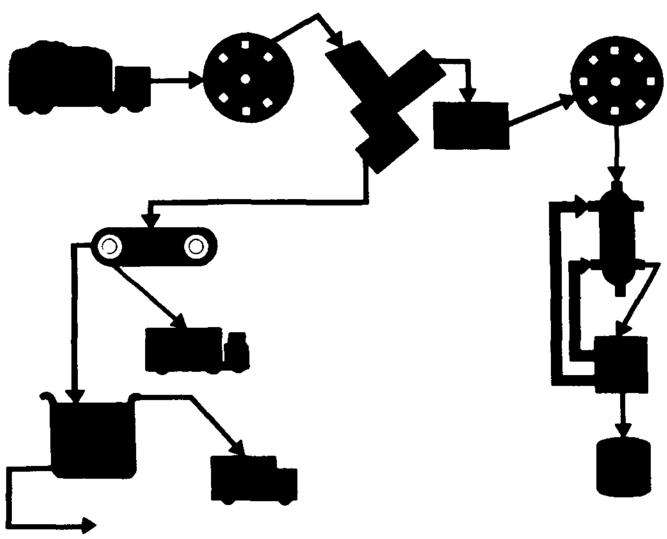
SAN DIEGO COUNTY DEMONSTRATES OF PYROLYSIS SOLID WASTE

to recover liquid fuel, metals, and glass



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foreword

In this time of concern about dwindling supplies of energy and materials, nearly all of the large amounts of energy and recyclable materials in municipal solid waste are still dumped or buried. In fact, locating land space for disposal of the growing waste loads is a serious problem in many cities, and in a number of places disposal is being carried out in ways that could create health and environmental hazards. This report describes a project that will recover energy, ferrous metals, and glass from municipal solid waste and so offer a means of saving these resources while also reducing the problems of disposal. The energy recovered will be in the form of a liquid fuel that is suitable for use in utility boilers.

The pyrolysis process being demonstrated in the San Diego County project is one of a number of technologies that can be used for resource recovery. To promote such technological development, the Congress, through the Solid Waste Disposal Act as amended, enabled the Federal solid waste management program to assist States and municipalities by assuming part of the risk of trying new technologies. The result was a significant expansion of the Federal resource recovery demonstration program.

Other grants in this program have been awarded to: Baltimore, Maryland, to demonstrate the recovery of steam by pyrolysis; the State of Delaware to demonstrate the use of solid waste as a supplemental fuel in an oil-fired utility boiler; to Franklin, Ohio, to demonstrate the recovery of paper fiber; to Lowell, Massachusetts, to demonstrate the recovery of materials from incinerator residue; and to St. Louis, Missouri, to demonstrate the use of solid waste as a supplemental fuel in a coal-fired utility boiler.

The pyrolysis process described in this report was developed by Garrett Research and Development Company, Inc., of LaVerne, California, a subsidiary of Occidental Petroleum Corporation. Construction of the 200-ton-per-day plant began in 1975 and full-scale operation is scheduled for 1976. Subsequent reports will follow the progress of the demonstration project, which will include a full evaluation of the environmental impacts, economics, and effectiveness of the process.

—ARSEN J. DARNAY
Deputy Assistant Administrator
for Solid Waste Management

SAN DIEGO COUNTY DEMONSTRATES PYROLYSIS OF SOLID WASTE

The recovery of energy from municipal solid waste has become a well-established objective. As increasingly sophisticated energy recovery alternatives are developed, the demand increases for systems that can convert solid waste into a fuel that can be used interchangeably with other fuels. The marketability of a fuel product is also improved if it can be stored and transported, because the user need not be located near the solid waste processing facility, nor must the operating schedules of the user and the processing facility be similar. The system being built by the county of San Diego is designed to produce a synthetic liquid fuel that, with certain constraints, will have these qualities of storability and transportability. And results of pilot-scale research indicate that the fuel produced can be used in conventional furnaces or boilers that use heavy residual fuel oil.

Pyrolysis is the physical and chemical decomposition of organic matter brought about by the action of heat in the absence of oxygen. When municipal solid waste is heated, the organic fraction (primarily cellulose) is broken down into compounds of simpler molecular structure, primarily hydrogen, carbon monoxide, methane, and carbon dioxide. By controlling certain operating parameters, such as temperature, pressure, operating time, and the presence of catalysts, it is possible to control what products are formed. For the San Diego County project, parameters were selected that would result in the formation of a product which is a liquid at room temperature.

The plant, which will have the capacity to handle 200 tons of waste per day, will utilize a flash pyrolysis process in which a nearly instantaneous reaction liquifies the organic solids. Incoming waste will first be shredded (Figure 1). The lighter, organic material will then be separated from the heavier, inorganic material, dried, and reshredded before being fed into the pyrolysis reactor to produce fuel oil. The heavy fraction will be processed further to recover ferrous metals and glass.

Objective

The objective of the demonstration project is to test the principles of the process and to scale up the pilot plant technology under normal operating procedures using municipal solid waste. Data collected on this plant will aid in evaluating the technical and economic viability of the process and will provide a data base for designing larger, optimally sized facilities.

Participants

The U. S. Environmental Protection Agency is supporting the construction and evaluation of this facility with a $3.5 million grant to San Diego County, provided under authority of the Solid Waste Disposal Act as amended.

The San Diego County Department of Sanitation and Flood Control, the agency responsible for solid waste disposal in the county, will be the owner and operator of the facility. The county is providing almost $2 million to carry out the program.

The plant is being built in the city of El Cajon and will receive refuse collected in the city and surrounding areas. The 5.3-acre industrial site was obtained from the city of El Cajon under a long-term lease.

The process was developed by the Garrett Research and Development Company of LaVerne, California, the research subsidiary of Occidental Petroleum Company. Under the provisions of its turn-key contract, Garrett is responsible for designing, constructing, and starting up the plant, which must be in fully operational condition when turned over to San Diego County. Garrett is contributing $3.5 million toward the cost of construction. The detailed design is being prepared by the Ehrhart Division of Procon, Inc., a subsidiary of Universal Oil Products, Inc., through a subcontract from Garrett.

The liquid fuel will be used by the San Diego Gas and Electric Company. Capital for minor modifications needed at the power plant will be provided by the utility. Following a comprehensive testing period, the utility will determine the value of the fuel based on its equivalency with other fuels. Although the utility will pay for the fuel, initial shipments will be credited against the utility's capital expenditures. After that investment has been retired, the utility will begin paying the county.

