MI-81-003

TECHNICAL AND ECONOMIC FEASIBILITY OF UTILIZING APPLE POMACE AS A BOILER FEEDSTOCK

with
Special Addendum on
Supplemental Fuels

DOE/R5/10307--1

DE83 017449

Technical Report for U.S. Department of Energy
Grant No. DE-FG02-81R510307 for the Period
9/28/81 to 6/30/83

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ACKNOWLEDGEMENT

Assistance in the economic analysis provided by Dr. Thomas R. Pierson, Department of Agricultural Economics, Michigan State University, was gratefully appreciated. Consultation provided by Mr. Rodney Bull (Cherry Hill Orchards, Bailey, Michigan) and Mr. James Mortensen (National Fruit Products Co., Kent City, Michigan) is also acknowldged.

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ABSTRACT

Apple pomace or presscake, was evaluated for suitability as a boiler feedstock for Michigan firms processing apple juice. Based upon the physical and chemical characteristics of pomace, handling/direct combustion systems were selected to conform with operating parameters typical of the industry. Fresh pomace flow rates of 29,030 and 88,998 kg/day (64,000 and 194,000 lb/day) were considered as representative of small and large processors, respectively, and the material was assumed to be dried to 15% moisture content (wet basis) prior to storage and combustion. Boilers utilizing pile-burning, fluidized-bed-combustion, and suspension-firing technologies were sized for each flow rate, resulting in energy production of 2930 and 8790 kW (10 and 30 million Btu/hr), respectively.

A life-cycle cost analysis was performed giving Average Annual Costs for the three handling/combustion system combinations (based on the Uniform Capital Recovery factor). An investment loan at 16% interest with a 5-year payback period was assumed. The break-even period for annual costs was calculated by anticipated savings incurred through reduction of fossil-fuel costs during a 5-month processing season.

Large processors, producing more than 88,998 kg pomace/day, could economically convert to a suspension-fired system substituting for fuel oil, with break-even occurring after 4 months of

operation on pomace per year. Small processors, producing less than 29,030 kg/day, could not currently convert to pomace combustion systems given these economic circumstances. A doubling of electrical-utility costs and changes in interest rates from 10 to 20% per year had only slight effects on the recovery of Average Annual Costs. Increases in fossil-fuel prices and the necessity to pay for pomace disposal reduced the cost-recovery period for all systems, making some systems feasible for small processors.

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List of Abbreviations

AAC - Average Annual Costs
Btu - British thermal unit
C - degrees Celcius
F - degrees Fahrenheit
FBC - Fluidized Bed Combustor
ha - hectare
hr - hour
kg - kilogram
kJ - kiloJoule; MJ = megaJoule; GJ = gigaJoule
kw - kiloWatt
lb - pound
m - meter
MC - Moisture Content, wet basis
PB - Pile-Burner Combustor
SF - Suspension-Fired Combustor
UCR - Uniform Capital Recovery factor
yd - yard
yr - year

Conversion Factors

1 Btu = 1.055 kJ
1 Btu/hr = 0.2931 W (2.931×10^{-4} kW)
1 Btu/lb = 2.326 kJ/kg
$^{o}F = 1.8 \times {}^{o}C + 32$
1 lb = 0.4536 kg
1 cu. yard = 0.7645 cu. meter
1 hp (boiler) = 9.803 kW
1 lb/ft^3 = 0.06243 kg/m^3

1. Introduction

Increasing energy costs continue to be a major concern for the Michigan agricultural sector. At the farm level, production expenditures from 1979 to 1980 rose by 17% to $2.6 billion, with fossil fuel prices increasing by 40%. Energy conservation practices and alternate fuel sources are receiving increased attention and acceptance throughout the industry as federal, state and private funds are made available for relevant research projects.

In 1982 Michigan ranked third nationally in terms of apple production, with a crop valued at $74.7 million. During the past five years the apple processing industry has been shifting to production of more juice and cider to meet growing consumer demand. This trend is expected to continue through the 1980's (Ricks, 1981). Juice and cider production utilized 32.7% or 98 million kg of the total apples harvested in 1981 (Figure 1) valued at $13 million. The apple harvest for 1982 is estimated at a record 431 million kg, which could result in 159 million kg of juice, based on data for the large apple crop in 1980 of which 37% was made into juice, (Figure 2)(Michigan Agricultural Reporting Service, 1982).

The apple juice processing industry consumes significant amounts of energy which is mainly used in producing steam required in pasteurizing, sterilizing and sanitizing operations. A significant amount of energy is also used for heating work areas during the winter months. A survey of the Food and Kindred Products Industries revealed that the Canned Fruit and Vegetable

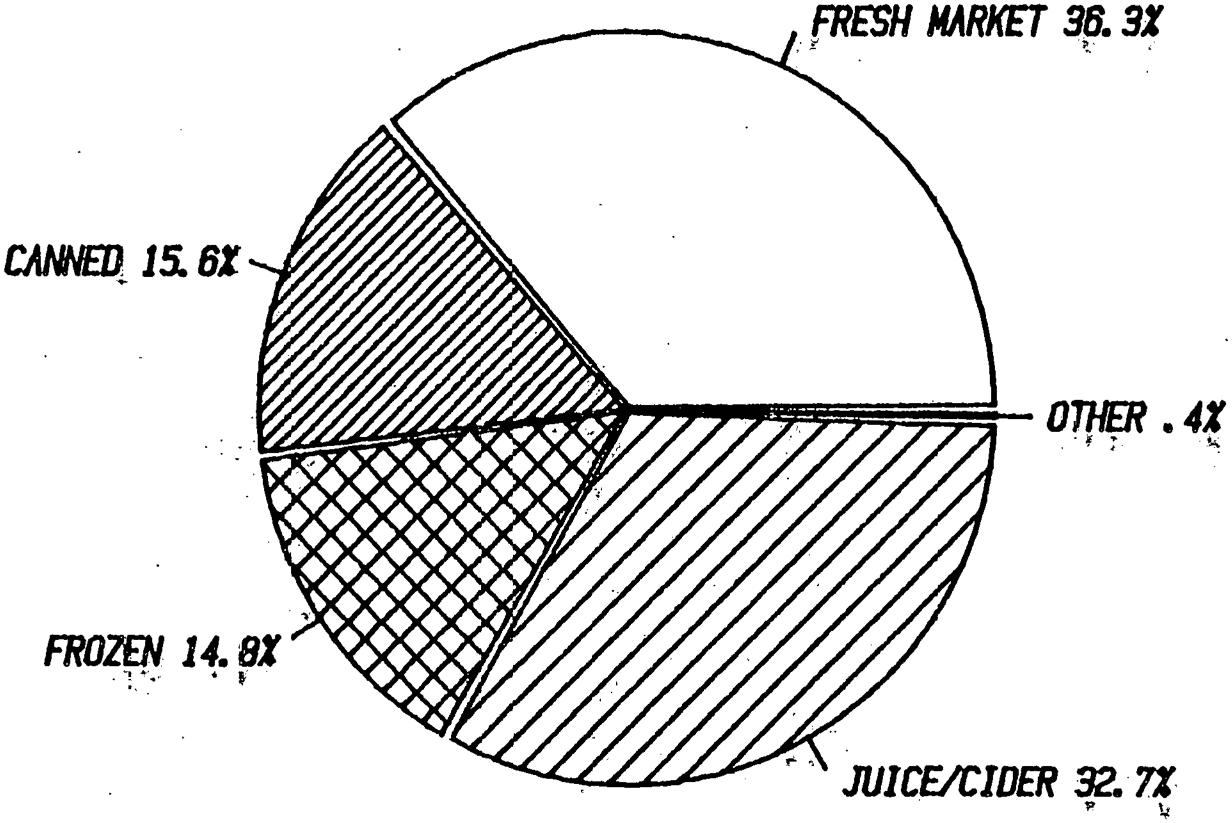

Figure 1. Michigan apple utilization for 1981 (Michigan Agricultural Reporting Service, 1982).

