MRI REPORT

CONCEPTUAL DESIGN STUDY ON INCORPORATING A 25-TON/DAY PYROLYSIS
UNIT INTO AN OPERATING TOTAL ENERGY SYSTEM

FINAL REPORT
December 13, 1976

MRI Project No. 4282-E-1

MASTER

Prepared for

Argonne National Laboratory, Argonne, Illinois
Operated for the
U.S. Energy Research and Development Administration
under Contract W-31-109-Eng-38

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Prepared for

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PREFACE

This report documents a preliminary review of the institutional, technical, and economic factors influencing the incorporation of a 25-ton/day pyrolysis unit into the Indian Creek Total Energy System. The project was funded by the Advanced Technology-Mix Energy Systems (ATMES) group at Argonne National Laboratory. The contract (Number 31-109-38-3588, Part 1) was funded in the amount of \$11,560,000 with a period of performance of 4 months.

The project leader was Mr. Jerry O. Bradley, Senior Engineer. Members of the project team include Dr. Roderick Athey, Mr. Carl Bingham, Mr. Rick Harper, Mr. Mike Scott, and Mr. David Posner of MRI and Mr. Ed Rice, Manager of Indian Creek Service Company. Technical information related to the 25-ton/day trash pyrolysis unit was furnished by Mr. Stuart Hoffer, Marketing Manager, Environmental and Energy Systems, Hamilton Standard Division of United Technologies.

Approved for:

MIDWEST RESEARCH INSTITUTE

Michael C. Noland, Director
Engineering Sciences Division

December 13, 1976

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I. INTRODUCTION

This report presents the results of a conceptual design study on incorporating a pyrolysis unit into an existing total energy plant. The study was performed by Midwest Research Institute and the Indian Creek Service Company for the Advanced Technology-Mix Energy Systems section of the Energy and Environmental Systems Division at Argonne National Laboratory. The objectives of this study were to examine the institutional, technical and economic factors affecting the incorporation of a 25-ton/day pyrolysis unit into the Indian Creek Total Energy Plant.

The report is divided into four chapters. A description of the Indian Creek total energy plant is presented in Chapter II. Chapter III presents the results of the conceptual design. Chapter III is divided into three sections. The first section presents the results of the analysis of institutional factors, including a survey of the availability of waste materials and a review of health and safety ordinances. The second section of Chapter III discusses the technical aspects of the pyrolysis system. Included in this section are the results of the review of facilities requirements for the pyrolysis unit, the analysis of necessary system modification, and an estimate of the useful energy contribution by the pyrolysis unit. Results of the life-cycle cost analysis of the pyrolysis unit are presented in the third section of Chapter III. Additional research efforts are briefly discussed in Chapter IV.

The major conclusions presented in this report are:

- There appear to be no institutional or technical barriers to constructing a waste pyrolysis unit at the Indian Creek Total Energy Plant.
- Pyrolysis gas can be consumed in the engines and the boilers by utilizing venturi mixing devices.
- The engines can consume only 5% of the output of the 25-ton/day pyrolysis unit. Therefore, consumption of pyrolysis gas will be controlled by boiler energy demand patterns.
- A waste pyrolysis unit is not cost effective at the current natural gas price of \$0.90/10⁶ Btu.
- Pyrolysis is economically attractive at natural gas prices above \$3.00/10⁶ Btu.

II. THE INDIAN CREEK TOTAL ENERGY SYSTEM

A. History of the Total Energy System

The Indian Creek Total Energy System was constructed in 1971 and became operational January 1, 1972. It was designed to meet the projected electrical, space conditioning and domestic hot water needs of Indian Creek Village, which currently consists of 274 garden-type apartments with a total floor area of approximately 300,000 ft². Indian Creek Village is located on approximately 53 acres in an upper middle-class neighborhood located in the City of Overland Park in northeast Johnson County, Kansas. The apartments are owned by Chase Manhattan Mortgage and Realty Trust. The power plant, valued at approximately 2.5 million dollars is owned by U.S. Realty and Investment Company. Overland Park is a suburb of the Greater Kansas City Metropolitan Area. Indian Creek Village is in a transition area between single-family residences and a commercial region consisting of mostly low-rise shopping centers.

When construction was started on Indian Creek Village in 1971, it was originally intended that the apartment complex be developed from the original 274 units to a total of 1,800 units in six phases over approximately 5 years. However, due to economic conditions which have existed from 1972 until the present, construction of the additional apartments has been delayed. Current planning is to add approximately 275 additional apartments sometime during the calendar year of 1977. This will bring the total floor area of apartments to approximately 600,000 sq ft. The total energy plant as it now exists, has sufficient capacity to supply the electrical and thermal requirements of the 600,000 sq ft of apartments without any significant additions or modifications. The following section provides a general description of the Indian Creek Total Energy System as it now exists.

B. Description of Indian Creek Total Energy System

1. General description: The Indian Creek housing development will consist of many low-rise and two high-rise buildings, with an ultimate capacity of 1,800 apartments. The project is being built in six phases, to be completed in approximately 5 to 10 years, and is presently preparing for the second phase of construction. The low-rise buildings consist of one-story and two-story units, with several apartments under one roof. A total energy plant, housed in a separate building, provides chilled water, hot water and electrical services for the project by means of underground distribution systems to the various buildings.

The generating plant presently consists of one 8-cylinder 720-rpm Fairbanks-Morse opposed piston engine driving an FM type TGZHO, 1137.5 KVA, 0.8PF, 10-pole generator and one 12-cylinder 720-rpm Fairbanks-Morse opposed piston engine driving an FM type TGZHO, 1706 KVA, 0.8PF, 10-pole generator, both feeding a three-phase, 4,160-V, 60-Hz power system. The ultimate plant will contain five engine generator units providing an estimated 8,000 KVA of generating capacity.

Photographs taken during construction of the plant appear in Figures 1 through 7.

2. Description of building services:

HVAC: The low-rise apartment buildings are served by fan-coil units in the basement which distribute hot or cold air to the various rooms via a system of ductwork. Fan-coil units have separate heating and cooling coils which are piped to the underground distribution mains via a system of automatic temperature control valves. The high temperature (300°F) water from the plant is reduced to 165°F by means of mixing valves, and is circulated through the heating coils in the fan-coil units. Chilled water (42°F) from the underground mains is piped directly to the cooling coils in the units.

Plumbing: Domestic hot water is generated in the basement of each building by means of a heat exchanger using high temperature (300°F) water as the heating medium.

Electrical: The 4,160-V power generated in the total energy plant is distributed underground to the various buildings. A local outdoor transformer at each building reduces the voltage to 240/120 V for building usage. Service into each low-rise building is either 37.5 KVA or 50.0 KVA, depending upon the building size. Apartments are individually paneled and circuited, and are served with a main distribution panel in the basement of each building. Provisions are made for a fire protection alarm system in each building which will be relayed to a central station.

3. Description of total energy plant: The total energy plant's basic function is to provide the chilled water, heating water and electrical power for all the apartment buildings on the project. The plant is self-contained and housed in its own building structure on the project site. The ultimate plant will contain five engine-generator units providing an estimated 8,000 KVA of generating capacity, four absorption-refrigeration units with a total capacity of approximately 4,600 tons of cooling, and three hot water heating boilers with a combined capacity of 90,000,000 Btu/hr. Each engine generator can provide an additional 5,000,000 Btu/hr of heating capacity by means of its heat recovery unit. A percentage of the above equipment capacities will always be held in reserve on a standby basis.

Figure 1 - Exterior View of Total Energy Plant and Cooling Tower

Figure 2 - Fairbanks-Morse I. C. Engines

Figure 3 - Prime Mover Heat Recovery Equipment

Figure 4 - Absorption-Refrigeration Equipment

Figure 5 - Water Heating Boilers

Figure 6 - Plant Operating Panel

Figure 7 - Electrical Switchgear Panel

Primary hot water (300°F) is generated in dual-fuel, water-tube boilers as well as in the heat recovery boilers for the engine generators. Secondary hot water pumps circulate part of the hot water through the engine oil coolers and jacket water coolers, where more heat is recovered, and then this water is reintroduced into the primary hot water circuit.

