for electric power generation.

Steam distribution systems are also a good prospective market. The scarcity and rising cost of fuels is creating a demand for new or expanded systems. These systems are centrally located in order to serve the greatest concentration of customers, so haul distance is minimized. There is less fluctuation in load than in electric power plants, and the lower operating temperature and pressure is compatible with the constraints of a refuse-fired system.

Comparison of energy forms. The key to marketing energy from solid waste is to produce an energy form that can be sold and used without regard to its derivation. In addition, the type of fuel produced should be storable and transportable so the solid waste facility will be independent of the fuel market.

Steam and electricity satisfy the first objective, but neither can be stored and steam can be transported only very short distances.

The solid and liquid fuels can be transported and stored for brief periods of time (several days to several weeks). However, both fuels require the user to install special storing and firing facilities. In addition, the user must follow special handling procedures to minimize problems of air pollution and corrosion.

Gaseous fuels are less likely to require special handling or separate facilities for storage and firing, but those currently being produced cannot economically be compressed for extended storage and shipment. The best of the gaseous fuels cannot be shipped more than 2 miles.

Comparison of technological alternatives. Municipalities require solid waste disposal systems that are reliable and involve a nimimum of technical risk. Furthermore, the system must meet acceptable environmental standards at an economical cost, though not necessarily at the least possible cost.

Risk and reliability are usually evaluated by examing full-scale systems in actual operation. A number of energy recovery systems which are currently being proposed to cities, however, have not had this long-term operating experience. These systems have generally been developed by private companies which hold patent rights to the process. The risk of procuring such systems can be reduced by a turnkey arrangement, whereby the contractor builds the system and turns it over to the city only when it meets detailed performance specifications. A municipality can also minimize risk and avoid large capital investments by entering into a long-term contract for private ownership and operation of a solid waste disposal/energy recovery system.

Waterwall incinerators are already in widespread use in this country. While there is little risk of technical failure, the long-term reliability of these systems has not yet been established. Waterwall incinerators are usually the most costly of the energy recovery systems, on the basis of both capital and operating costs.

The system expected to be the least costly of the energy recovery options is the use of dry shredded waste as a prepared fuel. One full-size plant has been in operation for over 2 years in St. Louis, and several others are presently under construction. This system has been particularly attractive because energy can be recovered with a minimum amount of processing.

The 1,000-ton-per-day pyrolysis and steam recovery system in Baltimore will be in full operation in late 1974. It is being built under a turnkey, fixed-price contract with guarantees on the daily throughput, the amount of air emissions, and the extent of burnout.

Oil and gas recovery through pyrolysis, as well as direct conversion to electricity, are undergoing demonstrations at less than full size. Further technological developments will be needed before widespread utilization can be expected.

In summary, the energy recovery options available for implementation now are waterwall incineration and prepared refuse fuel systems, although neither has been completely evaluated. Steam recovery through pyrolysis should be available soon for full-scale systems, but the other options will not be ready for full-scale use until the late 1970s.

Some acceleration of this can be expected if the companies producing the systems assume the development risk through direct ownership of the facility or by offering them to local governments initially on a no-risk basis.

Selecting an Alternative. Implementing a solid waste energy recovery program is more complex than just selecting a technology. The first and most important consideration is to secure a reliable and realistic market.

All aspects of the market must be carefully understood by both the user of the fuel or energy and the municipality supplying it. The constraints of the market will indicate the technical aternatives available. Once the various major markets for solid waste energy and the possible energy forms that can satisfy those markets are examined (Table 2), the possible alternatives will be narrowed to just one or a few technologies. The final selection of a system will depend on the relative technical risk and the estimated net operating cost.