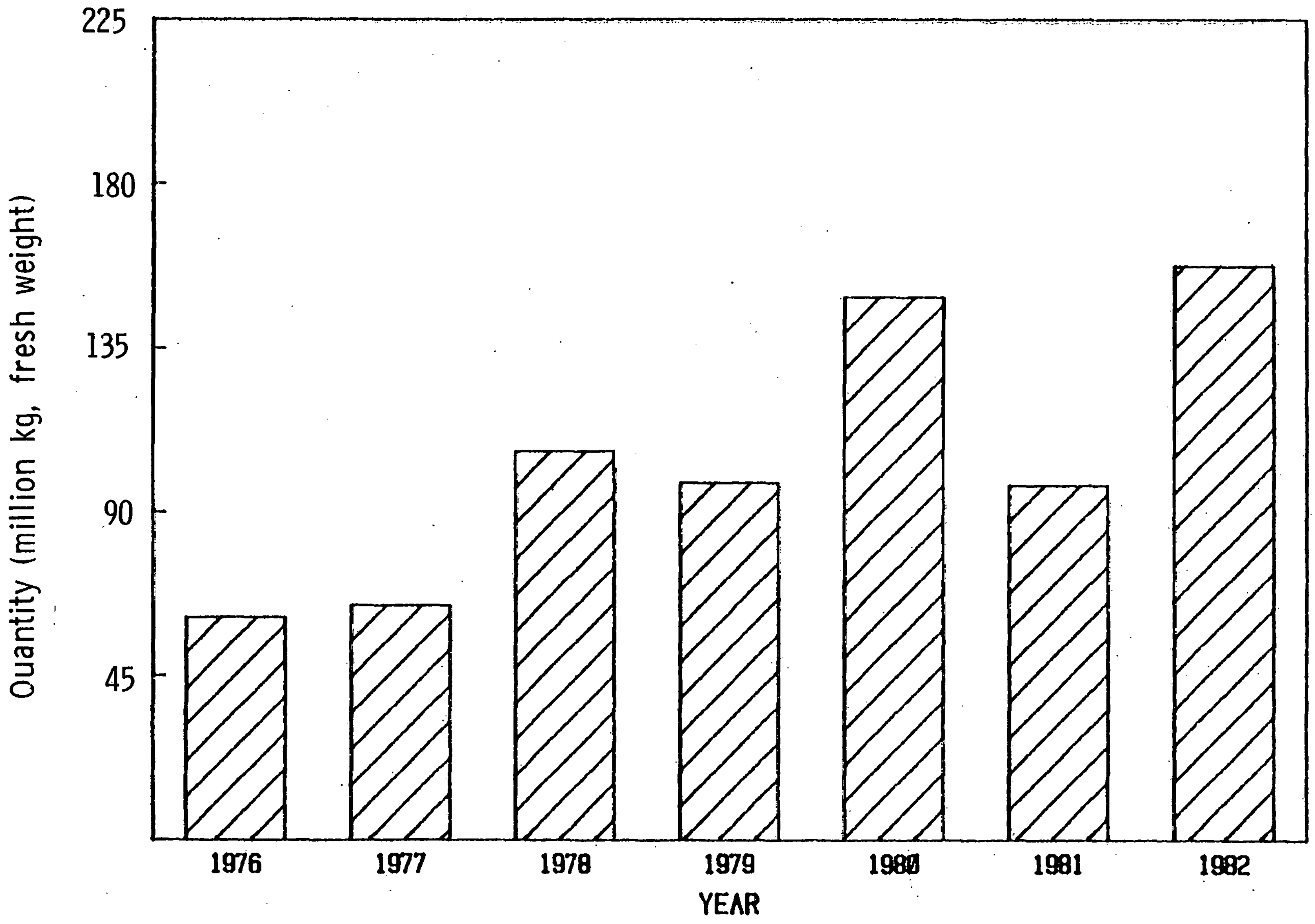

Figure 2. Process apple utilization for juice and cider, 1976-1982 (1982 estimate), (Michigan Agricultural Reporting Service, 1982).

Industry (which includes fruit juices) consumed 48.9 x 10^{12} kJ in purchased fuels and electricity (46.4 x 10^{12} Btu) in 1974. This ranked it fifth out of a total of 47 industries, with a consumption of 4.9% of the total energy consumed by the industries. Reduction of fuel expenditures translate into direct savings in operating expenses.

Juice processors must not only contend with increasing energy costs, but also with a large volume of by-product in the form of apple pomace, or presscake, which is the apple residue which remains after the juice is pressed. An efficient press will remove about 75% of the fresh weight of the apple leaving the pomace at 65% moisture content (MC) (Kranzler and Davis, 1981). (<u>In this report, all moisture content values will be expressed on a wet weight basis unless otherwise noted</u>). Thus 100 kg of apples yields roughly 75 kg of juice and 25 kg of pomace. Therefore with an estimated 160 million kg (350 million lbs) to be pressed during the 1982-83 season, 39.7 million kg. (87.5 million lbs) of pomace will require disposal in Michigan. For large processors, up to 88,998 kg (194,000 lb) of pomace are produced per day of operation, posing a significant disposal concern since pomace cannot be left in the plant. The high moisture content and presence of soluble sugars in pomace permits rapid fermentation which may cause objectionable odors. Pomace provides an excellent media for microbial pathogens, insects and other pests.

Pomace is currently disposed in three manners: in land fill sites, as an orchard mulch and as feed for livestock. It was formerly used as a source for pectin, but has since been replaced by citrus pomace (Henderson and Kesterson, 1965). Recently, apple pomace became available as a flavor/fiber ingredient for the baking industry (Apple Fiber and Rice Crunch; Mid-America Food Sales, Northbrook, IL 60062). At present these three methods are adequate for most processors, but each has limitations as a long-term solution.

Concern over environmental contamination has reduced the number of materials which are considered safe for disposal in landfill sites (Hills and Roberts, 1981). Large quantities of pomace disposed in pits could contaminate groundwater. Fresh fruit cannery waste can be spread on the topsoil at rates up to 250,000 kg/ha to dry followed by disking without contaminating the soil or groundwater with heavy metals (Noodharmcho and Flocker, 1975).

Growers who spread pomace as a mulch on their orchards periodically incorporate lime into the soil to neutralize the acidity added by the pomace. The fresh pomace left on the field surface has potential to be a host for disease organisms. Pomace is also fed to beef cattle, providing an inexpensive and palatable fiber source (Waller, 1982); however, pregnant cows which were fed pomace supplemented with non-protein nitrogen gave birth to dead or weak calves (Fotenot et al., 1977). In addition, rice hulls, routinely added as a press aid to apple pulp prior to pressing are not recommended as a solitary feed due to possible abrasion in the digestive tract of the animal (Hsu and Luh, 1980). Further study is necessary to evaluate the long-term effects of incorporating pomace into the feeding requirements of animals.

Producers of a wide spectrum of waste materials are finding it economical to utilize waste by-products as fuel in order to produce usable energy such as process steam or electricity (Table 1). Several processes exist which can transform biomass into energy. Selection of the appropriate process is dependent upon the physical state of the biomass (initial moisture content, heat value, physical properties), the efficiency of the energy conversion system, energy demands of the plant and economic feasibility.

There appears to be great potential in utilizing apple pomace as an in-plant fuel substitute for processors. It has a heat content equivalent to wood at 18,100 kJ/kg (7780 Btu/lb), dry basis (Kranzler and Davis, 1981). With assistance from state funding, Knouse Foods, Inc. has demonstrated the possibility of converting apple pomace into process steam and electricity by direct combustion (Schwieger, 1982).

The current study was designed to provide a technical and economic analysis on the feasibility of utilizing apple pomace as a supplemental fuel source. The systems analysis approach was used to identify physical and energy parameters characteristic of firms in the Michigan apple juice industry. The specific objectives of the technical analysis were:

Table 1. Industrial conversion of by-products into usable energy by direct combustion.

BY-PRODUCT	RESULTANT ENERGY PRODUCED	LOCATION	REFERENCE
Walnut hulls	Steam, electricity	Stockton, CA	Anonymous, 1981
Pecan shells	Steam	Florence, SC	Howard, 1981
Apple pomace	Steam, electricity	Orrtanna, PA	Schwieger, 1982
Plastic, paper waste	Steam	Charlevoix, MI	Reason, 1982
Solid municipal waste	Steam, electricity	Saugus, MA	Cheremisinoff, 1980
Sugar cane bagasse	Steam, electricity	Kauani, Hawaii	Reason, 1982

1) to identify physical constraints and chemical characteristics of apple pomace relevent to handling and energy conversion,
2) to perform a mass and energy balance on an apple processing system,
3) to identify the optimal conversion technology for in plant steam generation,
4) to select components for a handling/energy conversion system suitable to the varied needs of the industry.

The specific objectives for the economic analysis were:

1) to identify an appropriate analytical method to be used,
2) to determine cost-effectiveness of the handling/energy conversion system,
3) to perform a sensitivity analysis on vital economic parameters,
4) to develop an approach by which other biomass by-products might be evaluated in terms of energy potential and economic feasibility.

The results of this study will provide the Michigan food processing industry with a tool for evaluating the potential of using apple pomace and related agricultural by-products as fuel resources.