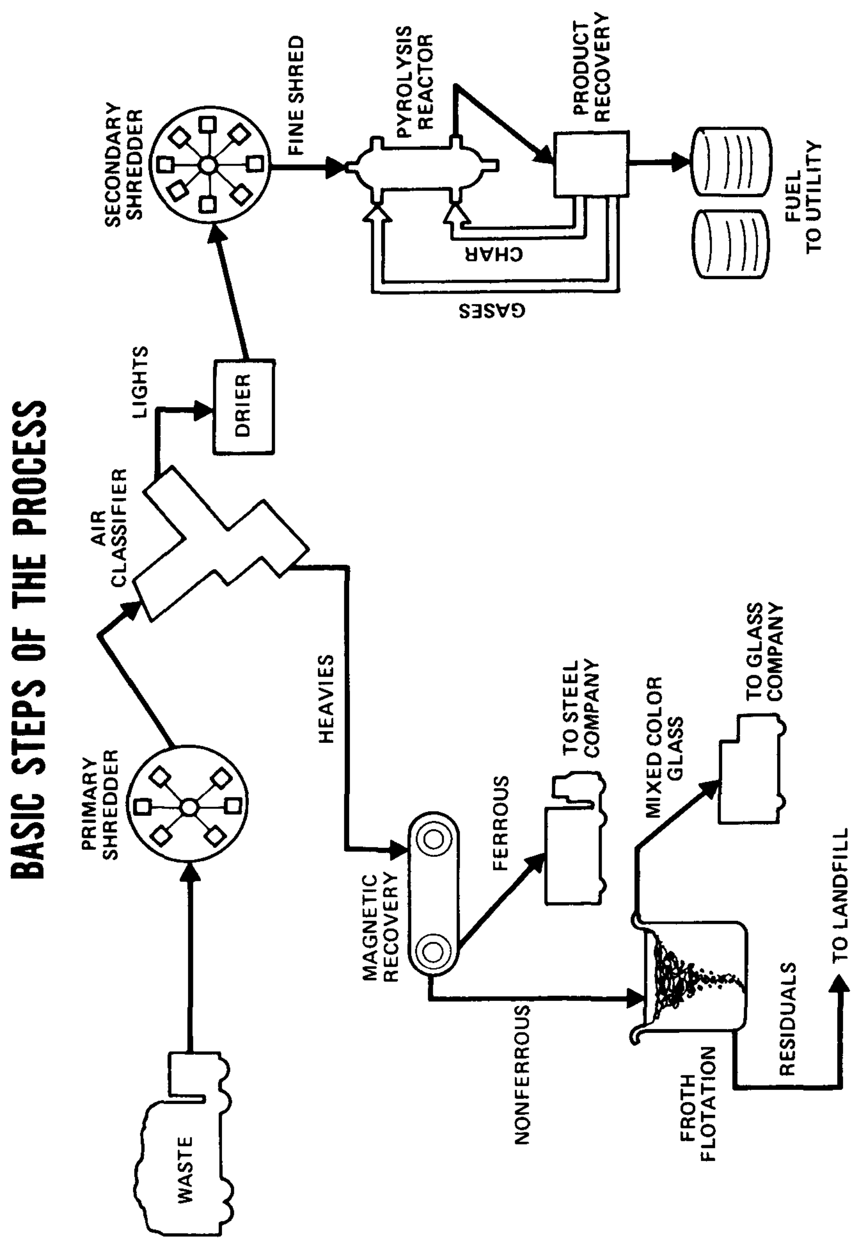


Figure 1. This very simplified diagram shows the main steps in the process that will be employed by the San Diego project.

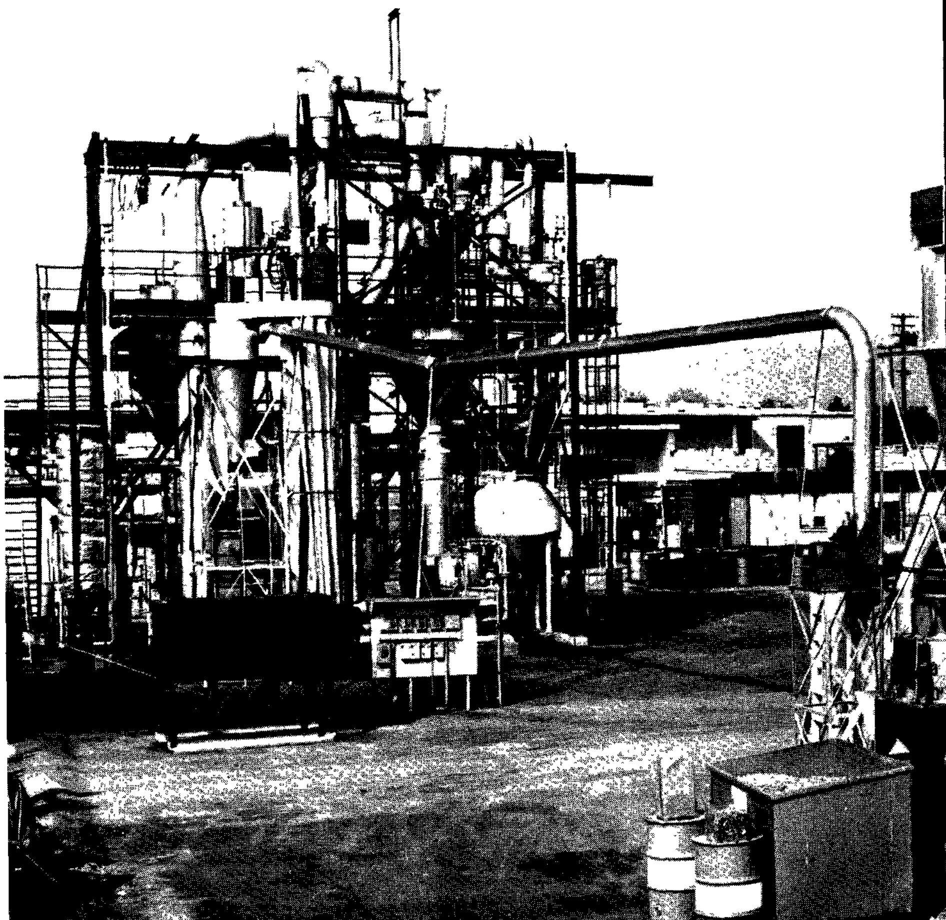
Schedule

The project is divided into three major phases: design, construction, and evaluation (Table 1).

TABLE 1

Project Schedule as of October 1, 1974

Milestone	Date
Grant award	September 1972
Begin design (start phase 1)	February 1973
Initiate turn-key contract (start phase 2)	September 1974
Begin ordering equipment	November 1974
Begin construction	August 1975
Complete construction	July 1976
Complete startup	August 1976
Begin evaluation (start phase 3)	September 1976
Complete evaluation (end of project)	September 1977



The design phase ended in the summer of 1974 when the turn-key contract was negotiated with Garrett. The second or construction phase will end when Garrett delivers a fully operational plant to the county.