The primary hot water is further heated up in heat recovery boilers, which extract heat from the engine-generator exhaust flues, before being pumped back to the boilers. This primary hot water serves the heating and domestic hot water systems in the apartment buildings as well as the refrigeration units in the total energy plant. Hot water compression tanks are nitrogen-loaded.

The absorption-refrigeration units utilize 290°F primary hot water to produce chilled water (42°F) for the air conditioning systems. This chilled water is circulated through a primary piping loop within the plant. Secondary chilled water pumps, connected to this loop, distribute water to and from the buildings by means of underground mains. These secondary pumps are of the variable-speed type to accommodate the changing cooling requirements in the buildings. Condenser water is cooled in a forced draft cooling tower, located outside the plant, and is circulated between the tower and the refrigeration units by means of vertical, turbine-type condenser water pumps.

The chilled water distribution system to the buildings consists of an underground, two-pipe, reverse-return piping system, with direct-return branches to each individual building. The high-temperature hot water distribution system is an underground, one-pipe arrangement, with both supply and return water to and from the buildings flowing through the same pipe main. Control air, for the automatic temperature control systems, is also run to the various buildings by means of underground conduits.

The engine generators in the total energy plant are of the low-speed, opposed piston type, 0.80 power factor, and feed the 4,160-V, three-phase, 60-Hz power system. The metal-clad switchgear equipment includes a master station control and logic cubicle, station swinging panel, generator control cubicle, bus-tie and bus isolations cubicles. Load-switching equipment includes fused disconnect cubicles, load-break contactors and isolation switches.

The generating equipment can operate either manually, semiautomatically, or automatically. A selector switch permits any engine-generator to operate in any of the three running modes or be locked out. Normally, the system will function in the automatic mode, with a minimum of one electric generator always running. Additional units will sequence on-the-line or off-the-line as load and/or faults are sensed by the master logic equipment.

Selection of the manual mode cuts out the master logic unit and relinquishes control of the engine generators and load dispatch to the operator. The order of starting and stopping the various engines can be present in any desired sequence. Load shedding equipment, alarms and other safety devices are also included in the generator plant equipment.

The dual-fuel engines are provided with both gas and No. 2 oil connections. Underground fuel oil storage tanks are piped to the engines through transfer pumps and day tanks. (The same fuel oil piping system also serves the hot water boilers.) Normally, gas is used for combustion purposes, with oil held in reserve as a standby fuel. Combustion air is ducted to the engines through individual air washers and filter equipment, located directly outside the plant. Heat from the exhaust flues is extracted in the heat recovery units.

The entire plant is mechanically ventilated by means of an air handling unit, with cooling coils, supply air ductwork, and roof mounted exhaust fans. Water treatment equipment is provided for the plant's major piping systems. Air compressors and storage tanks for the project's automatic temperature control systems are also located in the total energy plant.

III. RESULTS OF CONCEPTUAL DESIGN STUDY

A preliminary evaluation was made of the institutional, technical and economic factors influencing the incorporation of a 25-ton/day pyrolysis unit. Sources of waste materials were identified and existing health and safety ordinances were reviewed for possible barriers to installing the pyrolysis unit. Necessary system modifications were identified as were impacts on the manpower, maintenance and safety requirements of the total energy facility. The total demand for pyrolysis gas was estimated. Finally capital and operating costs and savings were estimated and a life-cycle cost analysis was made. This chapter discusses the methods used and the results obtained in each of these analyses.

A. Institutional Factors

1. Sources of waste material: A survey of the current availability of waste materials from sources located in the area surrounding the site for the proposed pyrolysis unit was conducted. The energy content of waste materials available for pyrolysis was also estimated. Solid waste availability and energy content are discussed in Sections (a) and (b) below. A discussion of the characteristics of solid waste appears in Appendix A.

a. Availability of solid waste: The following survey groups the amounts of solid waste generated in the Kansas City Metropolitan Area into residential, commercial and industrial categories. U.S. Census population and employment figures were combined with incremental estimates for solid waste generation for the (1) Kansas City SMSA, (2) Wyandotte County, (3) Johnson County and its six largest cities, and (4) the Indian Creek Apartment complex (the proposed site).

Figure 8 provides a reference scheme of where the pyrolysis installation will be located in the Kansas City region. The proposed site (Indian Creek Apartments) is located in the City of Overland Park, Johnson County, Kansas. Overland Park and the other major cities in Johnson County are identified. Adjacent to Johnson County, to the north, is Wyandotte County, the other major metropolitan Kansas county within the Kansas City region.

Table 1 lists each of these major statistical geographic units and provides estimates of solid waste generation (tons/year) for each location.

Table 2 illustrates that more than adequate amounts of solid waste are available to meet the proposed pyrolysis installations annual requirements of 9,125 tons.

Figure 8 - Location of Indian Creek Village Apartments.

TABLE 1

SOLID WASTE GENERATION DATA
(TONS/YR)

<u>Statistical Geographical Unit</u>	<u>Residential</u>	<u>Commercial</u>	<u>Industrial</u>	<u>Total</u>
Kansas City SMSA	489,717	315,701	226,844	1,032,262
Wyandotte County, Kansas	65,696	24,741	39,157	129,594
Johnson County, Kansas	95,336			
Leawood City	4,533	35,405	23,391	154,132
Merriam City	4,753			
Olathe City	7,848			
Overland Park City	33,561			
Prairie Village City	1,232			
Shawnee City	8,971			
Indian Creek Apts.				
Present	307	--	--	307
After planned expansion	613	--	--	613

TABLE 2

REGIONAL SOLID WASTE GENERATION AND INSTALLATION REQUIREMENTS

<u>Geographic Unit</u>	<u>Annual Solid Waste (in tons)</u>		<u>Ratio Potential to Requirements</u>
	<u>Generation Potential</u>	<u>Installation Requirements</u>	
Indian Creek Village Apartment Complex			
Present	307	9,125	0.03
After planned expansion	613	9,125	0.07
Overland Park City	54,000	9,125	5.90
Johnson County	154,000	9,125	16.90
Kansas City SMSA	1,032,000	9,125	113.10

Residential wastes: EPA recently published a report^{1/} estimating national average residential solid waste generation in 1971 to be between 2.4 and 2.6 lb/capita/day (including moisture). Data from a current solid waste study^{2/} for the Kansas City region provides somewhat lower estimates for local residential waste generation. Waste generation rates for three residential categories which were derived from this study are shown in Table 3.

TABLE 3

RESIDENTIAL WASTE GENERATION RATES

<u>Category</u>	<u>1974 Generation Rate (lb/capita/day)</u>
Urban	1.6
Suburban	2.4
<u>Unincorporated</u>	<u>1.8</u>
Regional Average	2.14

This information combined with current census population estimates was used to compute the waste generation totals shown in Tables 1 and 2.

Commercial wastes: Data available in the literature do not provide satisfactory definitions of the percentage components of commercial or industrial wastes. However, the incremental values shown in Table 4 do approximate the amount of solid waste generated per employee in the commercial sector. These values were combined with census information to derive estimates of commercial solid waste shown in Table 1.

TABLE 4

COMMERCIAL WASTE GENERATION RATE

<u>Category</u>	<u>SIC* Group Numbers</u>	<u>1974 Generation Rate^{3/} (tons/employee/year)</u>
Wholesale Trade	50-51	1.12
Retail Trade	52-59	1.37
Services	60-67 and 70-89**	1.15

* Standard industrial classifications as categorized by U.S. Census.

** Excludes major groups 80 (Health Services) and 82 (Educational Services).

^{1/} EPA (1975), Comparative Estimates of Post-Consumer Solid Waste (EPA/530/SW-148).

^{2/} Black and Veatch/Consulting Engineers and Franklin Associates, Ltd (1976), Resource Recovery and Hazardous Waste Study, Mid-America Regional Council (Draft).

^{3/} Ibid p. 10.

Industrial wastes: Data available concerning industrial solid wastes are subject to large variability between specific industries in similar standard industrial classification categories. Thus, local data have been given more emphasis in the development of the incremental waste generation factors in Table 5.