2. Technical Evaluation

2.1 Apple Pomace Physical and Chemical Properties

The handling and energy conversion of pomace is highly dependent upon the physical characteristics of the material. A description of a typical apple juice production system will clarify the physical origin of pomace (Fig. 3). Whole apples brought to the processor are held in common storage until processed. Lower grade fruits (usually those not suitable for fresh market) as well as peelings and cores (in plants with canning or freezing operations) are minced by a hammermill. At this point rice hulls or loose cellulose fibers are metered into the mixture at a rate of 2-4% weight/weight basis which improves juice extraction efficiency. Rice hulls are especially efficient as a press aid since the hard texture and waxy surface layer renders the hulls almost totally impermeable to juice infiltration, and the hull structure creates channels for the juice to flow from the pulp for recovery.

After pressing, a belt conveyor or a screw auger is generally used to remove pomace from the plant. Clumps of pomace may form during conveyance, particularly for the screw auger. Although particulate, pomace is very cohesive due to a high moisture content (65%, wet basis) and sugar content (17.5%, dry basis) (Fotenot, et al, 1975). For this reason pomace cannot be stored in the plant, since fermentation begins in the pile creating objectional odors and heat. When dried below 20% MC pomace has physical properties similar to wood particles or grain. It can be handled more easily, since it has a lower bulk density, and less friction than when at 65% MC. The bulk densities of apple pomace at 65% and 42% MC were found to be 385 and 210 kg/m^3, respectively (Sargent, S.A., unpublished data). Pomace could also be pneumatically handled at this MC, as is the case

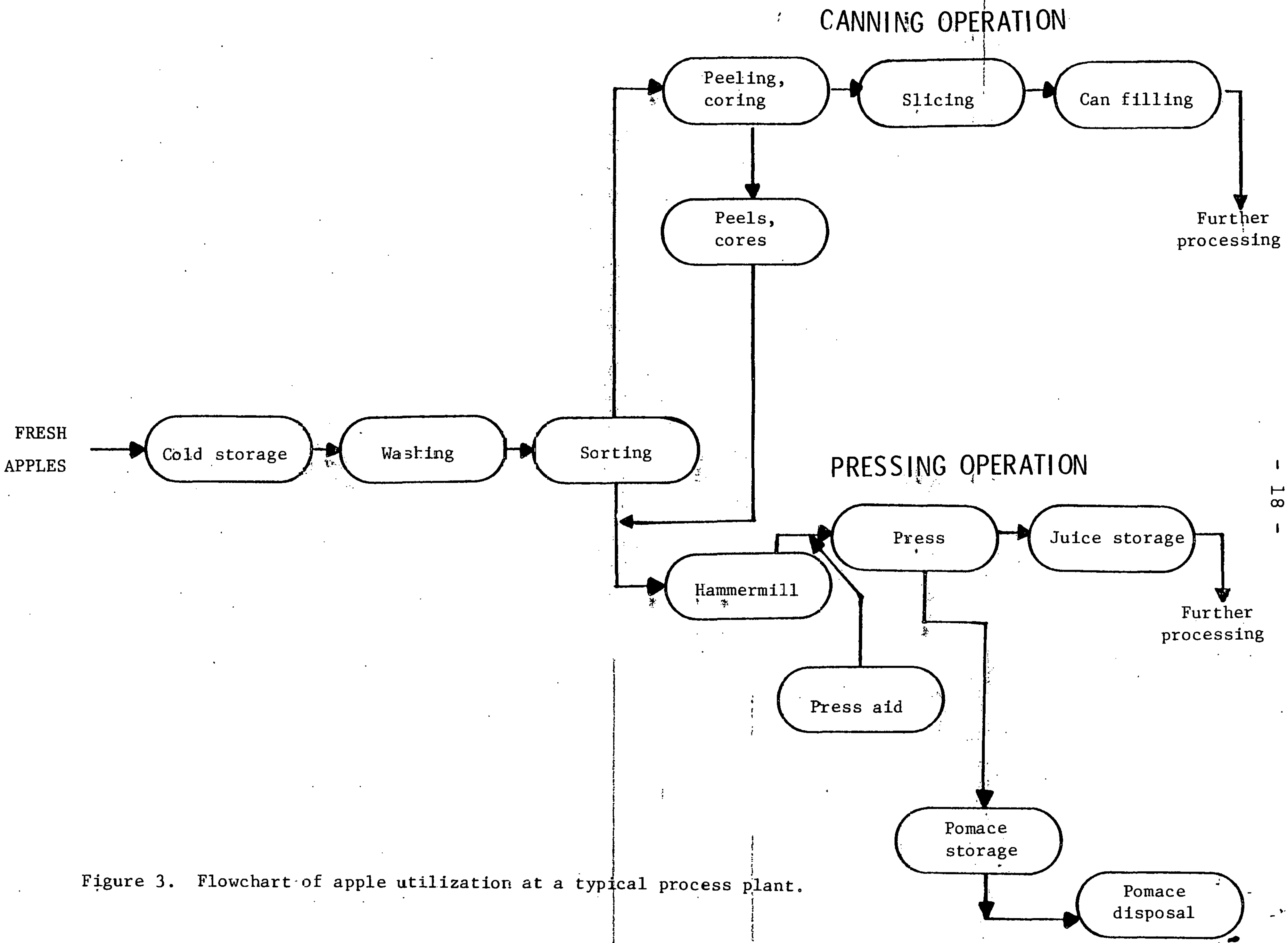

Figure 3. Flowchart of apple utilization at a typical process plant.

for wood particles; however, for pomace containing rice hulls, pneumatic abrasion occurs to equipment because of the high silica content in the hulls (Schwieger, 1982). Storage in bins can be easily used for low MC pomace since there is not enough water present to sustain fermentation. Fine particles are produced during handling of dry pomace which could create an explosion hazard, but when kept at 15% MC or above this should be minimal (White, 1980).

2.2 Pomace Fuel Characteristics

The primary consitituent of pomace is cellulose. Volatile and fixed carbon from pomace amount to 95.99% of bone dry pomace (0% MC) with the remaining 4.0% as ash and .05% as sulfur and trace elements. Ash and sulfur contents are much lower for pomace and wood than for coal, indicating it has good combustion characteristics. The heat content of 18,100 kJ/kg (7780 Btu/lb) is similar to wood and approximately 60% that of coal since it contains less fixed carbon. Rice hulls contain an average or 17.4% ash and, when present in pomace, will raise the overall ash content by less than 1%. When considered alone rice hulls have a heat content of approximately 13,398 kJ/kg (5760 Btu/lb) (Hsu and Luh, 1980). Selected analyses for pomace and fossil fuels are presented in Table 2.

The following energy conversion processes could have application for apple pomace: direct combustion producing heat, anaerobic digestion yielding methane gas (Lane, 1979) and fermentation resulting in ethanol. Of the three, direct combustion

Table 2. Comparison of selected analyses for apple pomace and fossil fuels.

	apple pomace 1/	rice hulls 2/	coal 3/	#2 fuel oil 4/	natural gas (96% methane) 5/
Ultimate Analysis (%)					
Carbon	44.6	39.2	75.5	87.3	74.9
Hydrogen	6.2	5.0	5.0	12.6	25.1
Oxygen	44.8	32.7	4.9	0.004	--
Nitrogen	0.4	2.0	1.2	0.006	--
Sulfur	0.05	0.1	3.1	0.22	--
Ash	4.0	17.4	10.3	--	--
H_2O	--	3.6	--	--	--
Heat Content					
Btu/lb	7,780	5,760 5/	13,000	18,670	23,885 (liquid)
kJ/kg	18,096	13,398	30,238	43,427	55,557

Ash Fusion Temperature

	bituminous coal 3/	apple pomace 6/	grape pomace 6/
°F	2,450	2,700	2,400
°C	1,343	1,482	1,315

Sources: 1/ Kranzler and Davis, 1981; 2/ Singh, et al, 1980; 3/ Elliot, 1980; 4/ Perry and Chilton, 1973; 5/ Hsu and Luh, 1980; 6/ Kranzler, et al. 1983.

releases the highest amount of heat per unit of fresh product (Hall, 1981) and has proven cost-effective on an industrial scale for many biological materials (see Table 1).

The net heat content of pomace, as with other biomass fuels, is inversely related to MC. As MC increases from 0 to 20 to 65%, the net heat content decreases from 18,100 to 12,330 and 3950 kJ/kg (7780 to 5300 and 1698 Btu/lb), respectively. Pomace, as other biomass fuels, burns very cleanly with nominal amounts of sulfur released to the atmosphere (less than .05%). The primary pollutant is fly ash which can be removed by cyclone separators, bag house filters and electrostatic or water scrubbers.