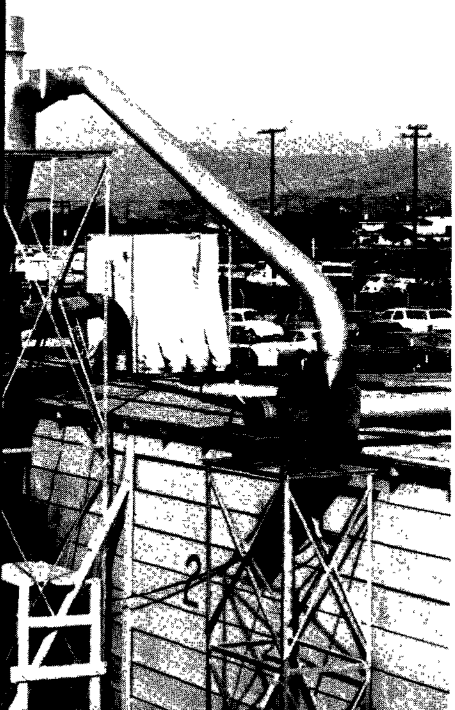
As soon as the plant is capable of performing according to design specifications, a 1-year testing and evaluation period will begin; this will be the third and final phase of the project.

Development of the Process

Garrett developed this process for solid waste as an extension of research on the liquification of coal. Initial theories were tested on a 3-pound-per-hour laboratory test unit. This unit has been used to test many different types of waste, including bark, rice hulls, and waste rubber, in addition to finely shredded municipal solid waste. It is still being used to test process changes.

A 4-ton-per-day pilot unit was completed in March 1971 (Figure 2). With this unit, Garrett was able to verify the theoretical processes established in the laboratory unit and to process enough material to allow definition of design parameters for a full-size plant. The pilot plant has produced fuel for combustion tests and is still being used for occasional tests using municipal solid waste and other organic waste materials.

Figure 2. A plant with a capacity of 4 tons of solid waste per day was operated in Vancouver, Washington, for pilot testing of the Garrett system. The data from this experience was used to design the 200-ton San Diego County plant.



the system

Feed Preparation

Only the organic fraction of the solid waste can be pyrolyzed; therefore, in order to obtain an efficient operation, the waste is first processed to remove the inorganic materials. The feed preparation is more rigorous in this system than in any other energy recovery system currently under development. In addition to being virtually free of inorganic contaminants, the feedstock must also be of extremely small particle size and essentially moisture-free.

In the first step of feed preparation, incoming solid waste is fed into a horizontal shaft hammermill driven by a 1,000-horsepower electric motor (Figure 3). The hammermill's heavy metal hammers, which swing on pins attached to the shaft, shred the waste to a nominal size of 3 inches (90 percent passing a 3-inch screen). Steel grates retain the oversize waste until it is shredded into particles small enough to pass through the grate openings.

The shredded material is then passed beneath an electromagnet to extract the ferrous metal, which will be sold to a scrap dealer. The remaining material goes into a storage bin until it is needed in the next step in the process, air classification. This storage capability assures that a uniform rate of feed into the air classifier can be maintained even though the shredder operates only 8 hours per day while the rest of the plant (except the glass recovery system) operates on a 24-hour basis.

The air classifier separates the heavier, mostly inorganic particles from the lighter, organic material. An upward-flowing column of air catches the lighter material as it is fed into the air classifier and carries it out the top. Heavier material falls through the air stream and is removed from the base of the classifier. The heavy fraction is processed further as described under "Glass Recovery."

The light fraction is dried to a moisture content of 4 percent using heat from burning either combustible gas produced in the pyrolysis reactor or fuel oil.

After drying, this fraction is purified further using a series of mechanical processes. A 0.125-inch screen is used to remove larger particles for secondary shredding in an attrition mill. In this mill, waste fed between two counter-rotating disks is ground into extremely fine particles having a nominal size of minus 14 mesh (that is, 80 percent of the particles could pass through a screen having 14 openings to the inch). Meanwhile, the particles that fall