TABLE 5

INDUSTRIAL WASTE GENERATION RATE

<u>Category</u>	<u>SIC* Group Numbers</u>	<u>1974 Generation Rate^{1/} (tons/employee/year)</u>
Construction	15-17	0.99
Manufacturing	20-39	1.16
Transportation	40-42 and 44-49	1.19
Government	43 and 91-97**	0.36
Unclassified	99***	0.26

* Standard industrial classifications as categorized by U.S. Census.

** Also includes the public funded hospital portions of major group 80 (Health Services) and the public school portion of major group 82 (Education Services).

*** Also includes firms whose major group classification is unknown.

Disposal costs: The proposed pyrolysis installation's feasibility is dependent upon its acceptance and use by those private refuse (solid waste) haulers operating in the Overland Park and Johnson County area. The private hauler's motivation to use the installation would be based on two economic factors:

1. Disposal costs - the installation's incremental charge for accepting solid waste must be competitive with other disposal sites in the region.

2. Location - the installation must be located near existing solid waste collection points and readily available for use.

Whether or not the proposed installation is used is dependent upon some combination of these two factors. Information regarding these factors was obtained through a telephone survey of private haulers, and several municipalities, county, regional, state and federal offices involved in solid waste handling and disposal.

^{1/} Ibid. p. 14.

Currently most of the Kansas City region's solid waste is handled by approximately 20 major disposal sites. Johnson County is served by only two of these sites, which are located in rural areas approximately 10 and 20 miles from the proposed location for the pyrolysis installation. Disposal costs vary within the Kansas City Region, ranging from \$2.75/ton to \$6.55/ton, depending upon the type of waste and disposal site. In Johnson County disposal costs are fixed by the county at \$3.98/ton. Because of this higher rate, and inconvenient disposal sites, many of the 18 private refuse haulers operating within Overland Park utilize disposal sites outside Johnson County.

Given the present cost structures and locations for disposal sites in Johnson County sufficient quantities of solid waste should be available for the pyrolysis installations operation because:

1. More than adequate solid waste is generated in the areas surrounding the proposed installation (see Tables 1 and 2).
2. The existing Johnson County disposal sites are located outside the heavily populated areas of Overland Park and Johnson County. The proposed pyrolysis installation location would be closer to existing collection points in the more heavily populated areas, thus making it more convenient as a solid waste disposal site.*
3. The only factor that may limit the installation's use would be its "dump charge" for solid waste.** Of the private refuse haulers surveyed all indicated a willingness to provide solid waste to the site (because of the more convenient location) if their operating costs could be reduced.

b. Energy content of waste material: Hamilton Standard has estimated the unit energy content for five different types of waste products, categorized by moisture content. These estimates are presented in Table 6.

Residential, industrial and commercial solid waste are the waste products that are expected to be used in the pyrolysis unit. According to Hamilton Standard, residential waste has a moisture content range of 35 to 60%. Interpreting from Table 6, the energy content of residential waste is in the range of 3,500 to 5,200 Btu/lb. Similarly, industrial waste has a moisture content range of 15 to 35% and an energy content of 5,200 to 7,000 Btu/lb. Commercial waste is expected to have similar unit energy content.

* The exception was Mid-America Waste Systems who currently operate the only major Johnson County landfill located in the Kansas City metro area.

** The "dump charge" for solid waste at the pyrolysis installation would likely be equal to the existing dump charge regulated by Johnson County (\$3.98/ton).

TABLE 6

ENERGY CONTENT OF WASTE

<u>Waste Type</u>	<u>Description</u>	<u>Energy Content</u>
Type 0 (10% moisture)	Paper, Cardboard, Wood, Floor Sweepings (commercial)	8,500 Btu/lb
Type 1 (25% moisture)	Paper, Wood, Foliage (commercial, residential)	6,500 Btu/lb
Type 2 (50% moisture)	Half Rubbish, Half Garbage (residential)	4,300 Btu/lb
Type 3 (70% moisture)	Animal and Vegetable Waste (restaurants, hotels)	2,500 Btu/lb
Type 4 (85% moisture)	Human and Animal Remains (labs and slaughterhouses)	1,000 Btu/lb

2. Review of Health and Safety Ordinances Regarding Operation of a Waste Pyrolysis Unit: A telephone survey of governmental offices at various levels was performed to determine if any laws, regulations, or ordinances existed that may influence either the design or operation of the proposed pyrolysis installation.^{1/} Results of the survey indicate no existing laws or regulations will either restrict the design or operation of the proposed pyrolysis installation.

a. Air, land and water pollution regulations:

Air quality: The state of Kansas has jurisdiction over the establishment and enforcement of air pollution standards for facilities located within the state. The design of the proposed unit falls within these standards.^{2/}

^{1/} Among the governmental offices contacted are:

Environmental Protection Agency - Enforcement Division (Stationary Source Section) - Water Quality Division

State of Kansas - Department of Health and Environment (Bureau of Air Quality and Occupational Health, and Division of Solid Waste Management)

Regional - Mid-America Regional Council (Solid Waste Management Program)

Johnson County - Department of Environmental Health - County Engineer

City of Overland Park - Department of Environmental Health - Community Development.

^{2/} These standards must conform to national guidelines issued by the Environmental Protection Agency (EPA).

Land quality: The state, county and city officials surveyed indicated the proposed pyrolysis installation's operation should be consistent with regulations governing other solid waste handling or disposal operations. At present no laws, ordinances or regulations exist or are anticipated that would restrict the proposed installations design or operation.

Water quality: Because the proposed pyrolysis installation is designed as a closed loop system, no wastewater will be discharged into open sewers. The sludge or frit generated is filtered or disposed by through use of a settling tank. This waste is then disposed of as solid wastes. Again the federal, state, county and city officials contacted indicated no legal problems were anticipated.

Zoning: The municipalities in the State of Kansas have jurisdiction governing community zoning. The Overland Park City officials contacted felt the proposed installation would be consistent with existing structures in the area and conform to existing zoning practices.

B. Technical Factors

1. Description of the pyrolysis system: A 25-ton/day pyrolysis unit of the type currently being developed by the Hamilton Standard Division of United Technologies was selected for this analysis. The pyrolysis unit is capable of pyrolyzing 25 tons/day of residential or industrial waste (25% moisture) into 130 Btu/ft³ of combustible gas at a flow rate of 736 scf/min. This is an output of approximately 138 million Btu's/day. The pyrolysis unit requires 97 kw, 480 V, 3 phase, 60 hertz electrical power, 125 gal/min cooling water, and a natural gas line for auxiliary fuel which will provide 190 ft³/min of gas. The pyrolysis unit can be contained on a concrete equipment pad 23 ft x 36 ft in a two-story enclosure having a height of approximately 28 ft. The equipment pad would be a portion of a 50 ft x 60 ft concrete pad for trash handling. Figures 9 through 11 illustrate the existing 10 ton/day pyrolysis unit constructed by Hamilton Standard. Technical data on the Hamilton Standard 25-ton/day pyrolysis unit are contained in Appendix B.

2. System modifications: An analysis of necessary modifications to the total energy system was made by the project team. The results of this analysis indicate that there are no major problems associated with the installation of the pyrolysis unit in the existing total energy facility. It was found that it will be necessary to purchase an additional third acre of land to provide sufficient space for the pyrolysis unit and associated concrete pads and also to provide access to the pyrolysis unit by the trash trucks. Figure 12 depicts a plan view of the total energy plant and the existing property lines. Superimposed upon the existing plant and boundaries is the proposed location of the 25-ton/day pyrolysis unit, its associated concrete pad and the additional land required for truck access.

Figure 9 - 10 Ton/Day Pyrolysis Reactor

Figure 10 - Interior of 10-Ton/Day Pyrolysis Facility

Figure 11 - Exterior of 10-Ton/Day Pyrolysis Facility with Flare Tube.

Figure 12 - Plan View of Total Energy Plant Showing Proposed Location of Pyrolysis Unit and Additional Land Required.