Direct combustion, occurs when fixed carbon in the biomass is oxidized in the presence of air in excess of stoichiometric requirements and held above the ignition temperature. The stoichiometric requirement is the theoretical amount of oxygen necessary to completely oxidize the carbon, hydrogen, sulfur and trace elements in the biomass to produce primarily carbon dioxide, water vapor and heat (Fryling, 1966). Derived fuels are obtained when the quantity of air is sub-stoichiometric (gasification) or when the temperature is reduced (pyrolysis). Gasification produces biogas, or producer gas, while pyrolysis results in charcoal or char liquid, both of low-to-medium heat value.

In order for sustained combustion of a solid material to occur, three conditions must be satisfied, i.e., proper temperature, time and turbulance. The material must be held for an adequate residence time above the ignition point (the temperature at which combustion becomes self-sustaining). Turbulance ensures that sufficient oxygen is available to combine with hydrogen, carbon, sulfur and trace elements. With these conditions met the three - stage combustion process begins. During the first stage water vapor must be driven off, which holds the fuel temperature near the boiling point, 100°C (212°F). The heat of vaporization requires 2256 kJ/kg of water at 100°C (970 Btu/lb). U on vaporization the flaming combustion stage occurs in which the volatiles are combusted between 149°C and 538°C (300° and 1000°F) and combustion becomes self-sustaining. Finally the remaining fixed carbon oxidizes during the glowing combustion stage, resulting in ash (Elliott, 1980). The principal reactions concerning direct combustion are described by (Babcock and Wilcox, 1978):

$$C + O_2 = CO_2 + 32{,}797 \text{ kJ/kg } (14{,}100 \text{ Btu/lb}), \text{ for carbon}$$

$$2H_2 + O_2 = 2H_2O + 142{,}119 \text{ kJ/kg } (61{,}100 \text{ Btu/lb}), \text{ for hydrogen}$$

Stack temperatures vary from 204-371°C (400-700°F). Waste heat recovery is possible so long as the stack outlet temperature is maintained above 204°C. Below this temperature condensation, corrosion and inadequate updraft become problems in the stack. Waste heat could be recovered by an air-to-air heat exchanger in the stack and used to supplement pomace drying in some applications.

In summary, thermochemical conversion of pomace by the direct combustion process was selected as the optimal process for this study for the following reasons:

1) direct combustion generates the most heat/unit fresh weight,
2) in-plant production and combustion of pomace is more energy efficient than other conversion processes,
3) the particulate nature of pomace facilitates drying, handling and combustion,
4) efficient biomass combustion boiler systems are readily available to the industry and have less complex design than those for other conversion processes,
5) the ash by-product of combustion, accounting for only 4% of the total volume, is sterile and has potential for use as fertilizer (Hsu and Luh, 1980).

2.3 Selection of Handling/Combustion System Components

Criteria for selection of system components were based upon four general considerations:

1) pomace availability including quantities produced, length of process season, plant process scheduling,
2) types of handling equipment available to the industry,
3) characteristics of the combustion furnaces including dependability, combustion efficiency, retrofit potential and multifuel capability,

4) equipment costs including those related to purchase, installation and maintenance.

It is advantageous to dry pomace prior to combustion for several reasons. As previously mentioned the amount of heat released from a solid fuel is inversely proportional to the moisture content. Therefore, with a lower initial moisture content more heat would be available to produce steam since less heat is required to evaporate the water from the pomace prior to combustion. In addition, handling dry pomace requires much less power and has fewer equipment problems than wet pomace and may be stored as a stable biological product prior to combustion. Also several biomass boilers require a dry fuel for efficient energy conversion. Wood chips are typically stored and combusted at 35% MC (Schwieger, 1980), while 20% MC was suggested for apple pomace as a compromise between net heat content and drying costs (Kranzler and Davis, 1981). Fifteen percent MC was used as the base for calculations in this study, reflecting a net heat content of 13,956 kJ/kg (6000 Btu/lb) of pomace. Pelletizing pomace would produce a dense fuel but because it is very energy intensive it was not considered in this analysis.

Pomace flow rates from the press (65% MC) were calculated for two production rates of 29,030 and 88,998 kg pomace/day, or 1836 and 5508 kg/hr (4048 and 12,144 lb/hr) representative of the firms in the Michigan apple juice industry. When dried to 15% MC, the flow rates reduce to 756 and 2268 kg/hr (1667 and 5000 lb/hr). At these rates 15% MC pomace would produce 2,930 and

8,790 kW (10 and 30 million Btu/hr) when combusted. Calculations are presented in Appendix 1, and assume a production schedule of 16 hr/day, 25 days/month and 5 months/process season (i.e., from mid-September to mid-February).

Handling system components were evaluated and selected from pertinent references and conversations with industrial representatives and sized according to the pomace flow rates. A rotary drier was selected due to the capability for efficient drying of particulate, high moisture content materials, and the flexibility for use in batch or continuous operations. The drier was assumed to combust natural gas or fuel oil, but has potential for supplementation by waste heat recovered from the boiler stack in some situations.

Pomace should be agitated after pressing to break up any clumps which may form. Clumps passing through the drier would be fed through a hammermill and reintroduced into the drier, since clumps case-harden at the surface and reduce drying efficiency. The dry surface acts as an insulating barrier, hindering moisture diffusion from the inside, and these clumps could block subsequent pomace flow and disrupt combustion in the boiler.

Upon drying, pomace would be transported by belt conveyor or bucket elevator to a bulk collector for storage (Brennan, 1969). Pneumatic handling would be advisable only for pomace without rice hulls, since the high silica content is very abrasive to transport piping. Note that rice hulls are actually used to pneumatically clean oxidized metal. Hulls can be partially separated from apple pomace by air classification, which would permit pneumatic handling and allow the hulls to be recycled on a daily basis as a press aid. The bulk collector would be located outside of the building adjacent to the boiler, providing protection from adverse weather. Screw augers at the base of the collector would transport and meter the pomace to the boiler (Fig. 4).

Several multifuel combustors are available for direct combustion of biomass fuels, traditional fossil fuels or combinations of these fuels. These combustors can be retrofitted to existing boilers or purchased as an integral part of a package boiler. Retrofit combustors require less capital investment than the package boilers; however from conversations with industry representatives, the heat recovery efficiency decreases by approximately 25% due to losses between the combustor and the heat recovery boiler. The package boilers considered have heat recovery efficiencies of 85-90%.

Three package boiler systems were selected and evaluated for the two pomace production rates assumed in this study. Combustion technologies employed are known as pile burning, fluidized-bed combustion and suspension firing. The boilers are of the fire tube design and would generate 4,536 and 13,608 kg/hr and (10,000 and 30,000 lb/hr) of steam, for the respective pomace flow rates. Pile burning and suspension firing have been extensively used by the wood products industry for combusting wastes ranging from hogged brush to sawdust fines. Fluidized-bed

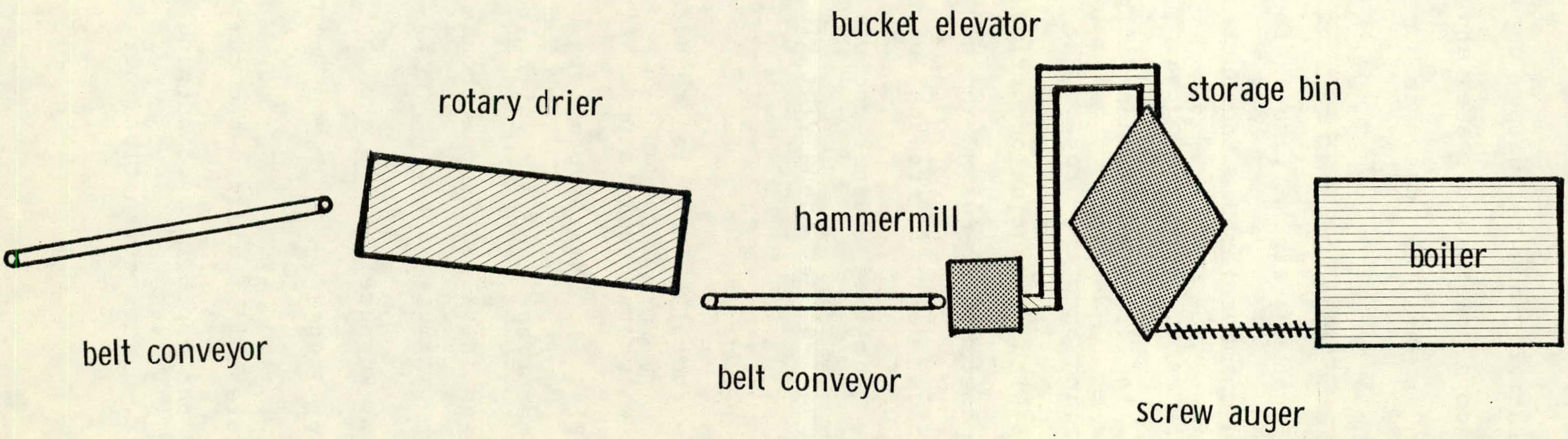

Figure 4. Proposed pomace handling system components.

combustion is a relatively new technology used for burning coal and municipal wastes on a powerhouse scale, and shows execellent promise for use on a smaller scale as a means of combusting biomass.