TABLE 2

MARKETS FOR ENERGY FROM SOLID WASTE

Conventional energy source	User	Solid waste energy form				
		Prepared fuel	Liquid fuel	Gas	Steam	Electricty
Coal	Industrial boilers and furnaces	x	x	x	x	
	Power plants*	x	x	x		
Oil	Industrial boilers and furnaces		x	x	x	
	Power plants*		x	x		
Gas	Industrial boilers and furnaces			x	x	
	Power plants*			x		
Steam	District heating/cooling				x	
Electricty	Utility distribution					x
	Industrial plants					x
	Municipal lighting					x
	Mass transit systems					x

* Electric or steam utility plants.

APPENDIX

DEMAND FOR CONVENTIONAL SOURCES OF ENERGY

In examining the prospects for marketing solid waste fuels, it is helpful to review the forms and uses of conventional fuels. Total energy demand in the U.S. in 1970 was 67.8 quadrillion Btu.[27] This is equivalent to 32.5 million barrels of oil per day.* This energy is supplied by three major fossil fuel sources--oil, coal, and gas--and by hydroelectric, geothermal, and nuclear power. Transportation, industrial operations, and residential and commercial needs account for the major uses of energy (Figure 7).

Coal. Coal has been the staple of the American energy supply. In addition to being abundant, coal is the cheapest source of energy currently available. Unfortunately, when coal is burned its high sulfur and ash contents contribute to air pollution. Coal's predominant use in this country is in large industrial and utility furnaces or boilers where the cost of adequate air pollution control equipment can be economically absorbed. Other environmental problems associated with coal are strip mining and the water pollution it causes. The Btu content of American coals range from 11,000 to 14,000 Btu per pound.

Oil. In 1970 the U.S. consumed 13.9 million barrels of oil per day. Of this, 3.5 million barrels were imports. All further increases in oil consumption were also projected to come from imports, mostly from the Middle East.[27] Since this supply has become politically vulnerable, new sources of oil will be needed to satisfy our increasing demand.

Crude oil is processed, by various refining operations, into more than 100 different products. The lighter (lower density) fuels are gasoline, diesel fuel, and jet fuels. These fuels are characterized by good vaporization and burning properties, low quantities of impurities and good storage stability. They account for more than 50 percent of the liquid fuel market and are utilized primarily for transportation.

Heating oils are heavier than the fuels used for transportation and are required to meet less stringent performance and quality characteristics. These fuels are graded from No. 1 to No. 6, with the higher numbered grades having higher viscosities and lower purity requirements. Grades No. 5 and 6, which require pre-heating facilities for pumping and storing the fuel, are used in large industrial boilers and furnaces where additional costs for handling and firing facilities can be accommodated. The heating value of liquid fuels varies from 110,000 to 150,000 Btu per gallon with the heavier fuels having the higher Btu contents.