In addition to the requirement for more land, it will be necessary to run facilities to the pyrolysis unit. This will entail providing 129 amp, 480 V, 3 phase, 60-cycle electrical service at an estimated installed cost of \$5,000. Piping will be required to supply domestic water for cooling tower make-up, sewage wastewater from a nearby sewage line to the pyrolysis reactor, a natural gas supply line and a return line for the pyrolysis gas. The cost associated with these modifications are discussed further in Section C of this chapter dealing with the economic factors influencing incorporation of the pyrolysis unit.

a. Boiler analysis: Indian Creek Service Company presently has two Cleaver Brooks D-60 water tube boilers with a rated capacity of 30 million Btu's/hr each. Using data from the Cleaver Brooks Performance Sheet which is based on 10% excess air, rated boiler output is obtained by burning approximately 625 scf/min of 1,000 Btu/ft³ (higher heating value) natural gas at a pressure of 66.5 in. of water column. Based on a stoichiometric air fuel ratio of 9.4:1, approximately 7,100 scf/min of flue gas is produced. The maximum rate of production of pyrolysis gas is 736 scf/min at 3 psig. Using an assumed air fuel ratio of 1.35:1, burning the total quantity of pyrolysis gas would release approximately 1,800 scf/min of flue gas products. The remaining 5,300 scf/min of flue gas could result from burning 500 ft³/min of natural gas at the original air fuel ratio. If this were done, the energy input to the boiler would be very nearly the same as with firing with 1,000 Btu/ft³ natural gas. This would seem to indicate that a resign of the boiler firebox, water walls, and forced-draft blower would not be required in order to burn all of the pyrolysis gas and a sufficient quantity of natural gas to provide nearly rated boiler capacity.

One problem which would have to be resolved through some modification and additional instrumentation would be to provide the proper air fuel ratio during the three modes of burning gas. These three modes would be (a) pyrolysis gas only, (b) mixture of pyrolysis and natural gas, and (c) all natural gas. Burning only pyrolysis gas would cause the capacity of the boiler to be limited to approximately 5 million Btu's/hr. This is not considered to be a significant problem because often times the boiler firing rate is held in the neighborhood of 6 to 7 million Btu's/hr to prevent unnecessary cycling of the system. When the demand for energy from the boiler exceeds 5 million Btu's/hr, then natural gas could be blended with the pyrolysis gas to increase the output of the boiler.

Two methods of blending pyrolysis and natural gas were examined. The first method is to recompress the pyrolysis gas and raise its pressure sufficiently to overcome pressure drops in the line from the pyrolysis unit to the boiler and allow proper regulation of the supply of gas into the boiler. The cost of compressing the pyrolysis gas from 3 psig to approximately 6-1/2 psig would appear to be approximately 1 kw/100 ft³/min. Using approximately 9,500 Btu's/kw as the heat rate for the diesel

generators, this recompression would require approximately 55,000 Btu's/hr or approximately 1% of the pyrolysis unit output. The second method of blending the boiler gas would use a venturi pump (aspirator) with the pump's high pressure side corrected to the natural gas line and the lower pressure branch corrected to the pyrolysis gas line. Pumping of the low-pressure pyrolysis gas into the boiler could be accomplished by taking the pressure drop in the natural gas line (which is at a pressure of 30 to 35 lb/in².) and using the energy normally lost in a regulator to pump and blend the pyrolysis gas with the natural gas.

Of these two methods, it would appear that the least complicated approach is to utilize the venturi pump. This would require running a separate header for the pyrolysis gas to the boiler. The pyrolysis gas would be fed through the venturi pump and blended with the natural gas utilizing necessary valving controls and safety shut-off. Pilot gas for the boiler would always come from the natural gas line and would be connected to the natural gas line upstream of the venturi pump. This is to insure that combustion of the gas mixture would always occur. Although the details of the conversion were not finalized, it appears that the air fuel ratio could be properly balanced and maintained by continuously sampling oxygen content of flue gas and controlling the air fuel mixture to the appropriate set point. It is estimated that the cost of modifying the boiler system would be approximately \$17,500.

b. Engine analysis: The generator prime movers are 2-cycle, naturally aspirated, opposed pistons, dual fuel engines. Because of the increased difficulty of ignition, the manufacturers have set an absolute lower limit of fuel energy content at 700 Btu's/standard cu ft (lower heating value) at 50 psig. To attempt the use of pyrolysis gas directly at greatly increased pressures would require a major redesign of the entire engine and would entail a severe cost penalty from the standpoint of the energy required to compress the pyrolysis gas. For example, the cost of compression from 3 psig to 35 psig would be about 10 kw/hundred ft³/min or approximately 500,000 Btu/hr. This compression cost alone would be around 10% of the total gas output of the pyrolysis unit. It appears that the best way to utilize the gas from the pyrolysis unit is to blend the pyrolysis gas with the natural gas using a venturi pump blending device as described in the discussion of the boiler analysis. As with the boilers, a separate header for pyrolysis gas would have to be run to each engine. A pyrolysis gas/natural gas interconnection, appropriate valving and a venturi mixing device with appropriate controls would also be required. Pressure sensing transducers could be utilized to operate the engines on 100% natural gas by bypassing the venturi in case a wide variation in distribution system pressure would occur.

One potential problem identified in the evaluation of utilizing pyrolysis gas in the total energy system was the concern over sulfur containing compounds in the pyrolysis gas. Although a wet scrubber is incorporated in the pyrolysis system to remove undesirable components such as sulfur-containing compounds, it is currently unknown as to what the probable sulfur content of the gas would be. Although the sulfur does not present any major problem with the boiler operation, it could produce severe damage to the engine in the form of corrosion of cylinder walls and rings. This increased corrosion could at best require increased maintenance and at worst could result in catastrophic failure of an engine. Thus, before the pyrolysis gas would be allowed for use in the engines, a significant history of chemical analysis of the gas would have to be obtained to assure that sulfur levels within the engines were maintained well below acceptable limits.

3. Additional impacts on facility operation:

a. Manpower: As it now exists, the Indian Creek Total Energy System is capable of fully automatic operation. Normally the total energy plant is left unattended during second and third shifts and on weekends. During normal business hours, preventive maintenance tasks are performed by members of the power plant staff. The addition of a 25-ton/day pyrolysis unit to the facility would require an operator on the premises at all times. The operator would be required to sort the waste material and load the hopper over the loading ram. Also, the operator may be required to reposition trash within the trash-holding bin if bridging of the trash should occur. Another function which the operator could perform during initial operation of the pyrolysis unit would be to monitor the sulfur content of the gas at regular intervals during the operation of the system. If sulfur levels would reach an unacceptable limit, then the operator could shift the engine to operation on only natural gas.

Depending upon the source and consistency of the waste material, it may be possible to automate the loading process. This would, of course, save a significant labor cost over the life of the plant. However, it is not clear at this time that automation of the process would be possible with the uncertain mix of residential waste. Therefore, the possibility of automation of the loading of the pyrolysis unit was not considered in this analysis.

b. Maintenance requirements: Because the Hamilton Standard Trash Pyrolysis Unit is a developmental item, it is difficult to estimate the maintenance and repair requirements. However, it would be foolish to ignore this potential expense. The project team, in the absence of any related experience, has relied upon estimates produced by Hamilton Standard of potential maintenance repair and hardware expenses for the pyrolysis unit. Hamilton Standard estimates for maintenance and repair labor were \$16,000/year while the estimated cost of replacement hardware was \$11,000/year. It is possible that a portion of the \$16,000/year maintenance/labor

cost could be eliminated through the use of operators or existing maintenance personnel. However, for the economic analysis in this study, it was assumed that maintenance and repair labor costs would be a real expense.

c. Safety: It would appear that the pyrolysis unit would fall under a hazardous location Class 1, Group D, Division 2 classification, as defined by the National Electric Code. Indian Creek Service Company would require compliance to all codes that would relate to the pyrolysis unit. Any addition to the existing plant of an experimental device such as the pyrolysis unit would require approval by the Insurance underwriters now covering the Indian Creek Power Plant. Any additional insurance premiums required because of the installation would have to be charged against the energy produced by the pyrolysis unit. However, it does not appear that there are any safety problems associated with the pyrolysis unit that could not be overcome by good engineering practice and proper compliance with related codes and laws such as those required by the Occupational Health and Safety Act.