In pile burning systems (Fig. 5), solid fuel is introduced into the combustion chamber through the bottom grate by a screw auger and forms a pile as it is pushed outward. It may also be pneumatically blown in from above where it partially burns in suspension before falling onto the grate. The fuel accumulates in a thick bed pile with combustion occurring at the surface of the pile, permitting fuels of 50-60% MC and non-uniform size to be combusted. Furnace designs are the Dutch oven, fuel cell, cyclone, wet cell, inclined water-cooled pinhole grate, traveling-grate spreader-stoker, and vibrating grate (Perry and Chilton, 1973).

Dry, particulate fuel (15% MC) is required by suspension firing systems in which the fuel is pneumatically fed into the combustion chamber (Fig. 6). Nearly complete combustion occurs by proportionally metering the air with the fuel flow rate. These systems have been installed in powerhouse operations, and pulverized coal is routinely combined with biomass fuels to increase heat output. Furnace designs are the cyclonic and solid fuel burners (O'Grady, 1980).

The current interest in fluidized-bed combustion systems has developed because of the capability of burning a variety of fuels up to 55% intitial MC. The combustion air is forced upward

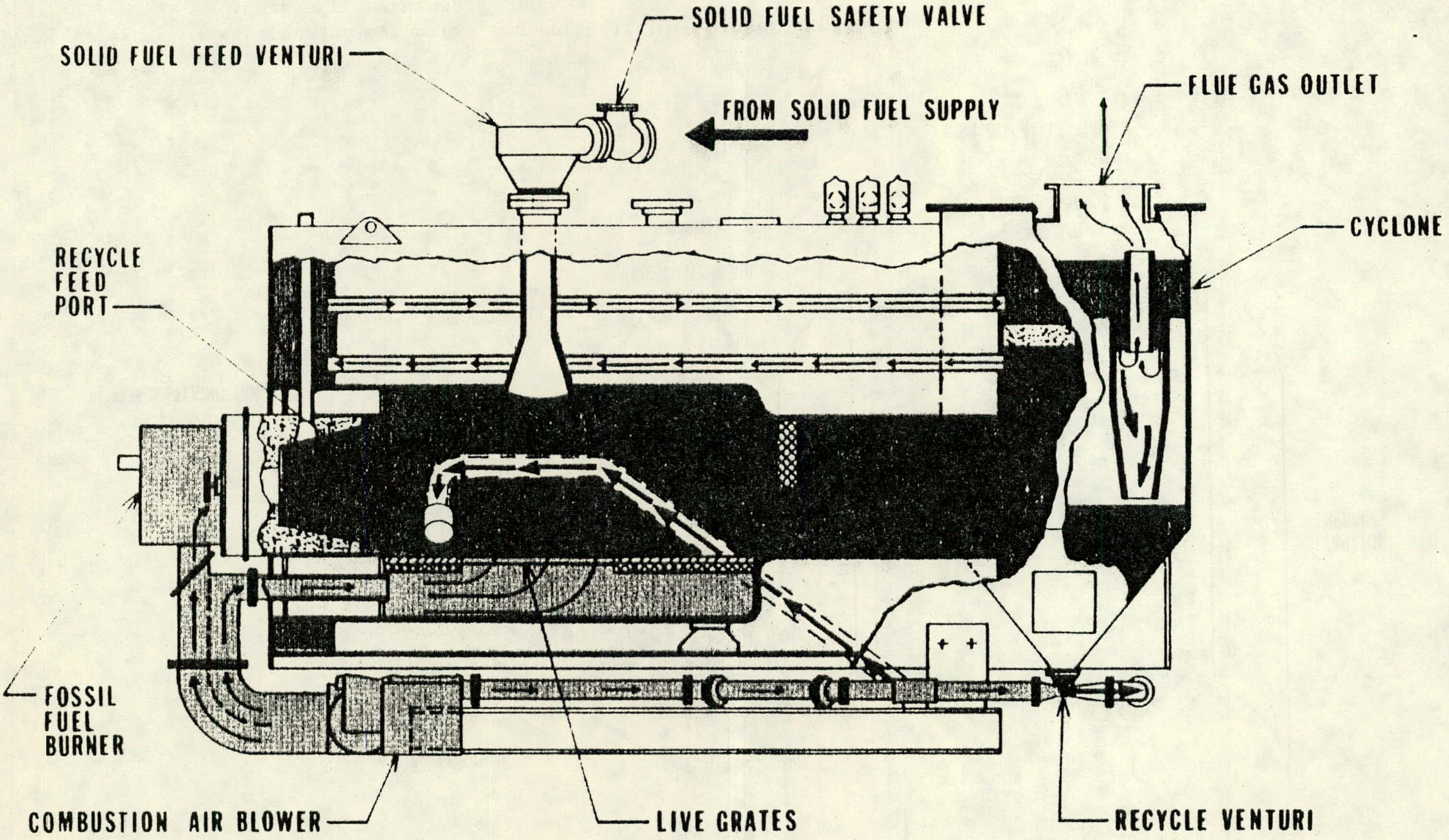

Figure 5. Suspension/pile burning solid fuel boiler (Ray Boiler Company).