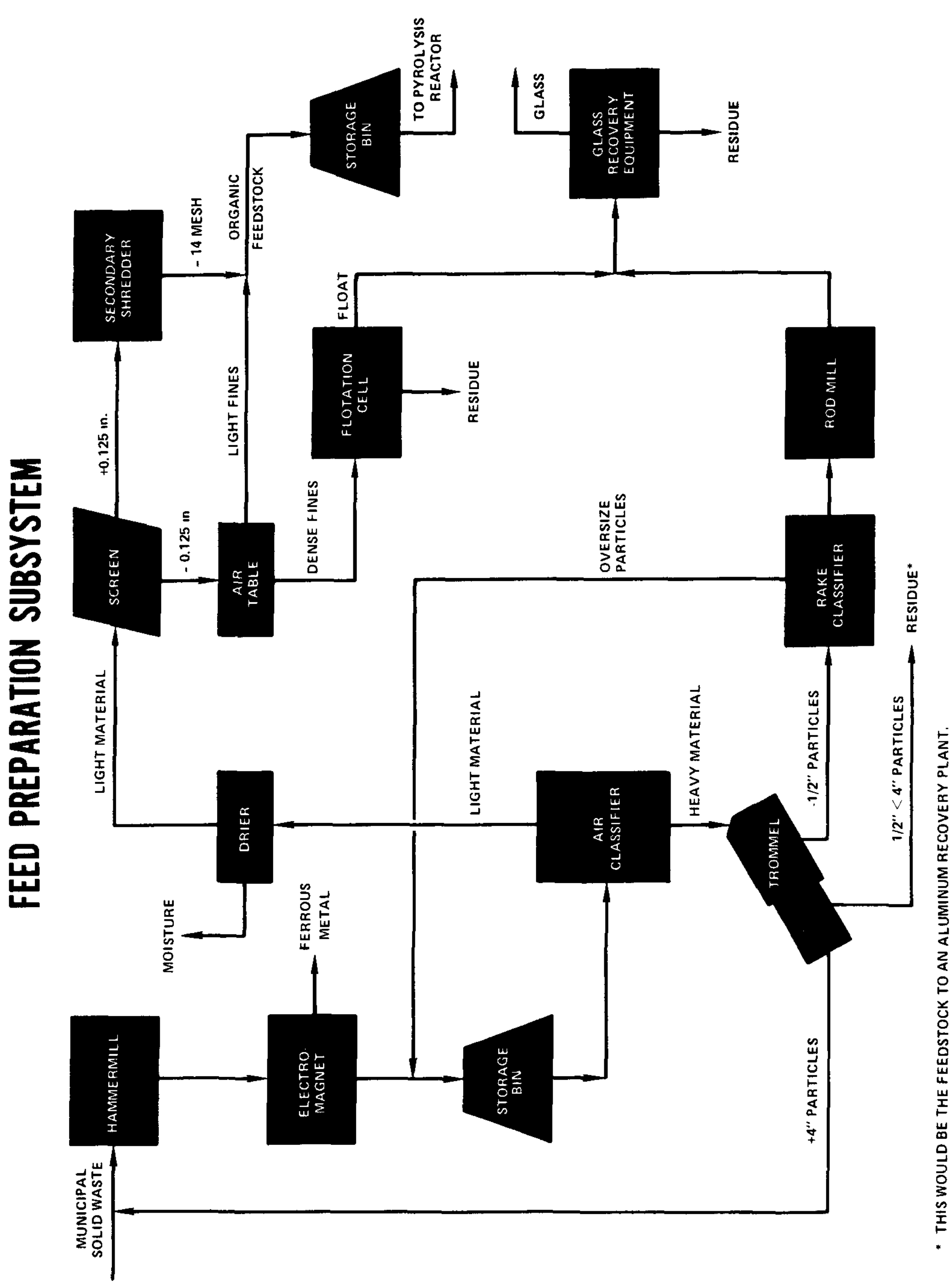


Figure 3. Preparation of feedstock for the pyrolytic reactor involves a number of steps to produce fine particles of moisture-free organic material. The glass recovery system results in recovery of about 75 percent of the glass in total incoming waste.

through the 0.125-inch screen are fed onto an air table where a combination of vibrating motion and air flow separates light organic particles from dense metal and glass particles. The light particles from the air table are combined with the secondary shredder output to form the organic feedstock, which is stored until it is fed into the pyrolysis reactor. The storage bin is large enough to hold a full day's feed for the reactor.

Glass Recovery

The remainder of the feedstock preparation portion of the system consists of the glass recovery process at this time; Garrett will probably add an aluminum recovery process at a later date.

There are two sources of glass-rich feedstock: heavy particles coming from the air classifier underflow and the dense fines recovered from the air table separator.

The heavy fraction from the air classifier is passed through an inclined rotating cylinder called a trommel. At the head or feed end of the trommel, ½-inch perforations in the wall allow small particles to drop out.

These particles are then further separated using a rake classifier, a screening device in which a mechanical rake continuously scrapes the oversize particles from the face of the screen. The particles that fall through the screen are put through a rod mill (a rotating chamber in which steel rods move about crushing the friable material) and then passed into the glass recovery processes. The oversize particles are returned to the storage bin that feeds into the air classifier.

Back at the trommel, beyond the ½-inch holes is a section with holes 4 inches in diameter, where the particles larger than ½ inch but less than 4 inches fall out. This material will be the feedstock to the aluminum recovery plant, if it is added; otherwise, this fraction will be disposed of in a sanitary landfill. Particles greater than 4 inches fall out the end of the trommel and are returned to the front of the plant where they go back through the primary hammermill.

The second source of feedstock to the glass recovery subsystem, the dense fines recovered from the air table, require further processing. From the air table, the fines pass into a flotation cell where the glass is crudely separated by froth flotation. In this step the mixture is coated with a liquid reagent that causes the glass to have a greater affinity for air than for water. The flotation cell is filled with water, and air is pumped into it continuously. As the coated material is pumped into the flotation cell, the glass particles are carried to the surface along with the air bubbles. The glass floats on the surface while the nonglass material sinks to the bottom of the cell. This "float," along with the small particles recovered from the trommel, constitutes the