4. Demand for pyrolysis gas: The output of the pyrolysis unit will be approximately constant at 736 scf/min at 130 Btu/ft³. This gas output must be consumed by the engines and the boilers or burned (wasted) in the flare tube. An analysis of the quantity of pyrolysis gas which can be consumed by the engines and boilers is contained in this section.

a. Engine gas consumption: As the Btu content of the gas introduced into the engines decreases, ignition of the air-fuel mixture becomes more difficult and flame propagation velocities are reduced. Therefore, the engine manufacturers have set an absolute lower limit of 700 Btu/scf (lower heating value) of inlet gas. The lower heating value of the available natural gas is 905 Btu/scf while the lower heating value of the pyrolysis gas is 130 Btu/scf. Using the above information, the maximum quantity of pyrolysis gas which can be blended with natural gas can be determined.

Let x = the portion by volume which is pyrolysis gas. Then:

$$\frac{130 \text{ Btu } (x)}{\text{scf of pyrolysis gas}} + \frac{905 \text{ Btu } (1-x)^2}{\text{scf of natural}} \geq \frac{700 \text{ Btu}}{\text{scf of mixture}}$$

The above inequality when solved for the maximum portion of pyrolysis gas (x) results in 0.265 scf of pyrolysis gas per 0.735 scf of natural gas. This is roughly a 3:1 ratio of natural to pyrolysis gas. However, the fraction of the energy which can be supplied from pyrolysis gas is:

$$\frac{0.265 \frac{\text{scf of pyrolysis gas}}{\text{scf of mixture}} \times \frac{130 \text{ Btu}}{\text{scf of pyrolysis gas}}}{1.0 \text{ scf of mixture} \times \frac{700 \text{ Btu}}{\text{scf of mixture}}} = 4.92\%$$

Thus, less than 5% of the total energy requirements of the engines can be provided by the pyrolysis gas. The specific gas consumption of the engines ranges from 8,980 Btu/kw at 100% load to 10,200 Btu/kw at 50% load, on a lower heating value basis. Therefore, assuming a heat rate of 9,500 Btu/kw, 0.75 w/ft² of apartment, minimum power consumption by the plant of 85 kw and power consumption by the pyrolysis unit of 47 kw, the floor area of apartments necessary to consume the entire output of the pyrolysis unit in the engines can be calculated.

Let A = floor area of apartments in ft². Load on the engines (kw) = 85 kw + 47 kw + 0.00075 x A

$$\begin{aligned} \text{Rate of consumption of pyrolysis gas } \frac{\text{Btu}}{\text{hr}} &= \\ 0.0492 \frac{(9,500 \text{ Btu})}{\text{kw-hr}} \times (85 + 47 + 0.00075 \times A) &= \\ 130 \frac{\text{Btu}}{\text{scf}} \times 736 \frac{\text{scf}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} & \end{aligned}$$

Solving for A:

$$A = 16.20 \times 10^6 \text{ ft}^2$$

This floor area is approximately eight times greater than the ultimate floor area of the complex and is 27 times greater than the total floor area anticipated in 1977. Therefore, the engines could only consume 0.272×10^6 Btu/hr or 4.7% of the total output of the pyrolysis unit when the apartment complex floor area is expanded to 600,000 ft² in 1977.

From the above analysis it is obvious the engines can consume only a small portion of the output of the pyrolysis unit. Thus, the boilers must consume most of the pyrolysis gas.

b. Boilers gas consumption: The boilers each rated at 30×10^6 Btu/hr output, are operated at times when the waste heat available from the engines is not sufficient to supply the demand by the apartments for domestic hot water, space heating and space cooling. The minimum demand for energy from the boilers occurs during the spring and fall when only domestic hot water is required.

Hourly hot water consumption data on a 70 to 75°F day (April 28, 1975) were averaged over a 24 hr period. The average demand for domestic hot water was found to be 1.62×10^6 Btu/hr, or 5.39 Btu/ft² hr.

These data were combined with the specific fuel consumption data for the engine at 1/3, 2/3 and full load and the recoverable energy was estimated assuming that 75% of the energy input to the engine is recovered as electricity or usable heat. Table 7 illustrates the results of these calculations.

TABLE 7

COMPARISON OF RECOVERABLE ENERGY TO DEMAND FOR PROCESS HOT WATER

<u>Apt. Area</u>	<u>KW Demand</u>	<u>Recoverable Energy (Btu/hr)</u>	<u>Demand for Process Water (Btu/hr)</u>
224,000	300	2.115×10^6	1.55×10^6
624,000	600	3.044×10^6	3.70×10^6
1,037,300	910	4.025×10^6	5.93×10^6

From Table 7 it can be seen that the hot water demand for energy will exceed the supply from the engines by approximately 0.65×10^6 Btu/hr when the new apartments are completed (approximately 600,000 ft²). When factored by a boiler efficiency of 0.85, this becomes 0.76×10^6 Btu/hr. Thus we have a total continuous base demand for pyrolysis gas of approximately 1.03×10^6 Btu/hr. This continuous demand accounts for approximately 18% of the total output of the 25 ton/day pyrolysis unit. During the summer and winter when heating and cooling of the apartments is required, it appears that the entire output of the pyrolysis unit can be utilized by the boiler. For example, currently the boiler typically consumes an average of 2 to 6×10^6 Btu/hr during the winter months and 4 to 10×10^6 Btu/hr during the summer months. These values will approximately double when the new apartments are added in 1977. Also, because these thermal loads will vary on an hourly basis, it may be necessary to add energy storage to the system to fully utilize the content output of the pyrolysis unit.

In the absence of a detailed analysis of the supply and demand for pyrolysis gas, an annual load factor of 0.70 for the 25 ton/day unit will be assumed for economic analysis. A load factor of 0.70 means that 70% of the maximum yearly gas output of the pyrolysis unit can be utilized by the total energy system. This estimated load factor accounts for down time for the pyrolysis unit as well as for periods when the rate of generation of gas is greater than the rate of consumption and thus, flaring of the gas is required.

C. Life-Cycle Cost Analysis

An MRI-developed life-cycle cost computer model was used to evaluate the economic feasibility of the pyrolysis unit. The total life-cycle costs of installing the operating and pyrolysis unit were calculated. Revenues

from waste disposal were subtracted from the operating and maintenance costs to obtain a net operating and maintenance cost. The value of the fuel savings realized from the introduction of the pyrolysis unit during the unit's lifetime, therefore, represents the system's major benefit. Values of fuel savings were calculated for a wide range of fuel prices.

Two sensitivity analyses were performed. By comparing the value of the fuel savings to the life-cycle costs of the pyrolysis unit at the current unit price, the fuel price at which the pyrolysis unit becomes cost-effective was determined. Similarly, the capital costs of the pyrolysis unit were varied to determine the unit price which makes the pyrolysis unit cost effective at current and expected fuel prices.

The model used for this analysis takes into account all anticipated expenses to be incurred in the construction and operation of the pyrolysis unit. These costs include the cost of capital equipment, financing costs, maintenance and operating costs, taxes, depreciation and tax credits.

1. Life-cycle cost model inputs:

Economic parameters: Basic economic parameters affecting the cost and benefit of the pyrolysis unit were defined. These parameters were inputs into the computer model and are presented in Table 8. The parameters have been defined so that they approximate a realistic investment situation for Indian Creek Service Company.

TABLE 8

ECONOMIC PARAMETERS

Real long-term interest rate	
Real rate of return on stock	
Percent of organization financed by equity	20%
Percent of system financed by equity	20%
Percent of system financed by debt	80%
Corporate tax rate	48%
Investment tax credit	10%
Ownership	Corporate
Depreciation method	Double declining switching to straight line

Costs of pyrolysis unit: The nominal capital costs of installing the pyrolysis unit were estimated and are presented in Table 9.