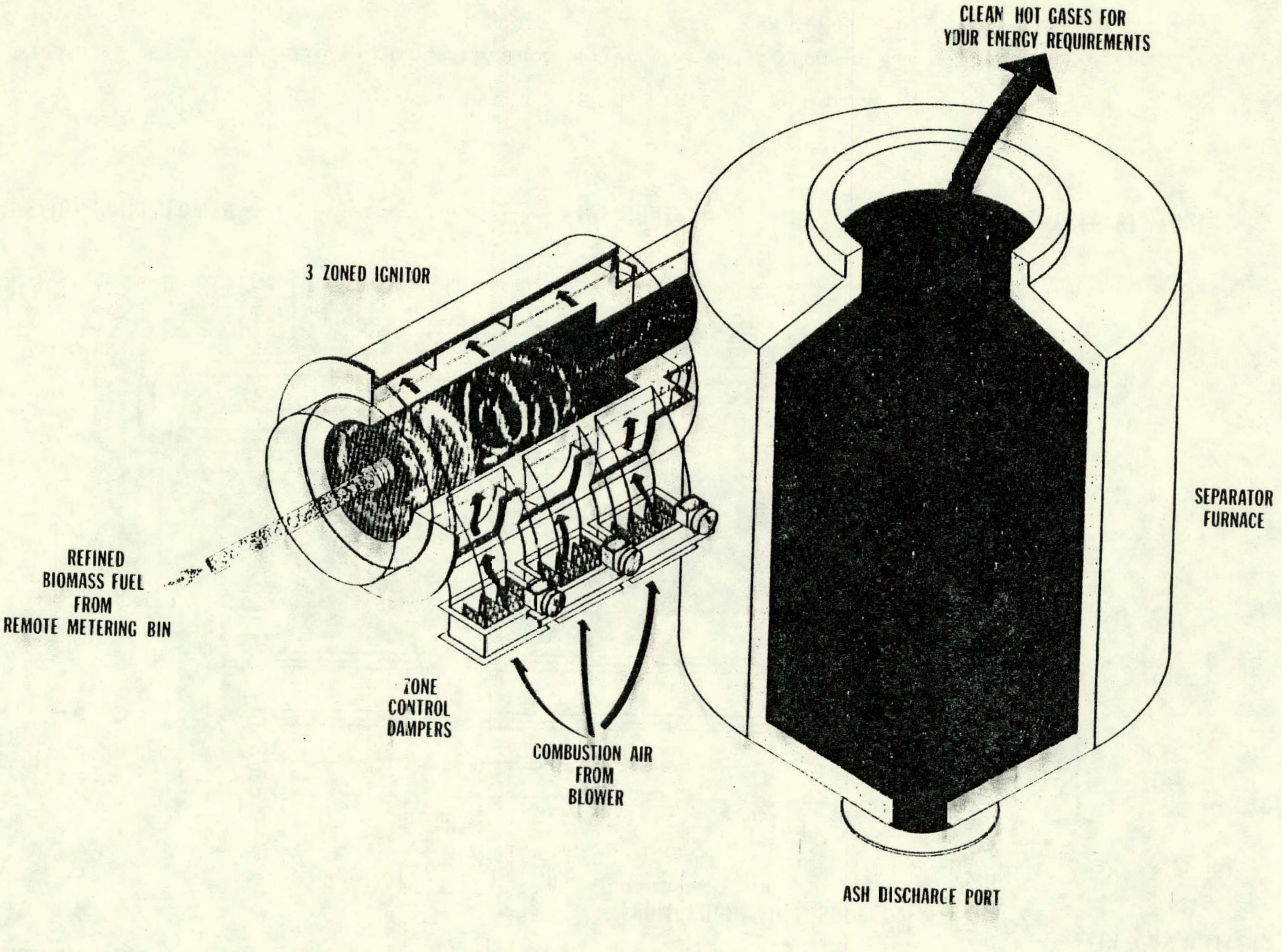

Figure 6. Suspension combustor for retrofit to heat recovery boiler (Guaranty Performance Company).

through a bed of heated sand, maintained at approximately 927°C (1700°F) causing the sand particles to become fluidized (Fig.7). The fuel is introduced into the bed and is readily dried and combusted by continuous agitation from the hot sand particles. Slagging is minimized by maintaining bed temperatures below the fusion temperature for ash, which is approximately 1482°C (2700°F) for apple pomace. Values for fusion temperatures of apple and grape pomace and coal are presented in Table 2. The advantages and disadvantages of these technologies with respect to pomace combustion are summarized in Table 3.

Due to the higher amounts of ash derived from thermochemical conversion of cellulosic materials, a rigid schedule for ash removal from the combustion chamber must be maintained. The trend has been to design combustors which have automatic ash removal systems in the grate area to permit continuous operation. Several of these systems also reinject unburned char pieces back into the combustion zone, improving efficiency by up to 7%.

The amount of fly ash carried by the stack gasses varies with the combustion method and system. Federal standards for stationary sources relevant to waste fuel combustion are presented in Table 4. The common primary collector is the cyclone which removes larger particulates and may be adequate for efficient combustion systems. Bag collectors can be added if emissions standards are not met by the cyclone collectors. Wet scrubbers remove fines but require substantial post-treatment of the waste-water. Electrostatic precipitators are also widely

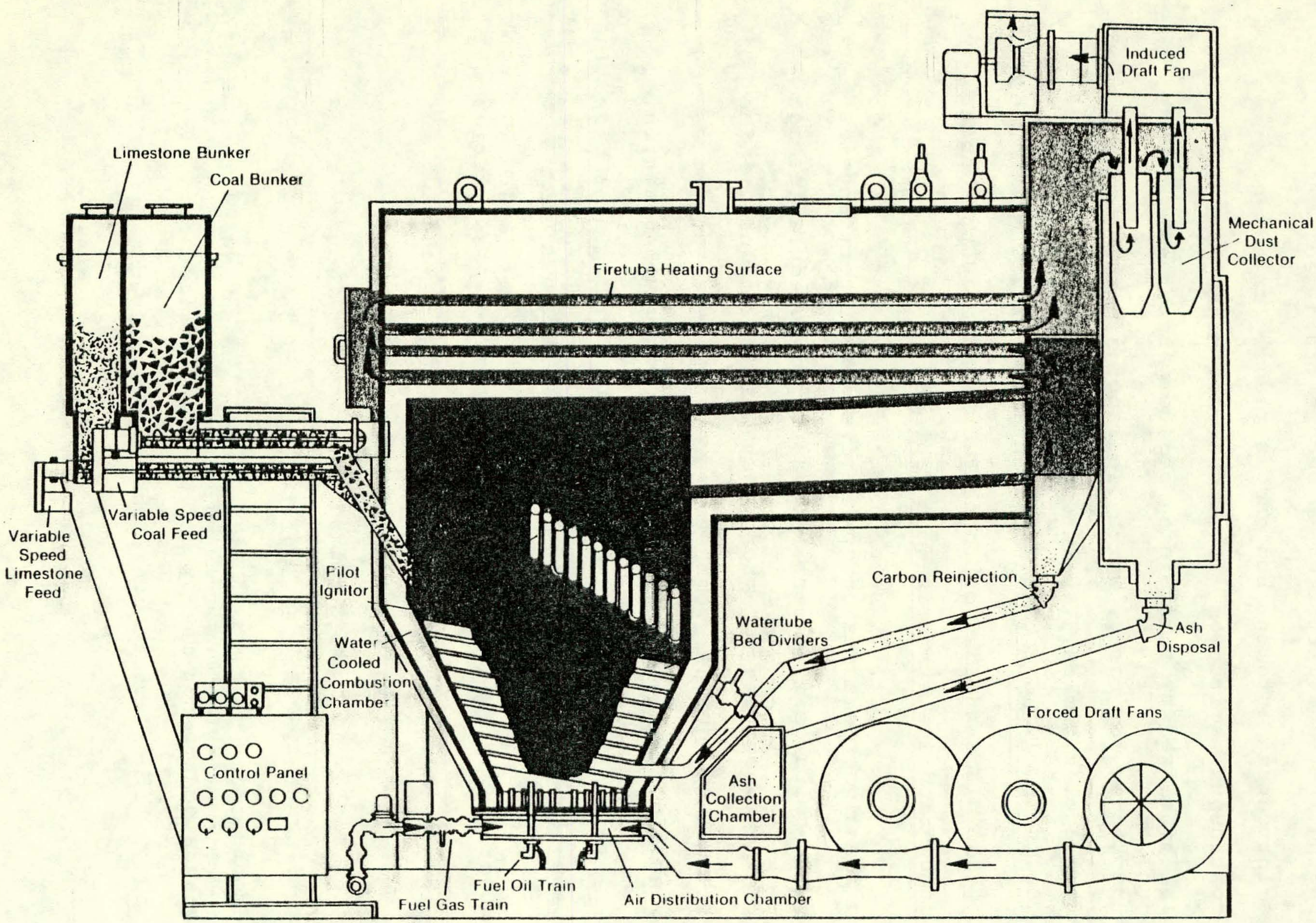

Figure 7. Fluidized-bed combustion boiler (Johnston Boiler Company).

Table 3. Differences between direct combustion systems*.

	ADVANTAGES	DISADVANTAGES
PILE BURNING	1) use of high MC fuels 2) non-uniform fuel size 3) simple design and operation	1) high refractory repair costs 2) slow response to load changes 3) manual ash removal (some systems)
SUSPENSION FIRING	1) low particulate emission 2) rapid response to load changes	1) low MC fuels only 2) uniform fuel particles 3) pneumatic handling only 4) very accurate air control required
FLUIDIZED BED COMBUSTION	1) use of high MC fuels 2) non-uniform fuel size 3) package boilers available	1) slow response to load changes 2) preheat bed with fossil fuel 3) clinker formation in bed

*Sources: Schwieger, 1980; Bullpit, 1980.

Table 4. Federal stationary source emission performance standards.*

SOURCE	POLLUTANT	STANDARD
A. Coal; Coal/Wood *Residue-Fired Boilers over 264 GJ/hr	Particulate Opacity SO_2 NO_x	0.043 kg/MJ 20%; 40% 2 min/hr 0.516 kg/MJ 0.301 kg/MJ
B. Gas;Gas/Wood *Residue-Fired Boilers over 264 GJ/hr	Particulate Opacity NO_x	0.043 kg/MJ 20%; 40% 2 min/hr 0.086 kg/MJ
C. Incinerators over 45.4 Mg/day	Particulate	0.18 g/dry standard m^3, corrected to 12% CO_2

*Olexsey, 1980.

used where biomass is burned in conjunction with fossil fuels.

Although combustion temperatures are maintained below slagging temperatures, some slag accumulates eventually in the combustion chamber, requiring manual cleaning. Slagging may be increased with prolonged combustion of rice hulls due to the high silica content, however, this has not been verified under operating conditions. Fly ash, ash and slag are sterile materials and can be readily disposed.