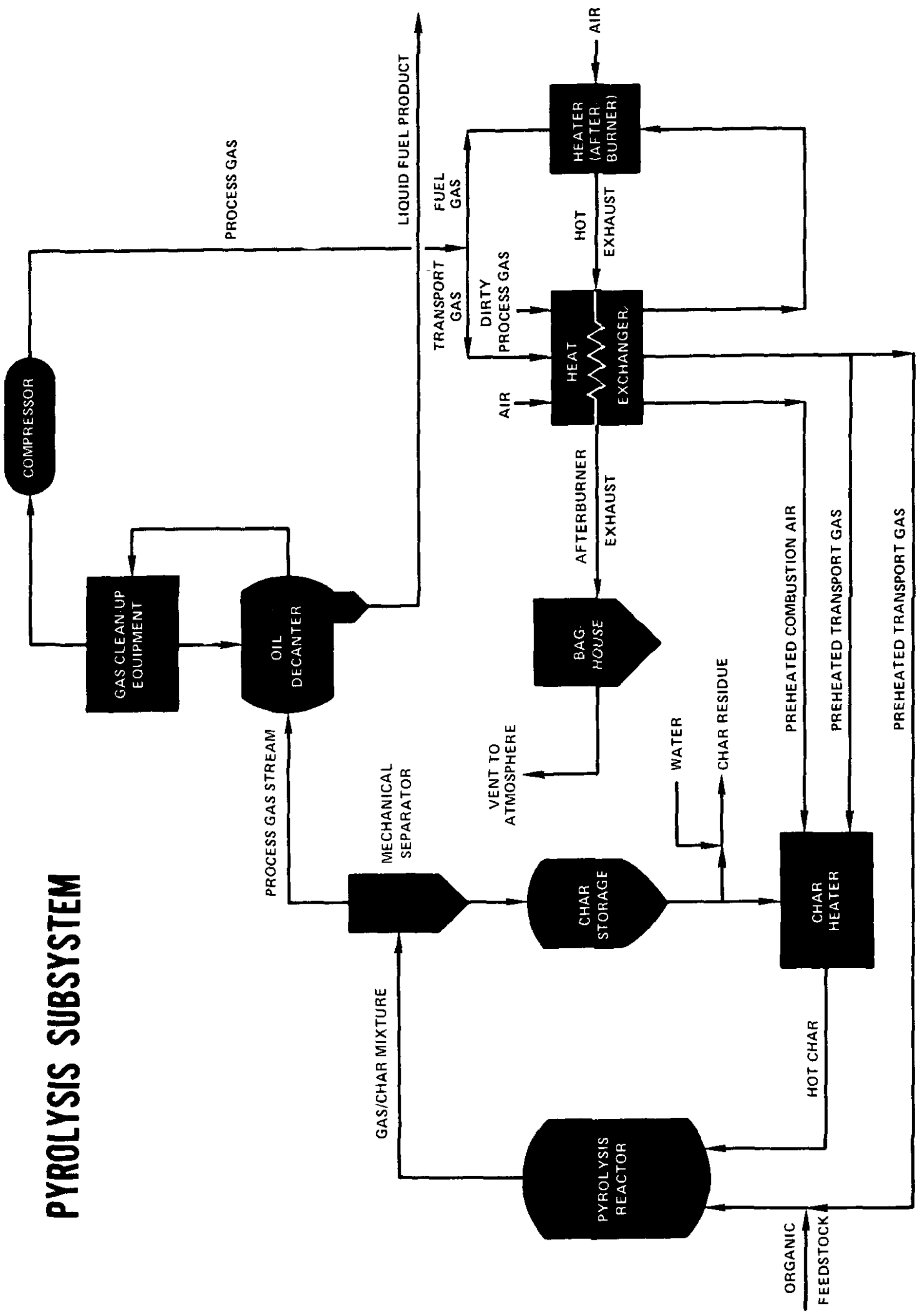


Figure 4. When the organic feedstock is mixed with hot char, it decomposes into a gas-char mixture. The gas is then immediately cooled to produce the liquid fuel.

feedstock to the glass recovery subsystem.

The glass recovery subsystem consists of a series of froth flotation cells which, by recirculating both the float and sink fractions several times, is expected to recover 99 percent of the glass *in the glass feedstock* at a purity of better than 99.5 percent. However, the total recovery of glass from the incoming solid waste will be only 75 percent because there is loss in various parts of the process before the feedstock is formed.

Pyrolysis Process

The pyrolysis reactor is a vertical, stainless steel pipe through which the organic feedstock is pneumatically blown (Figure 4). In the reactor, hot particles of char provide the energy needed to pyrolyze the organic material. The char, which is actually the solid residue remaining after the pyrolysis reaction, enters the reactor after having been heated to a temperature of 1,400 F and is mixed turbulently with the organic material. Five pounds of char is mixed with each pound of organic material. The pyrolysis reaction takes place as the char-waste mixture proceeds through the reactor. The organic feedstock is broken down into a gas and char mixture. Because this reaction is endothermic, that is, requires heat to proceed, the temperature of the mixture falls to about 950 F by the time it leaves the reactor.

A mechanical separator or cyclone is used to remove the char from the gas. The char, which now consists of the char fed into the reactor as well as that newly formed by the pyrolysis reaction, is stored for reuse in the reactor. Before being recirculated to the reactor, this stored char is reheated. Excess char will be cooled with water and removed for disposal in a sanitary landfill; it is possible, however, that markets can be developed for this material.

The process gas that has been separated from the char is cooled quickly to 175 F in an oil decanter. In this device, oil is sprayed into the gas stream, causing it to cool. The cooling must be done very quickly to halt the chemical reactions taking place in the gas and thus prevent a reduction in the yield of fuel. The oil used for cooling is a combination of the liquid fuel produced by the plant and No. 2 fuel oil. After cooling, the liquid fuel settles in the base of the decanter. Approximately 36 gallons of fuel will be recovered from each ton of mixed solid waste. (Additional fuel will be recovered if the aluminum recovery subsystem is added, because this subsystem would allow for the recovery of organic material left in the feedstock for the aluminum recovery processes.)

The remaining gas stream goes through a series of cleanup steps and is compressed for plant use. Part of the gas is used as the oxygen-free medium for pneumatically transporting both the organic feedstock and the char into and through the pyrolysis reactor. The rest of the gas is burned to preheat combustion air for the char heater, to preheat the reactor transport gas, and to preheat dirty gas streams that are produced in various parts of the system. The dirty gases are then burned along with the fuel gas in the afterburner. The combustion gases coming out of the afterburner are cooled in the heat exchanger, cleaned in a baghouse, and then vented to the atmosphere.

The liquid fuel product either goes directly to the oil storage tank or is passed through a centrifuge if the solids content is too high. Liquid fuel that does not meet product specifications is burned in a small boiler to produce steam for heating certain pieces of equipment throughout the plant.

energy and materials balance

Energy Balance

It is expected that each ton of solid waste processed will yield a minimum of 36 gallons (0.9 barrels) of liquid fuel product plus char and gas. The excess combustible char will not be suitable for use as a fuel because its high ash content will make it difficult to burn without producing excessive particulate emissions. Combustible gas will be used internally in lieu of purchased fuel.

Energy inputs to the system, in addition to the solid waste, will amount to 135 kilowatt hours (kWh) of electricity and 2/3 gallon (5 pounds) of No. 2 fuel oil per ton of solid waste processed. The electricity will be used to operate the various pieces of equipment. A small quantity of No. 2 fuel oil, used to quench the process gas stream, will be vaporized and burned with the uncondensed gas for process heat.

To express *net energy yield* per ton of solid waste, the energy inputs are subtracted from the energy recovered and the result is shown as a percent of total energy present in the waste. The energy value of the liquid fuel product less the energy value of the electricity (calculated on the basis that the average steam electric power plant in the United States uses 10,000 Btu of fuel to produce 1 kWh of electricity) and No. 2 fuel oil used amounts to 2.66 million Btu of energy per ton of waste.* Since municipal solid waste

$$\text{*Yield} = \frac{\text{Energy out (liquid fuel)} - \text{Energy in (electricity, No. 2 oil)}}{\text{Total energy in solid waste}}$$

$$= \frac{(36 \text{ gal} \times 113{,}910 \text{ Btu}) - [(135 \text{ kWh} \times 10{,}000 \text{ Btu}) + (5 \text{ lb} \times 19{,}200 \text{ Btu})]}{1 \text{ ton} \times 9{,}200{,}000 \text{ Btu}}$$

$$= \frac{4{,}101{,}000 - (1{,}350{,}000 + 96{,}000)}{9{,}200{,}000}$$

$$= \frac{2{,}655{,}000}{9{,}200{,}000} = 0.29$$

$$= 29 \text{ percent}$$

has an original heat value of about 9.2 million Btu per ton, the net energy yield is about 29 percent.

The *energy efficiency* of the process, however, is expected to be more favorable. This term refers to the fraction of energy recovered from the total amount of energy put into the system, i.e., energy out divided by energy in.* The San Diego plant will convert 39 percent of the energy input into useful energy. Although this ratio is lower than those of most solid waste energy recovery systems, it compares quite favorably with ratios for other methods of converting solid fuels into gas or liquid, such as coal gasification and production of petroleum from oil shale.

Materials Balance

The plant will process mixed municipal solid waste collected in packer trucks from residential sources in El Cajon and surrounding communities. Unfortunately, no composition analysis is available for El Cajon waste. The analyses presented in this report are based on studies conducted on solid waste generated in Vancouver, Washington, because this waste was the feedstock for most of the pilot plant tests conducted by Garrett during 1972-73. These studies found that about half of the waste was organic material, 12 percent ferrous metal, 1 percent aluminum, and 7 percent glass (Table 2). The ferrous metal content of Vancouver waste is relatively high; the percentage may well be somewhat lower at El Cajon.