TABLE 9

NOMINAL CAPITAL COSTS

Services

Electrical 129 amps/480 v - 3Ø 60Hz, 300 ft feeder line	\$5,000
---	---------

Mechanical

2-1/2 in. PVC domestic waterline with valving	1,000
1-1/2 in. Sch 40 natural gas supply line 200 ft	3,000
4 in. Sch 40 low Btu gas return line 350 ft	8,000
2-1/2 in. PVC quench water line to sewage line	5,000
Boiler modification costs	17,500

Additional Land

1/3 acre at \$15,000/acre	5,000
---------------------------	-------

Structural

Building w/concrete pad at \$20/ft ²	15,000
---	--------

25 ton/day pyrolysis unit (note: developmental pyrolysis unit would cost \$500,000)	350,000
	<u>\$409,500</u>

Contingency (10%)	40,950
	<u>\$450,450</u>

Table 10 presents the annual operating and maintenance costs of the unit. Waste revenue is entered as a negative value in the table because it represents the payments received for disposing of the waste. A \$3.98/ton dump charge and a 0.95 plant utilization factor were assumed for this calculation.^{1/}

The pyrolysis unit was assumed to have a lifetime of 20 years. Construction time was assumed to be 1 year.

$$\frac{1}{\text{ton}} \times \frac{\$3.98}{\text{ton}} \times \frac{25 \text{ ton}}{\text{day}} \times \frac{365 \text{ days}}{\text{year}} \times 0.95 = \frac{\$34,500}{\text{year}}$$

TABLE 10

ANNUAL OPERATING AND MAINTENANCE COSTS

1 man around the clock at \$10/hr	\$87,600
Maintenance and repair labor	16,000
Hardware	11,000
Waste revenue	-34,500
Net Total	\$80,100

Energy savings: The value of the energy savings over the life the pyrolysis unit represents the benefit of the unit. The annual energy savings have been estimated to be $35,200 \times 10^6$ usable Btu's/year.^{1/} This estimate assumes that the unit produces $736 \text{ ft}^3/\text{min}$ of $130 \text{ Btu}/\text{ft}^3$ gas. A utilization factor of 0.70 is assumed. This utilization factor reflects that there will be times when the entire output of the pyrolysis unit cannot be utilized in the total energy plant.

2. Results of the model: For the first sensitivity analysis, the present value of the life-cycle cost of the pyrolysis unit at a total nominal capital cost of \$450,450 (this cost includes approximately \$100,000 installation cost), accounting for all taxes, depreciation and finance costs, was calculated. The life-cycle cost of the unit was calculated to be \$664,000. This value was compared to the present value of the fuel savings at a wide range of fuel prices. The losses in tax deductions because of reduced fuel consumption were accounted for. The results of this analysis are presented in Figure 13. Interpreting from this figure the pyrolysis unit would be cost effective at fuel prices greater than \$3.05/million Btu.

The results of the second sensitivity analysis are presented in Figure 14. The total nominal capital costs of the pyrolysis unit were varied over a wide range. It is evident from Figure 2 that at the current fuel price of approximately \$1.00/million Btu, the pyrolysis unit would never be cost effective, regardless of cost. The value of the fuel savings at a fuel price of \$2.50/million Btu is also included in Figure 14. Interpreting from the figure, the total nominal installed capital cost of the pyrolysis unit would have to be less than \$120,000 for the unit to be cost effective. From Table 9 it can be seen that electrical, mechanical, boiler, structural and land costs are approximately \$100,000. These must be considered fixed costs. Therefore, in order for the pyrolysis to be cost effective at a fuel price of \$2.50/million Btu, the cost of the unit must be reduced to less than \$20,000.

$$\frac{1}{\text{min}} \times \frac{736 \text{ ft}^3}{\text{min}} \times \frac{130 \text{ Btu}}{\text{ft}^3} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} \times \frac{365 \text{ days}}{\text{yr}} \times 0.70 = 35,200 \times 10^6 \text{ usable } \frac{\text{Btu}}{\text{yr}}$$

Figure 13 - Fuel Price at Which Pyrolysis Unit is Cost Effective.

Figure 14 - Capital Cost at Which Pyrolysis Unit is Cost Effective at Current and Expected Fuel Prices.

It can be concluded from this analysis that the cost effectiveness of the pyrolysis unit is much more sensitive to increases in fuel price than to reductions in the cost of the unit. It seems highly unlikely that the cost of the unit (not including installation costs) can be reduced to \$20,000. Fuel prices of \$3.00/million Btu, however, may not be unreasonable at some time in the future.

IV. ADDITIONAL RESEARCH EFFORTS

The preliminary analyses presented in this report indicate that a 25-ton/day waste pyrolysis system can be installed in the Indian Creek Total Energy System. There appears to be no major institutional or technical problems. The economic analysis indicates that the pyrolysis unit is not cost-effective at current fuel prices but would be cost-effective at fuel costs above \$3.00/10⁶ Btu. However, before installing a developmental pyrolysis unit, detailed engineering and economic analyses of the installation will be required. Possible future studies and resulting benefits are discussed in this chapter.

A. Systems Analysis to Define the Seasonal and Hourly Demand for Pyrolysis Gas

This report has shown that the engines would consume only 5% of the pyrolysis gas. The remainder of the gas must either be consumed by the boilers or burned in the flare tube. A detailed system analysis is required to identify the hourly boiler firing rate throughout the year. Such an analysis would define the anticipated load factor for the pyrolysis unit and identify appropriate times for scheduled maintenance and overhaul of the pyrolysis unit. Such an analysis would also indicate whether thermal storage would be necessary to accommodate hourly variations in the demand for thermal energy.

B. Detailed Engineering Design of System Modifications

This study has examined, only at the conceptual level, the technical feasibility of installing a waste pyrolysis unit at the Indian Creek Total Energy Plant. Additional engineering evaluation of the details of incorporating the pyrolysis unit is required prior to actual installation of a demonstration unit. It will be necessary to consult with technical staff members of both the engine and boiler manufacturers on the specific system modifications which will affect the operation of the engines and boilers. Control logic must be developed and system components must be selected. Detailed engineering drawing and specifications are required to obtain construction estimates and to submit to insurance underwriters for approval.

Such a detailed engineering analysis would provide a well-defined implementation plan for a demonstration pyrolysis unit in an existing total energy system. The cost and schedule for demonstrating an advanced technology mix energy system would thus be available to the ATMES program planners for comparison with other alternative demonstrations.

APPENDIX A

SOLID WASTE CHARACTERISTICS

The characteristics of solid waste for residential, commercial and industrial waste categories is presented in this section. Also included is a municipal waste category which is a combination of residential and commercial waste. This information was compiled from a literature review of solid waste composition data for cities outside the Kansas City region. Although waste characteristics may show variation between different regions, this information should be beneficial for planning purposes.

Residential: Table A-1 provides percentage estimates of residential waste components for urban, suburban, and rural wastes within the Kansas City SMSA. The primary difference between urban and suburban wastes is attributable to more lawn wastes.^{1-4/}

Approximate analysis of solid waste shown in Table A-2 indicates (on a percentage basis) how much moisture, volatile matter, fixed carbon and ash is contained within a sample. Specific components of the analysis include:

Volatile Matter - That portion which is driven off in a gas or vapor form when the solid waste is subjected to a standardized temperature test. It consists of hydrocarbons and other gases.

Fixed Carbon - The combustible residue left after driving off the volatile matter.

Ash - The noncombustible residue left after complete combustion of the solid waste.

Sulfur - The amount is useful in judging the corrosiveness of the products of combustion of the fuel.

Heat Value -

High - The Btu's liberated when a pound of solid waste is burned completely and the products of combustion are cooled to the initial temperature of the solid waste, as in a calorimeter.

Low - The high heat value minus the latent heat of vaporization of the water that is formed by burning the hydrogen in the fuel.

^{1/} Ibid. p. 27.

^{2/} EPA (1975) Minimum Sampling Program--Residential and Commercial Solid Waste Generation (EPA Region VII).

^{3/} Fiscus, D. E., P. V. Gorman, M. P. Schrag, L. V. Shannon (1976), St. Louis Final Report: Refuse Processing Plant Equipment, Facilities and Environment Evaluations. Midwest Research Institute, Kansas City, Missouri.