3. Economic Evaluation

3.1 Analytical Approach

A firm will invest in a new technology only if it is economical. Energy-related projects are considered cost-effective if the investment is recoverable within a viable payback period. An appropriate cost analysis provides a base from which a promising technology can be realistically evaluated in terms of future returns to the company. Life cycle costing is a cost analysis method which is becoming more widely adopted in both the public and private sectors. This method considers not only investment costs, but more importantly, the significant costs which would be incurred over the life of the asset. In order for a firm to make a major investment such as a handling/combustion system, capital would be required, often obtained by a loan. The interest rate required for the loan, or the opportunity cost of owned capital, must be included since the present value of a sum of money is worth more than its value would be after one year, due to the time value of money. Interest rates and opportunity costs are thus an inherent cost of any analysis concerning the cost of capital. Annual operating and maintenance costs are also important factors which cannot be ignored. These costs outweigh initial purchase costs for long-term investments.

After considering several methods which evaluate the time value of money, the Uniform Capital Recovery (UCR) factor was selected for use in this analysis. The UCR factor is used to determine the Average Annual Costs of a loan at a fixed interest rate such that:

Average Annual Costs = Principle x UCR + yearly operating and maintenance costs

$$\text{where UCR} = \frac{i(1+i)^n}{(1+i)^n - 1}$$

i = interest rate (decimal)
n = number of interest periods

Knowledge of the Average Annual Costs (AAC) of the proposed investment and the resultant savings in fossil fuel costs over the current equipment permits calculation of the time necessary to recover the AAC. The point at which AAC equal savings is known as the break-even point. The Break-Even Analysis was chosen for this study since it considers the time value of money and provides for determination of the payback period (Brown and Yanuck, 1980).

3.2 Calculation of Total Costs

The analyses for the three handling/combustion systems involved determining total costs which consist of investment and operating costs. Costs for components of the large capacity system were obtained from the manufacturers, while the costs for the small systems were calculated from these figures using the following scale-down formula (Humphreys and Katell, 1981):

$$\text{Unknown equipment cost} = \text{known equipment cost} \times \left(\frac{\text{unknown size}}{\text{known size}}\right)^{.61}$$

where .61 is the cost capacity exponent for a 1968 kW (200 hp.) package boiler (Table 5). Costs for both handling systems are proportional and are represented in Fig. 8. The most expensive component in the handling system is obviously the rotary drier.

Another important factor in determining the investment costs is that of the interest rate charged by lending institutions. From a conversation with a local bank officer, calculations were based on 16% annual interest (1% above the prime rate at 15%, July 1982).

Operating costs were estimated for the following: labor, maintenance, insurance on equipment, property taxes and electrical costs. Specific tax calculations based on depreciation of the investment were not made since individual processor tax brackets are widely varied. The salvage value of the old system was assumed to be equal to removal costs required to install the

Table 5. Comparative installed costs of system components.*

	Total Cost ($)	
COMPONENT	SMALL SYSTEM	LARGE SYSTEM
Belt Conveyor		6,588
Rotary Drier		252,000
Hammermill		12,701
Bucket Elevator		8,300
Storage Bin		11,272
Screw Auger		3,345
	150,525**	294,206
Boilers		
Pile Burner	401,732	785,200
Fluidized-bed	340,000	695,000
Suspension-fired	156,968	306,800

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*July 1982 prices
**from Scale-down formula

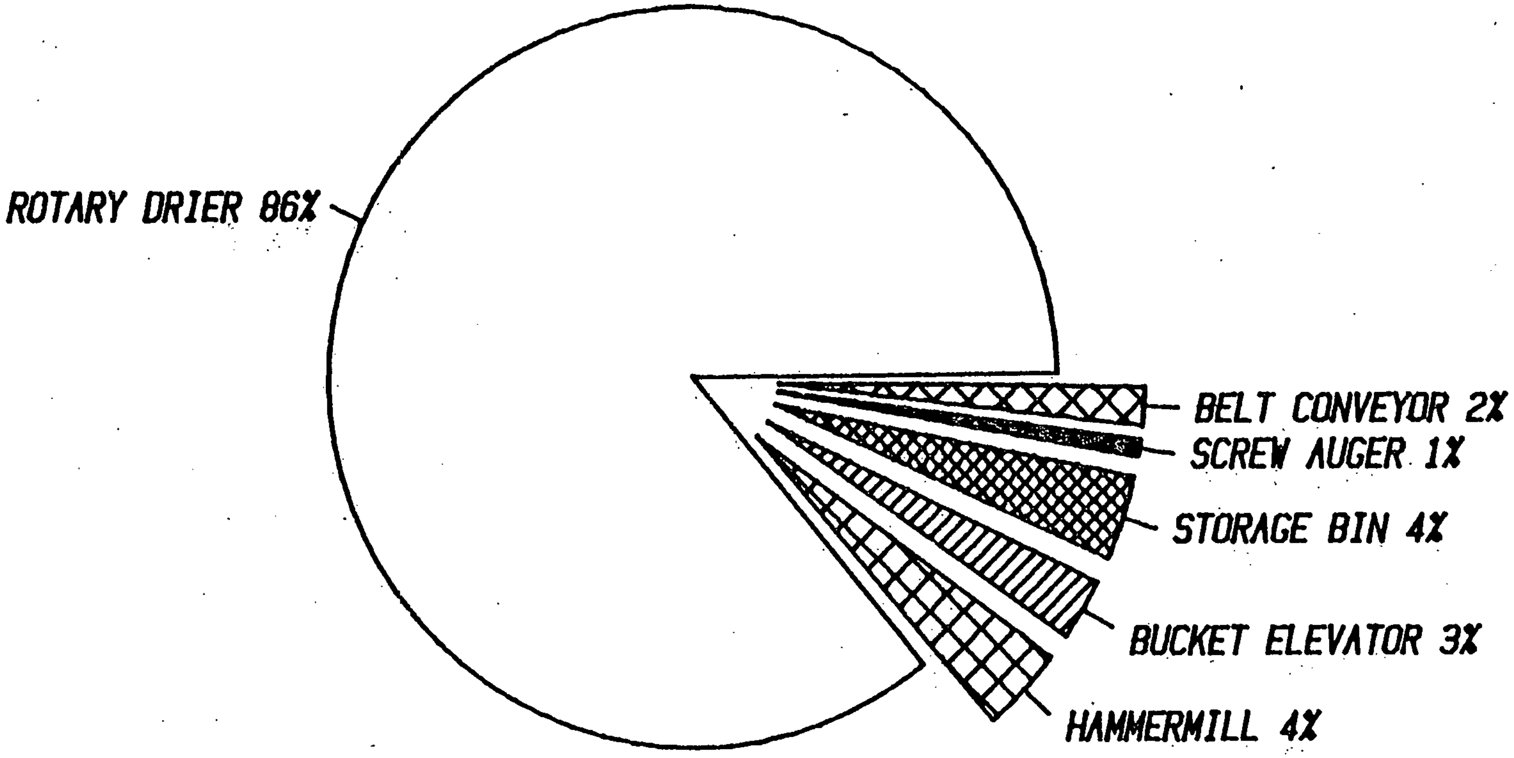

Figure 8. Representative investment costs for pomace handling system components.

new system. Depreciation of new equipment was not considered either since the cost is included in the initial purchase price. Administrative costs were assumed to be equal to those for the fossil fuel system and therefore ignored. Operation of the new boilers on fossil fuel during off-hours was assumed to be equal to that of the old system. Cost estimates were derived as follows (Humphreys and Katell, 1981):

Maintenance:	2% of investment cost/year
Insurance:	Private company estimate
Property tax:	1% of investment cost/year
Labor:	$2500/season, (2 hrs/day x $10.00/hr x 25 days/month x 5 months)

Costs for the monthly total electrical consumption were based on the sum of the demand rate, the base rate, the fuel-cost adjustment and a 4% Michigan sales tax. It was assumed that the company owned the transformer, qualifying it for the least expensive primary rate. Power demands for each system component were obtained from the manufacturers. Component power consumption for the larger system was as follows:

Handling Components	Power Consumption (kW)	Monthly Costs ($)
Belt conveyor (65% MC)	.67	--
Rotary drier	111.63	--
Hammermill	54.00	--
Bucket elevator (15% MC)	4.50	--
Screw auger	2.70	--
Components Total	173.50 kW	2,860.42
Boilers		
Pile Burner	144.00	3189.20

Fluidized-Bed Combustion	119.00	2638.56
Suspension-Fired	103.00	2278.60

Utility costs of the smaller system were based on 11.3% less power requirements, from manufacturers' data. Operating costs are summarized in Tables 6 and 7.