The salable products–glass, ferrous metal, and liquid fuel–represent about 34 percent of the wet weight of incoming materials (Table 3 and Figure 5). The remaining material is moisture (25 percent), solid residuals (21 percent), and gaseous emissions (20 percent).

$$\text{*Efficiency} = \frac{\text{Energy out (liquid fuel)}}{\text{Energy in (solid waste, electricity, No. 2 oil)}}$$

$$= \frac{36 \text{ gal} \times 113{,}910 \text{ Btu}}{(1 \text{ ton} \times 9{,}200{,}000 \text{ Btu}) + (135 \text{ kWh} \times 10{,}000 \text{ Btu}) \cdot [illegible] \; 19\,200 \text{ Btu})}$$

$$= \frac{4{,}101{,}000}{9{,}200{,}000 + 1{,}350{,}000 + 96{,}000}$$

$$= \frac{4{,}101{,}000}{10{,}646{,}000} = 0.39$$

$$= 39 \text{ percent}$$

TABLE 2
Composition of Municipal Solid Waste*

Component	Percent	Tons per day at plant
Organics	52	104
Metals		
Ferrous	12	24
Aluminum	1	2
Glass	7	14
Other inorganics	2	4
Miscellaneous solids	1	22
Moisture	25	50
Total	100	200

*Based on data from pilot testing conducted at Vancouver, Washington, 1972-73.

TABLE 3
Materials Balance

Input = 200 tons per day municipal solid waste (150 tons dry weight).*

Outputs	Percent of wet weight	Tons per day
Products (dry weight)		
Ferrous metals	12	23.7
Glass	5	10.4
Oil	17	33.8 (172 barrels)
Residue to landfill (dry weight)		
Solid residuals	16	31.5
Waste char	5	11.1
Waste gases†	20	39.5
Moisture	25	50.0
Total	100	200.0

2.

the combustible gas which is used as a fuel in the afterburner and ied in the pyrolysis reactor.

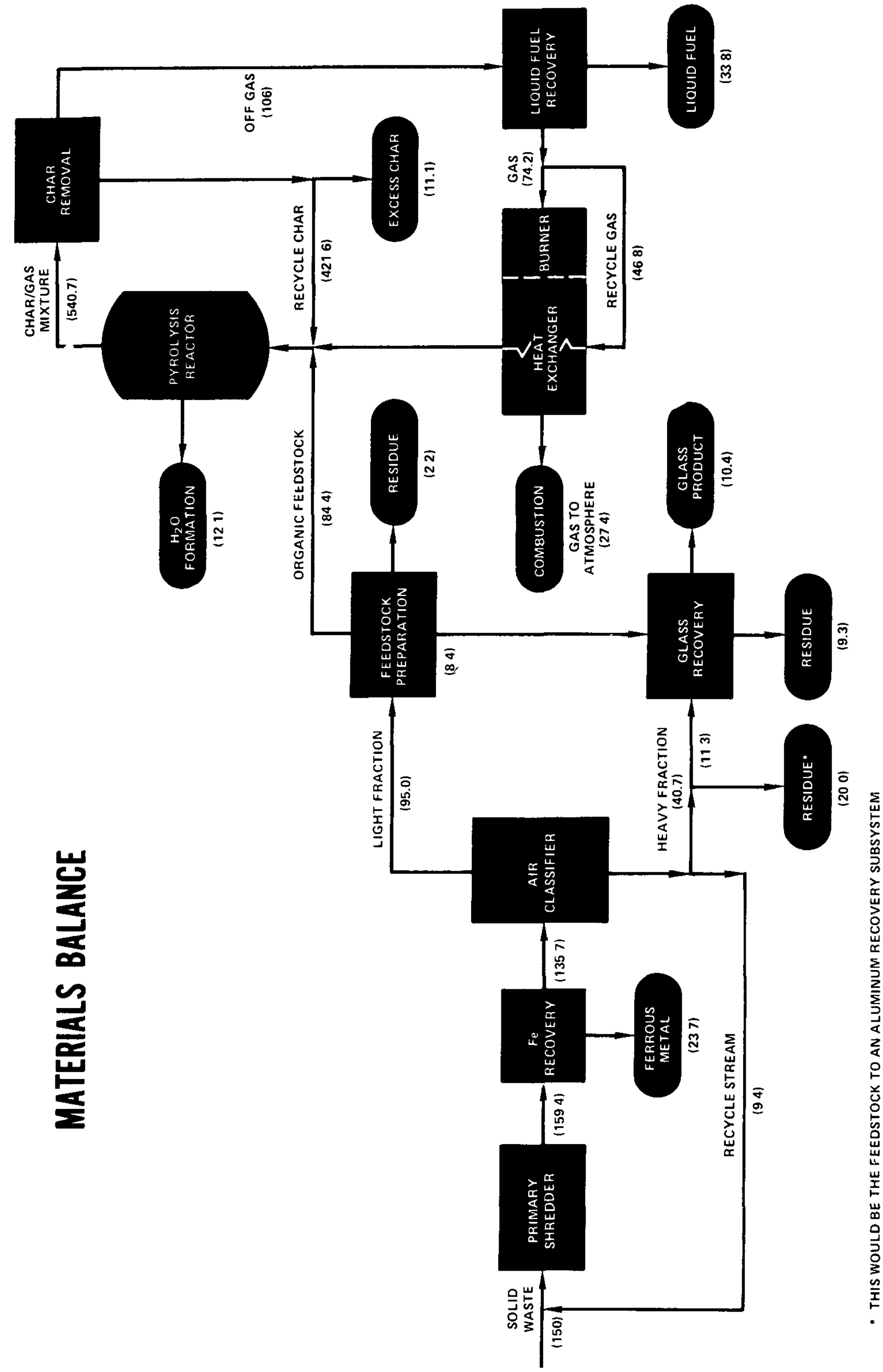


Figure 5. Thirty-four tons of liquid fuel, 24 tons of ferrous metal, and 10 tons of glass will be produced each day from 150 tons of municipal solid waste. (All numbers represent dry weight in tons per 24 hours.)

quality of the products

Liquid Fuel

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

The average heating value per pound of the pyrolytic "oil" is about 10,500 Btu, compared with 18,200 Btu per pound for typical No. 6 fuel oil (Table 4). The lower heating value is due to the fact that pyrolytic oil is lower in both carbon and hydrogen and contains much more oxygen. Fuel oils are generally sold on a volume basis, however, and since the specific gravities of pyrolytic oil and No. 6 are 1.30 and 0.98 respectively, a comparison of heating values is much more favorable to the former when expressed on a volumetric rather than weight basis. A gallon (or barrel) of oil derived from the pyrolysis of municipal waste contains about 76 percent of the heat energy available from No. 6 oil. Each ton of solid waste yields about 4.1 million Btu of energy as liquid fuel.