^{4/} Hickman, H. L. and John C. Kennedy, "Solid Waste Research and Development" Engineering Foundation Research Conference, Conference Preprint No. F-3, Studies of Characteristics of Municipal and Residential Solid Waste.

TABLE A-1

RESIDENTIAL WASTE COMPONENTS

<u>Component</u>	<u>Percent by Weight*</u>			<u>Significant Seasonal Variation</u>
	<u>Urban</u>	<u>Suburban</u>	<u>Rural</u>	
Paper	40.0	40.0	46.5	No
Glass	10.0	9.0	5.4	Yes
Ferrous Metals	7.0	5.5	8.0	Yes
Aluminum	0.6	0.6	----	Yes
Other Nonferrous	0.4	0.4	----	No
Plastics	4.5	4.5	2.3	No
Rubber and Leather	2.0	1.5	----	No
Textiles	1.5	1.0	1.6	No
Wood	2.0	1.5	0.6	No
Food Waste	17.0	13.0	30.4	No
Yard Waste	15.0	23.0	1.4	Yes
Miscellaneous Inorganics	----	----	----	Yes
Miscellaneous	----	----	3.8	No

* Percent by weight as received.

TABLE A-2

PROXIMATE ANALYSIS FOR REFUSE-DERIVED FUEL*
FROM RESIDENTIAL WASTE

	<u>Percent by Weight</u>
Moisture	25.25
Ash	20.85
Volatile matter	44.75
Fixed carbon	<u>9.15</u>
Total	100.00

* Sample from the cyclone discharge.

The data contained in Table A-2 was derived from a previous MRI study.^{1/} These data are not for raw waste, but rather for cyclone discharge portion of the processed waste. The data are average values for the sampling period, September 23, 1974 through September 5, 1975.

Finally, an ultimate analysis or chemical analysis of the solid waste indicating the amount of carbon, hydrogen, sulfur, nitrogen, oxygen and ash developed by Niessen and Chansky is shown in Table A-3.^{2/} Data shown in Table A-4 were prepared by Schoenberger from an ultimate analysis of the combustible fraction of household refuse for Philadelphia.^{3/}

Commercial: Commercial wastes are defined, for this study, as wastes generated by retail trade, wholesale trade and services. Retail trade includes establishments engaged in selling merchandise for personal or household consumption and rendering services incidental to the sale of the goods. Wholesale trade includes establishments primarily engaged in wholesale distribution of goods to retail outlets. Services include hotels, laundries, automotive repair, and similar establishments that provide a service to the public.

Insufficient data does not allow accurate definition of commercial waste components. The following statement from a 1975 EPA publication^{4/} expresses current thinking on commercial waste characteristics.

"Little work has been done to characterize the material composition of commercial type waste, but the consensus appears to be that commercial and institutional sources have a very high percentage of paper--higher than 50% and perhaps as high as 75% on the average."

Municipal: The existing published data on municipal wastes generally reflect national averages. Two general approaches have been used for the estimates. The first is analysis of data for waste samples received at processing and disposal facilities. The second approach uses

^{1/} Fiscus, D. E., P. V. Gorman, M. P. Schrag, L. V. Shannon (1976), St. Louis, Final Report: Refuse Processing Plant Equipment, Facilities and Environmental Evaluations, Midwest Research Institute, Kansas City, Missouri.

^{2/} Niessen, W. R. and S. H. Chansky, "The Nature of Refuse," Proceedings of 1970 Incinerator Conference, ASME.

^{3/} Schoenberger, Robert J., "Studies of Incinerator Operation," Proceedings of the 1972 National Incinerator Conference, ASME.

^{4/} EPA (1975), Comparative Estimates of Post-Consumer Solid Waste (EPA/530/SW-148).

TABLE A-3

ESTIMATED ULTIMATE ANALYSIS OF REFUSE CATEGORIES (%)

Category	C	H	O	N	Ash	S	Fe	Al	Cu	Zn	Pb	Sn	p*	Cl	Se	Fixed Carbon	Heat
																% (Dry Basis)	Value (Btu/lb) (Dry Basis)
Metal	4.5	0.6	4.3	0.05	90.5	0.01	77.3	20.1	2.0	---	0.02	0.6	0.03	---	---	0.5	740
Paper	45.4	6.1	42.1	0.3	6.0	0.12	----	----	---	---	----	---	----	---	Trace	11.3	7,930
Plastics	59.8	8.3	19.0	1.0	11.6	0.3	----	----	---	---	----	---	0.01	6.0	---	5.1	11,500
Leather, Rubber	----	---	----	---	----	---	----	----	---	2.0	----	---	----	---	---	6.4	10,175
Textiles	46.2	6.4	41.8	2.2	3.2	0.2	----	----	---	---	----	---	0.03	---	---	3.9	8,030
Wood	----	6.0	42.4	0.3	2.9	0.11	----	----	---	---	----	---	0.05	---	---	14.1	8,400
Food Wastes	41.7	5.8	27.6	2.8	21.9	0.25	----	----	---	---	----	---	0.24	---	---	5.3	8,540
Yard Wastes	49.2	6.5	36.1	2.9	5.0	0.35	----	----	---	---	----	---	0.04	---	---	19.3	7,300
Glass	0.52	0.07	0.36	0.03	99.02	---	----	----	---	---	----	---	----	---	---	0.4	65
Miscellaneous	13.0**	2.0**	12.0**	3.0**	70.0	---	----	----	---	---	----	---	----	---	---	7.5	3,500

* Excludes phosphorus in CaPO_4 .

** Estimated (varies widely).

TABLE A-4

ULTIMATE ANALYSIS OF HOUSEHOLD REFUSE

	<u>(%) by Weight</u>
Carbon	30.24
Hydrogen	4.53
Sulfur	0.14
Nitrogen	0.21
Oxygen	23.04
Ash	41.72
Miscellaneous	<u>0.12</u>
	100.00

production and marketing statistics for materials and products to estimate the flow of goods which are produced, consumed and discarded. The percentage by weight of components shown in the Third Report to Congress^{1/} is shown in Table A-5. The data reflect EPA's estimate of the material composition of post-consumer solid waste. With the exception of the food, yard and miscellaneous inorganic fractions, all the product and material figures are derived from analyses of aggregate U.S. industrial material production and product marketing data, together with estimates of average product lifetime and material recovery rates. These estimates have thus

TABLE A-5

MUNICIPAL WASTE COMPONENTS

<u>Component</u>	<u>% Weight*</u>
Paper	39.6
Glass	10.3
Metals	9.9
Plastics	4.1
Rubber and leather	2.7
Textiles	1.6
Wood	3.6
Food waste	13.3
Yard waste	14.1
Miscellaneous inorganics	<u>1.5</u>
Total	100.7

* As disposed weight.

^{1/}EPA (1975) (SIC 281) "Assessment of Industrial Hazardous Waste Practices, Inorganic Chemicals Industry."

been developed entirely independently of refuse collection data and sample refuse composition measurements. The food, yard and miscellaneous inorganics categories, on the other hand, are based on average proportions of these materials reported in published refuse collection studies.

Industrial: Industrial wastes result from manufacturing processes as well as from transportation firms, utilities, government establishments and contract construction firms. The composition of solid waste for each of these categories as well as individual units within each category are as variable and diverse as the products of the industries themselves. This variability is most apparent in the manufacturing sector where the components of the solid waste depend on the raw materials, end-product, and disposition of byproducts.

Table A-6 summarizes industrial solid waste data gathered from two statewide EPA studies (Texas and Kentucky). Other EPA industrial assessment studies also provide data on industrial solid waste composition.^{1-5/} The six reports footnoted below quantify and characterize solid wastes associated with a specific industry. The data are presented from an industry point of view and are most useful to similar industries in evaluating solid waste practices. For purposes of this study the information presented in these studies is useful only as general background material.

Data shown in Table A-6 provides a rough indication of industrial waste components. One weakness in the data is the generally large percentage classified as trash. No further definition was made of the materials included as trash. A comparison of waste from the Texas and Kentucky studies show wide variation in percentage of several materials including paper, ferrous metals and plastic. It is concluded that the range of wastes from industry is too broad to allow a well-defined list of components for each category.