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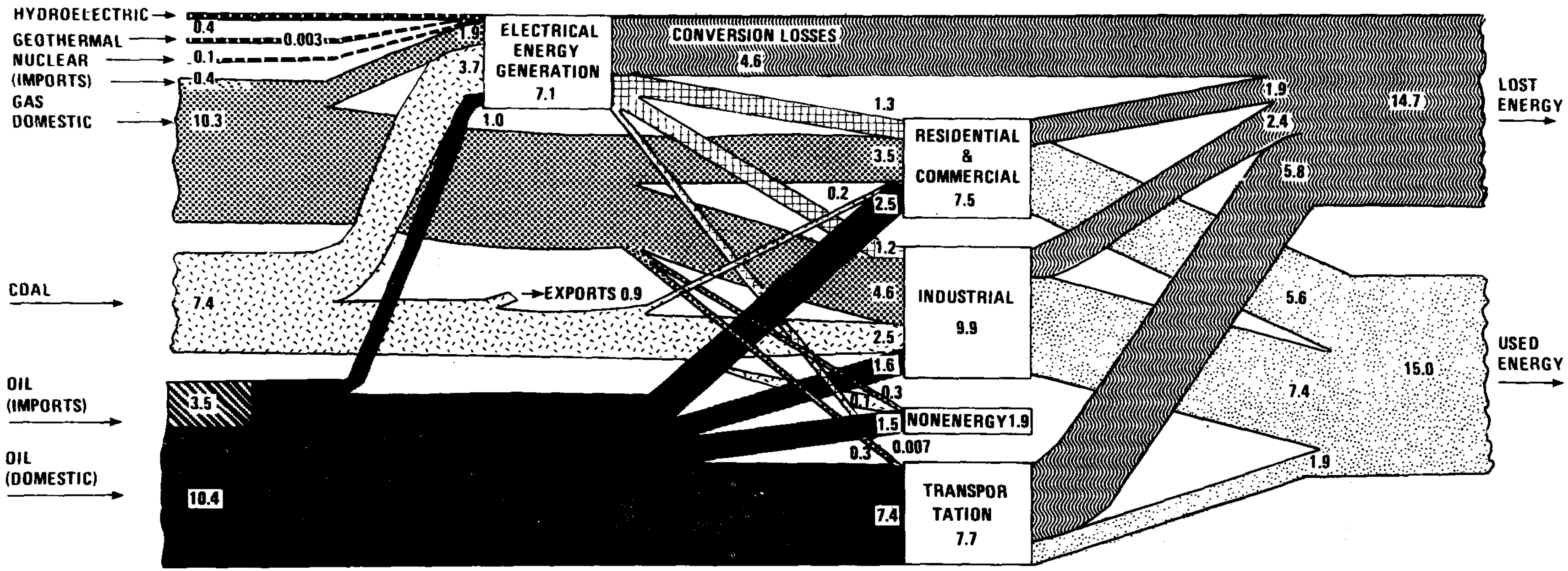
* Calculated by converting the energy produced from other forms of fuel to the equivalent amount of oil needed to produce the same amount of energy.

[27], p. 16.
[27], p. 273.

1970 ENERGY SUPPLY AND CONSUMPTION



(Each unit represents 1 million barrels of oil per day or its equivalent in energy)

Figure 7. Coal, gas, and oil are the major sources of the nation's energy, which is used for industry, transportation, and residential and commercial purposes. Source: U.S. Congress JOINT COMMITTEE ON ATOMIC ENERGY. Understanding the "national energy dilemma." Washington, Georgetown University, The Center for Strategic and International Studies, 1973. Tables C and E.

Gas. The demand for gasous fuels currently exceeds the avilable supply. Gas is a particularly popular fuel because price regulations make it cheaper than most other fuels. It is easily stored, shipped, and fired, and burning causes no pollution.

The major gaseous fuel is natural gas, an odorless, colorless substance that accumulates in the upper part of oil or gas wells. It consists chiefly of methane, and has a heating value between 1,000 and 1,100 Btu per cubic foot.

Propane and butane are produced in the process of refining petroleum. Their heating values are considerably higher than natural gas. Because they are easily liquefied under pressure, they are usually "bottled" in steel cylinders or shipped in large pressurized tanks. They are used either as standby supplies for users of natural gas or as fuel for stoves, trucks, buses, etc.

There are also many types of manufactured gas which are produced by heating various solid fuels under specific controlled conditions. These gases are referred to as coal gas, coke-oven gas (or coke), producer gas, blast-furnace gas, water gas, etc. The heating value of these gases ranges from 100 to 750 Btu per cubic foot. In many instances they are used by the industry producing them because their heating value is low and it is not generally economical to compress them for shipment or storage.

Electrical generation. The electric utility industry is a supplier of energy to consumers and, at the same time, is itself a major consumer of fuels. In 1970, in fact, 25 percent of the energy used in the U.S. was consumed by the electric generating industry. More than half of this fuel input came from coal, with gas comprising 24 percent and oil 15 percent. Nuclear energy supplied only 2 percent of the industry's needs in 1970. Although nuclear generating plants are expected to supply 53 percent of the total utility load by 1990, the use of coal and oil is also projected to increase but at a less rapid rate.

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