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

It has been found that pyrolytic oil from municipal waste can be blended with several different No. 6 oils, although over a period of hours the heavier pyrolytic oil settles out from the mixture because there is little mutual solubility.

Successful combustion trials were carried out at the Kreisinger Development Laboratory of Combustion Engineering, Inc., in Windsor, Connecticut, with pyrolytic oil blended at 50 percent and 25 percent by volume with No. 6 oil derived from an Alaskan crude. Combustion Engineering's formal report on the work states:

> Pilot-scale laboratory tests indicate that pyrolytic oil or blends of pyrolytic oil with No. 6 fuel oil can be successfully burned in a utility boiler with a properly designed fuels handling and atomi-

TABLE 4
Typical Properties of Liquid Fuel from Solid Waste and No. 6 Fuel Oil*

	Liquid fuel product	No. 6 fuel oil
Physical properties (dry basis):		
Heating value (Btu/lb)	10,500	18,000
Specific gravity	1.30	0.98
Density (lb/gal)	10.85	8.18
Volumetric heating value (Btu/gal)	113,910	148,840
Handling properties (at 14 percent moisture):		
Pour point (F)	90	65-85
Flash point (F)	133	150
Pumping temperature (F)	160	115
Atomization temperature (F)	240	220
Viscosity (sSu at 190 F)	1,000	90-250
Chemical analysis (dry basis, % by weight):		
Carbon	57.5	85.7
Hydrogen	7.6	10.5
Sulfur	0.1-0.3	0.5-3.5
Chlorine	0.3	†
Ash	0.2-0.4	0.5
Nitrogen	0.9	2.0 (Nitrogen and Oxygen combined)
Oxygen	33.4	

*Finney, C. S., and D. E. Garrett. The flash pyrolysis of solid wastes. Presented at Annual Meeting, American Institute of Chemical Engineers, Philadelphia, Nov. 11, 1973. p. 18b.

†Not available.

zation system. Ignition stability with pyrolytic oil and with the blends was equal to that obtained with No. 6 alone; and stack emissions when burning pyrolytic oil or blends indicated negligible amounts of unburned carbon at excess oxygen levels over two percent.*

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

Several properties of the fuel are of special concern to the utility:

Corrosion. Because this fuel is more corrosive to metals than natural residual oils, particularly at high storage and handling temperatures, the use of corrosion-resistant materials in the storage and handling equipment will be required.

Temperature degradation. At temperatures above 200 F the fuel begins to undergo chemical changes which adversely affect its viscosity. It will therefore be necessary to store the fuel at a lower temperature and heat it when it is used.

Mixing. This fuel cannot be mixed with No. 6 oils for extended periods because it is not soluble, and the great difference in specific gravities (Table 5) causes rapid separation unless the mixture is thoroughly agitated.

Composition. This fuel has higher ash and nitrogen content than No. 6 oil; this could affect the rate of boiler tube fouling and the emission of particulates and oxides of nitrogen.

Ferrous Metal

Ferrous metal will be separated magnetically following the primary shredding operation. Ninety-five percent of the ferrous in the waste stream will be recovered, and the recovered material will be about 95 percent pure ferrous. Several scrap dealers in San Diego and Los Angeles have expressed a desire to purchase the ferrous metal.

Glass

Glass will be recovered as a mixed-color cullet. It should be better than 99 percent pure with a moisture content of about 20 percent. The glass prod-

*Borio, R. W. Combustion and handling properties of Garrett's pyrolytic oil. Windsor, Conn., Kreisinger Development Laboratory (Department 683), Dec. 4, 1972. p.1-2.

uct will consist of very small particles (at least 60 percent by weight will be less than 50 mesh). A tentative market has been established with Glass Container Corporation to use the cullet in the manufacture of either green or amber bottles. Its small particle size will require the user to maintain separate handling and feeding facilities; it will thus command a somewhat lower sales price than would normally be expected for glass cullet of this purity.

Char and Gas

In addition to the salable products, two fuel products will be produced for internal use.

Char produced at the rate of about 110 pounds per ton of solid waste will be used internally as the heat transfer medium. It will first be heated in the char heater and then mixed with the solid waste as it is fed into the pyrolysis reactor. Five pounds of char will be fed into the reactor for every pound of organic feedstock. Once a stockpile of char has been established, the excess will be discarded. The discarded char will have a heat value of 9,000 Btu per pound, but its high ash content (32 percent) will make it unsuitable for sale as a fuel. Garrett is examining its potential value as a filler for various plastic products.

Combustible gas will be produced from the solid waste at a rate of 275 pounds per ton. This gas will be used internally as a fuel in the drier, in the char heater, and in the preheater for combustion air and transport gas.

economics

An economic analysis of the 200-ton-per-day facility to be built in El Cajon has been made on the basis of definitive estimates of the capital cost and expected operating costs and revenues. It should be kept in mind, however, that this plant is below the size range normally considered cost-effective.

The capital cost for the facility was estimated in June 1974 to be $6.3 million. This includes engineering design, site development, construction, overhead, and the contractor's profit (Table 5).

Amortization of capital is assumed to be at 6 percent over 20 years.

Annual costs for normal operation, exclusive of a detailed testing and evaluation program, are projected as follows:

Operating costs	
Electric power	$. 127,000
Other utilities	39,000
Labor (20 positions)	361,000
Maintenance	317,000
Land rent	34,000
Residual transfer and disposal	38,000
Total operating costs	916,000
Capital costs	
Amortization of $6,344,000 (20 years at 6 %)	553,000
Total annual cost	$1,469,000

To estimate the plant's revenues, a dollar value can be assigned to the liquid fuel based on its energy value to the utility (less an allowance for the utility's extra handling costs). The actual price to be paid for the fuel will be determined during the first operating year. Revenues will also be generated through the sale of ferrous metals and mixed-color cullet.

Total quantities of recovered materials are calculated on the assumption that the plant will achieve 85 percent of its design capacity on an annual basis. The plant is designed (and operating expenses are calculated) for 24-hour-per-day operation, 7 days per week. Throughput will thus be 62,050 tons per year (85 percent of 200 tons X 365 days).