- 1/ EPA (1975) (SIC 369) "Assessment of Industrial Hazardous Waste Practices: Storage and Primary Batteries Industries."
- 2/ EPA (1973) (SIC 024) "Dairy Waste Management."
- 3/ EPA (1973) (SIC 363) "Solid Waste Management in the Household Appliance Industry."
- 4/ EPA (1973) (SIC 281) "Solid Waste Management in the Industrial Chemical Industry."
- 5/ EPA (1974) (SIC 26) "Study of Solid Waste Management Practices in the Pulp and Paper Industry."

TABLE A-6

INDUSTRIAL WASTE COMPONENTS
(% by Weight as Received)

Waste Component	<u>Texas Study</u>		Transportation, Communication Public Utilities	<u>Kentucky Study</u>	
	<u>Construction</u>	<u>Manufacturing</u>		<u>Manufacturing</u>	<u>Unclassified</u>
Paper	2.64	18.94	17.64	11.46	19.39
Glass	1.33	2.85	---	3.56	---
Ferrous Metals	6.09	10.16	5.32	25.24	61.28
Nonferrous Metals	1.02	4.15	0.71	4.85	---
Plastics	0.27	6.32	0.92	2.54	0.39
Rubber	---	---	---	1.58	---
Leather	1.79	5.74	0.27	0.40	---
Textiles	---	---	---	5.16	---
Wood	1.97	10.77	11.58	11.35	1.94
Food Wastes	---	1.04	0.16	2.55	---
Yard Wastes	---	---	---	---	---
Miscellaneous Inorganics	78.80	9.62	3.46	5.23	6.89
Ashes	---	1.81	---	3.80	7.76
Trash	6.06	22.89	39.04	15.98	1.94
Organic Chemicals	0.03	2.06	6.97	1.60	0.42
Manure	---	0.01	7.62	---	---
Animal Wastes	---	1.32	0.20	0.61	---
Garbage	---	0.16	4.94	2.67	0.02
Crop Wastes	---	0.25	1.16	0.04	---
Water and Wastewater Treatment Sludges	---	1.66	0.01	1.38	---
Solvents	---	---	---	---	---
Oil and Hydrocarbons	---	0.15	---	---	---

APPENDIX B

TECHNICAL DATA

HAMILTON STANDARD 25 TPD PYROLYSIS UNIT

HAMILTON STANDARD

TECHNICAL DATA

HAMILTON STANDARD 25 TPD PYROLYSIS UNIT

Submitted to Midwest Research Institute

17 September 1976

GENERAL DESCRIPTION OF REACTOR

As shown in Figure 1, the Hamilton Standard pyrolysis unit is basically self-contained, requiring only electricity, auxiliary fuel (for start-up and shut-down only), air and make-up cooling water. The pages which follow present a summary description of the reactor and system operation.

Trash Loading

A human operator uses a hydraulically powered lifting arm to pick unprocessed trash and load the trash holding bin. The lifting arm is controlled either from the control room by the remote arm control unit or by controls located at the lifting arm.

The trash holding bin is located on top of the loading ram and contains an ultrasonic level sensor which alarms in the control room when the trash holding bin requires refilling. The loading ram and its controls are activated from the control room when the operator desires to initiate or terminate the reactor loading operations. However, operation of the loading circuit is controlled by ultrasonic level sensors which detect the absence of trash at the required level in the reactor. The reactor level controllers then apply hydraulic pressure to the loading ram. Limit switches on the loading ram establish the required position of the loading ram hydraulic diverter valve. When trash in the reactor is at the proper level, the level controllers will terminate the loading operations by opening and closing the proper valves. If bridging should occur in the trash bin, and no trash is being introduced while the loading ram is cycling, an excess cycle alarm will stop the loading operation. The operator can then reposition trash within the trash holding bin. If bridging of trash within the reactor should occur, causing either no trash to fall to the bottom or causing blockage of the level sensors, the operator will also be alerted by an alarm.

Slag and Frit Handling

The inert portion of the trash is discharged from the reactor in the form of molten slag and is immediately quenched in water contained in the quench tank. As the molten slag contacts the water, it solidifies and fractures into a fine gravelly substance (frit) which is removed from the quench tank by a screw type frit conveyor and deposited into the frit container.

The water in the quench tank is continually cooled by submerged cooling panels which absorb the heat caused by frit quenching. A supply of cooling water to the panels is thus required.

Gas Handling and Control

The oxidation air burner provides heated air to the reactor as required to maintain the proper rate of pyrolysis. This burner is capable of burning either an auxiliary fuel or pyrolysis gas and is used for starting and stopping the pyrolysis process.

FIGURE 1 PYROLYSIS PROTOTYPE SCHEMATIC

It remains in an auxiliary fuel mode until steady state conditions are obtained, when it will burn approximately 15% of the pyrolysis gas for air heating. Startup and shutdown of this burner is initiated by start/stop of the oxidation air blower (from the central control panel).

During all operating modes, the gas exiting from the top of the reactor is cooled to approximately 200°F. The temperature controller modulates the temperature control valve to control a cooling/cleansing water spray entering the gas stream through one of the two nozzles. Switchover to the alternate nozzle will occur if one should become clogged. High and low temperature alarms and a temperature indicator provide continuous monitoring of gas cooling performance.

There are three modes of disposing of the gases produced by the pyrolysis reactor:

A. Primary Mode

The primary operating mode is to utilize the pyrolysis gas at its end use point. In this mode, the gases are scrubbed and compressed by a blower/scrubber, and then passed through the product gas control valve.

B. Secondary Mode

This mode is used if the end user cannot use the gases. In this mode, the gases are scrubbed and compressed and then passed to the flare tube. The flare tube utilizes an auxiliary fuel burner for combustion of the pyrolysis gases.

C. Backup Mode

A backup is employed in the event that the blower is not operational. In this mode, the gases are combusted in the flare tube. They are sent to the flare tube via their own pressure head.

During the primary mode, the flare burner and blower are not operated. However, the flare tube is continuously purged by the oxidation air blower by means of a bleed valve. This purge is intended to remove auxiliary fuel or pyrolysis gases which might leak into the flare tube while the burner is off. In addition, the base of the flare tube has air openings to allow air to enter while the flare burner is operating and to allow heavier propane gas to escape from the flare tube when the burner is not operating.

The startup of the flare blower is verified by a pressure sensor. If the flare blower discharge pressure is not up to the required level within a predetermined time period, the control system will open a valve to provide air from the oxidation air blower. This valve will then remain open until manually closed. This feature is included to ensure that a source of air from the flare burner is available following a failure of the flare blower.

INSTALLATION/INTERFACE REQUIREMENTS

Electricity: Operational - 47 kw (480 V, 3 Ø, 60 Hz)
Installed - 97 kw (480 V, 3 Ø, 60 Hz)

Cooling Water: 125 gpm at 90°F maximum

Auxiliary Fuel: Natural gas at 190 cfm or propane at 80 cfm

Startup - 2 hour cycle requiring 4800 cu ft propane at a flow starting at 80 cfm and decreasing to 0 or 11,300 cu ft natural gas with a maximum flow of 190 cfm.

Shutdown - 4 hour cycle requiring 9600 cu ft. propane propane at a flow starting at 0 cfm and increasing to 80 cfm or 22,600 cu ft natural gas with a maximum flow of 190 cfm

Installation: Equipment Pad - 23' x 36' with a maximum height of 28'

Overall Envelope - 50' x 60' pad including trash enclosure and equipment pad with a maximum height of 28'.

<u>Output Gas:</u>	Lower Heating Value:	130 Btu/cu ft.
	Flow Rate:	736 SCFM
	Btu Output per day:	137.8 m Btu (LHV)
	Composition:	CO 14.3%
		CO ₂ 14.0
		H ₂ 8.8
		CH ₄ 2.7
		C ₂ H ₂ 0.9
		C ₂ H ₄ 0.9
		NH ₃ 0.3
		N ₂ 57.5
		O ₂ 0.4
		Misc. 0.2
		100.0

Overall energy efficiency - 72%

NOTE: All Btu numbers based on lower heating values

ENERGY BALANCE