TABLE 5

Breakdown of Capital Costs Estimated for 200-Ton-per-Day Pyrolysis Plant

Item		June 1974 estimates
Design		$ 777,000
Site development costs		679,000
Construction		3,716,000
Receiving and preparation (through air classifier and trommel)		
Equipment	596,000	
Installation	885,000	
Organic feed preparation		
Equipment	317,000	
Installation	306,000	
Pyrolysis and fuel recovery		
Equipment	254,000	
Installation	398,000	
Glass recovery		
Equipment	113,000	
Installation	262,000	
General and utility (product storage, afterburner, package boiler, spare parts)		
Equipment	312,000	
Installation	273,000	
Inflation, overhead, and contractor's profit		1,172,000
Total		$6,344,000

On a wet weight* or as-sold basis, the amounts of revenue-producing materials are:

Ferrous metal	7,874 tons per year
Glass	4,033 tons per year
Liquid fuel	53,644 barrels per year

Revenues for the various products are calculated on the basis of mid-1974 market values less an allowance for transporting the products to the users' facilities. Revenues actually produced from the sale of ferrous metal from this plant may be somewhat less because El Cajon's waste is not expected to have as high a metal content as the waste samples used in this analysis. Annual estimated revenues are:

Ferrous metal (7,874 tons at $47/ton)	$370,000
Glass (4,033 tons at $6.40/ton)	26,000
Liquid fuel (53,644 barrels at $4/bbl)	232,000
Total	$ 628,000

Net costs will thus be:

Total annual cost	$1,469,000
Annual revenues	- 628,000
Net cost	$ 841,000

This results in a net cost per ton of $13.42. It should be noted that the cost per ton would be lower in a full-sized plant with a throughput larger than that of this demonstration unit.

*The weights for the products as shown in the material balance in Table 3 are dry weights. In actual operations these materials will contain certain amounts of moisture. Product values are based on the wet weight of the respective materials. Ferrous is 6.64 percent moisture; glass is 20 percent moisture; the fuel is 14.2 percent moisture.

environmental impacts of the system

Conservation of Resources

Using this system, fuel, metal, and glass are recovered from solid waste, all of which would ordinarily be buried in a landfill. Each ton of waste delivered to the facility will provide the equivalent of 27 gallons of No. 6 heating oil; in addition, 237 pounds of ferrous metal and 104 pounds of glass will be recovered. The amount of waste going to the landfill will be reduced by over three-fourths.

Also, as a form of disposal the system is free of the health and environmental hazards sometimes associated with conventional disposal methods; such hazards include leachate production from disposal sites and subsequent water pollution, air pollution from open burning and incinerators, dangerous accumulations of gas in landfills, and harborage of rodents and other vectors.

Atmospheric Emissions

Pyrolysis Plant. In designing the plant careful attention was directed to minimizing the chance of any adverse impact on air quality. Although air will be used throughout the system, the equipment will be designed to control emissions. The air from the drier, air classifier, and pneumatic transport systems will be used as combustion air in the process heater. All other air will be recirculated within the system. Exhaust gases from the process heater will be cooled and then passed through a bag filter, so that when finally released to the atmosphere, they will be in compliance with Federal, State, and local standards.

Combustion of Fuel Product. In converting solid waste to a liquid fuel one of the primary objectives is to produce a fuel that burns cleaner than the original solid waste and that can economically be made to burn at least as clean as the fossil fuel it replaces. Limited test data have been collected on emissions of sulfur dioxide and oxides of nitrogen produced when the pyrolytic oil is burned. Concentrations of sulfur dioxide in the flue gas were directly proportional to the sulfur content of the fuel. They ranged from 120-155 parts per million (ppm) when the fuel was blended with No. 6 oil (having a sulfur content of 0.4 percent), up to 290 ppm when 100 percent pyrolytic oil was burned. This compares quite favorably to the 380 ppm produced when No. 6 fuel oil having a 1 percent sulfur content was burned. Nitrogen oxide production was somewhat higher for the pyrolytic oil than No. 6 heating oil. Blends of No. 6 and pyrolytic oil produced an average of 420 ppm of oxides of nitrogen. Additional experimentation with various firing methods is needed to determine the impact this fuel will have on emissions of oxides of nitrogen. In order to assess fully the environmental impact of this fuel, the San Diego Gas and Electric Company has proposed a 21-month test program incorporating both laboratory and boiler tests. Flue gas analysis will include particulates, oxides of nitrogen, oxides of sulfur, hydrochloric acid, carbon monoxide, and visible emissions.

Water

The plant will use 16,800 gallons of water per day. This water will be used in the glass recovery process, and part of it will be recycled for char quenching.

Water from the plant will be discharged to the sanitary sewer system following removal of settleable solids. No significant impact on the treatment plant appears likely as this effluent is equivalent to the waste produced by less than 200 people.

Land

All residual waste will be disposed of in a sanitary landfill. This amounts to 42.6 tons per day or about 21 percent of the original quantity of solid waste.

Odors

Special precautions will be taken to insure that no odors emanate from the plant. All solid waste will be unloaded in a fully enclosed building, and no waste will be stored at the site longer than 24 hours. The pyrolysis process will be contained fully so that there are no emissions.

Air used in air classification will be combined with the combustion gases and dryer exhaust and will be injected into the process afterburner and heat exchanger to destroy odors. These gases will then be cooled, scrubbed, and filtered before being released to the atmosphere.

Noise

Noise can result from truck traffic making deliveries to the plant and from equipment in the plant. Approximately 35 truckloads of refuse will be delivered to the plant each day between 8:00 am and 5:00 pm. Unloading will be done inside the receiving building. Any equipment which would create a noise disturbance above ambient levels at the property line will be insulated so as to muffle the sounds.

summary

The San Diego County demonstration plant, now under construction and scheduled to begin operating around August 1976, will recover at least 36 gallons of liquid fuel (equivalent in heating value to 27 gallons of No. 6 fuel oil) from each ton of municipal solid waste using the Garrett flash pyrolysis system. This system employs a relatively complex fuel preparation process involving two stages of shredding and air classification. The fuel will be purchased by the San Diego Gas and Electric Company for use in its oil-fired boilers. The pilot tests indicate that the liquid fuel can be stored and transported, but some modifications in equipment and handling may be necessary because of its special characteristics.

Ferrous metal and glass will also be recovered, and an aluminum recovery system may be added later.

The demonstration plant, with a capacity of 200 tons of waste per day, is not considered large enough to be cost-effective, but the data collected on its operations will enable evaluation of the process and provide a base for designing larger facilities.

The potential environmental benefits from this system–the resources saved and the reduction in volume of wastes–are great. In order to control all possible impacts on the environment, careful attention has been given to this aspect of plant design; the emissions from combusting the liquid fuel will be fully tested.

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