3.3 Break-Even Analysis

Average Annual Costs were calculated for the three handling/combustion systems for small and large processors as follows:

	Small System	Large System
Pile Burner	$220,318	$401,782
Fluidized-Bed	194,260	367,674
Suspension-Fired	127,594	234,948

Figure 9 shows the investment costs to account for over 50% of the AAC for the pile burner system at both sizes. Investment costs were higher for the larger system; however, operating expenses were proportionally lower (18% vs 21.2%).

Savings through reduction of fossil fuel and pomace disposal costs were used to determine the Break-Even period required for Average Annual Costs over a 5-year payback period. Net savings from fossil fuel costs were determined by subtracting the hourly osts of drying pomace from 65-15% MC from the hourly operating costs for either natural gas or fuel oil. Calculations for net savings from reducing fossil fuel costs and eliminating disposal costs are presented in Appendices 2 and 3, respectively.

Table 6. Annual operating costs for the small system.

Component	Investment 1/	Labor (5 mo.)	Maintenance (2%)	Insurance 2/	Property Taxes (1%)	Utility 3/ Costs	TOTALS/YR Component	TOTALS/YR System
HANDLING SYSTEM	$150,525	$2,500.00	$3,010	$613	$1,505	$7,151	$14,779	
BOILER SYSTEM								
Pile Burning	401,732	4/	8,035	4/	4,017	19,801	31,853	46,632
Fluidized Bed	340,000	4/	6,800	4/	3,400	16,386	29,670	44,449
Suspension Firing	156,698	4/	3,139	4/	1,570	14,195	18,904	33,683

1/ Based on scale-down formula

$$c_x = c_k \left(\frac{E_x}{E_k}\right)^{.61},$$

when C_x = unknown value, C_k = original value of equipment

E_x = scaled rating,

E_k = original rating.

2/ Private company estimate for boiler and related machinery.

3/ Based on 11.3% less power requirement, for smaller boiler. Handling system costs based on 5 months operation; boiler systems based on 9 months (total season). Boiler system costs based on 5 months full rate for 16 hours/day and 1/2 rate for 8 hours/day + 4 months 1/2 rate for 24 hours/day.

4/ Costs for boiler systems included with handling system costs.

Table 7. Annual operating costs for the large system.

Component	Investment	Labor (5 mo.)	Maintenance (2%)	Insurance [1]	Property Taxes (1%)	Utility[2] Costs	Component Total	System Total/Yr.
HANDLING SYS.	$ 294,206	$ 2,500	$ 5,884	$ 613	$ 2,942	$ 14,302	$ 26,241	
BOILER SYS.								
Pile Burning	785,200	[3]	15,704	[3]	7,852	22,324.4	45,880.4	$ 72,121.4
Fluidized-Bed	695,000	[3]	13,900	[3]	6,950	18,470.2	39,320.2	65,561.2
Suspension-Fired	306,800	[3]	6,136	[3]	3,068	15,950.2	25,154.2	51,395.2

[1] Private company estimate for boiler and related machinery.

[2] Based on 5 months operation; boiler systems based on 9 months (total season) - 5 months at full rate 16 hrs./day and 1/2 rate for 8 hrs./day + 4 months 1/2 rate for 24 hours/day.

[3] Costs for boiler system included with handling system costs.

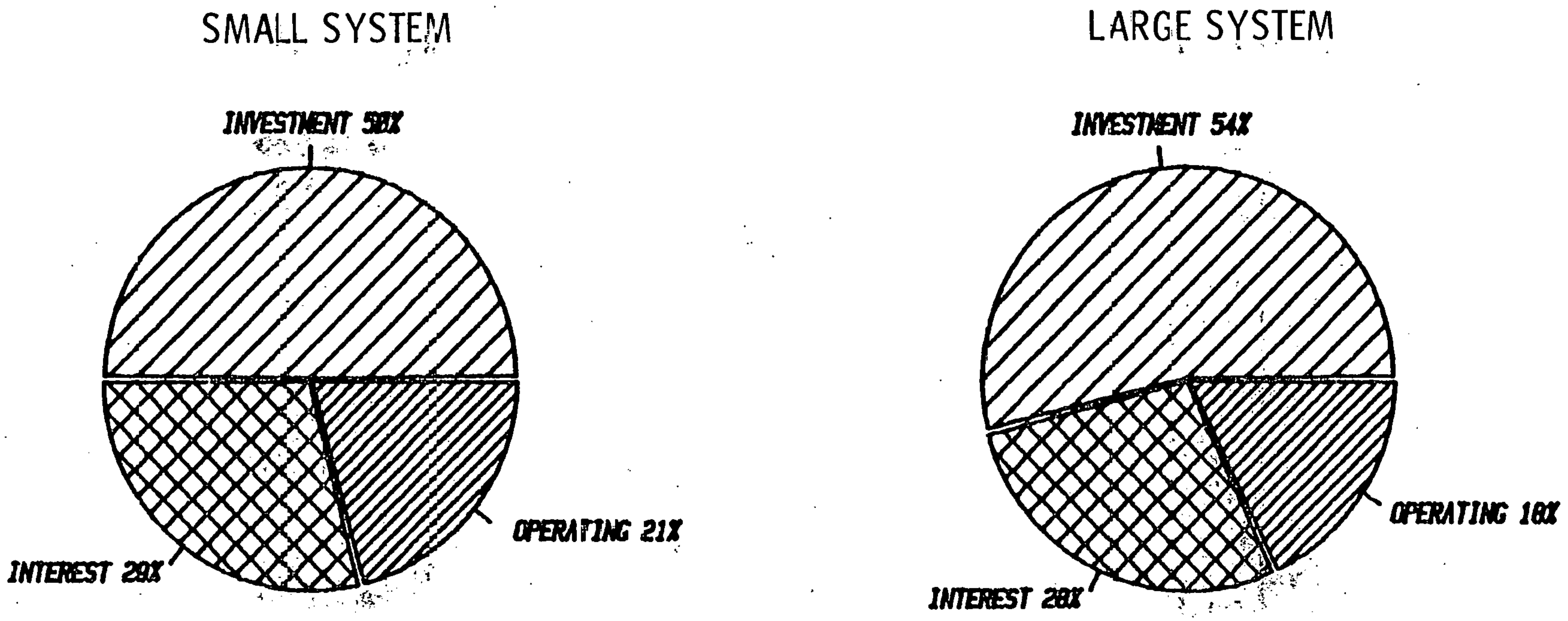

Figure 9. Breakdown of Average Annual Costs for the pile burner systems (5-year payback period).

Net Savings by Pomace Fuel Replacing:

	Natural Gas	#2 Fuel Oil	Disposal Savings
Small System	$29.29/hr	$48.81/hr	$50,000/yr
Large System	87.87/hr	146.43/hr	145,625/yr

With realistic values for the Average Annual Costs of the proposed systems and the potential savings, the Break-Even Analysis was performed.

In evaluating the feasibility of investment in a new technology, it is helpful to have a perspective as to the variables which have significant effects on the cost structure of the systems (Ostwald, 1974). A Sensitivity Analysis was performed on variables which could affect the length of operation on pomace necessary in order to recover the annual costs of the new systems. The loan interest rate was varied from 10 to 20%, fossil fuel costs were doubled, electrical costs were increased by 25, 50 and 100% and the payback period was extended to 10 years. Labor, insurance and tax costs were constant over the payback period.

4. Results and Discussion of Break-Even Analysis

4.1 Recovery of Average Annual Costs

From estimates of the Average Annual Costs (AAC), the number of months of operation on pomace required to break-even were calculated by dividing the AAC by the monthly savings in fossil fuel costs. The systems which indicated a 5 month break-even point or less were considered viable; of course if the processor were to have a process season longer than 5 months, longer break-even periods could be permitted.

For small processors (producing less than 29,030 kg pomace/day) none of the combustion systems would be cost-effective at current fossil fuel prices and 5-year loan payback period (Figure 10). The SF system would break-even for fuel oil substituted by pomace only if the process season were extended to 6.5 months. The SF system would become cost-effective for natural gas substitution when costs of pomace disposal are eliminated (Table 8). The more expensive PB system would become economical after 4.4 months of operation for applications replacing fuel oil at doubled prices and eliminating disposal costs (Figure 11).

Large processors (producing over 88,998 kg pomace/day) substituting fuel oil could currently purchase a SF system (Figure 10), with break-even occurring after 4 months of operation. All three combustion systems would become economical if disposal were necessary and fuel price increases were to occur (Table 8). Inclusion of savings from doubled natural gas prices and disposal costs would allow the FB system to be cost-effective (Figure 12).

Differences in capital investments and operating costs are the primary reason for the fluctuations in the AAC of the three combustion systems. However, each system has advantages and disadvantages. The SF system represents the least-cost

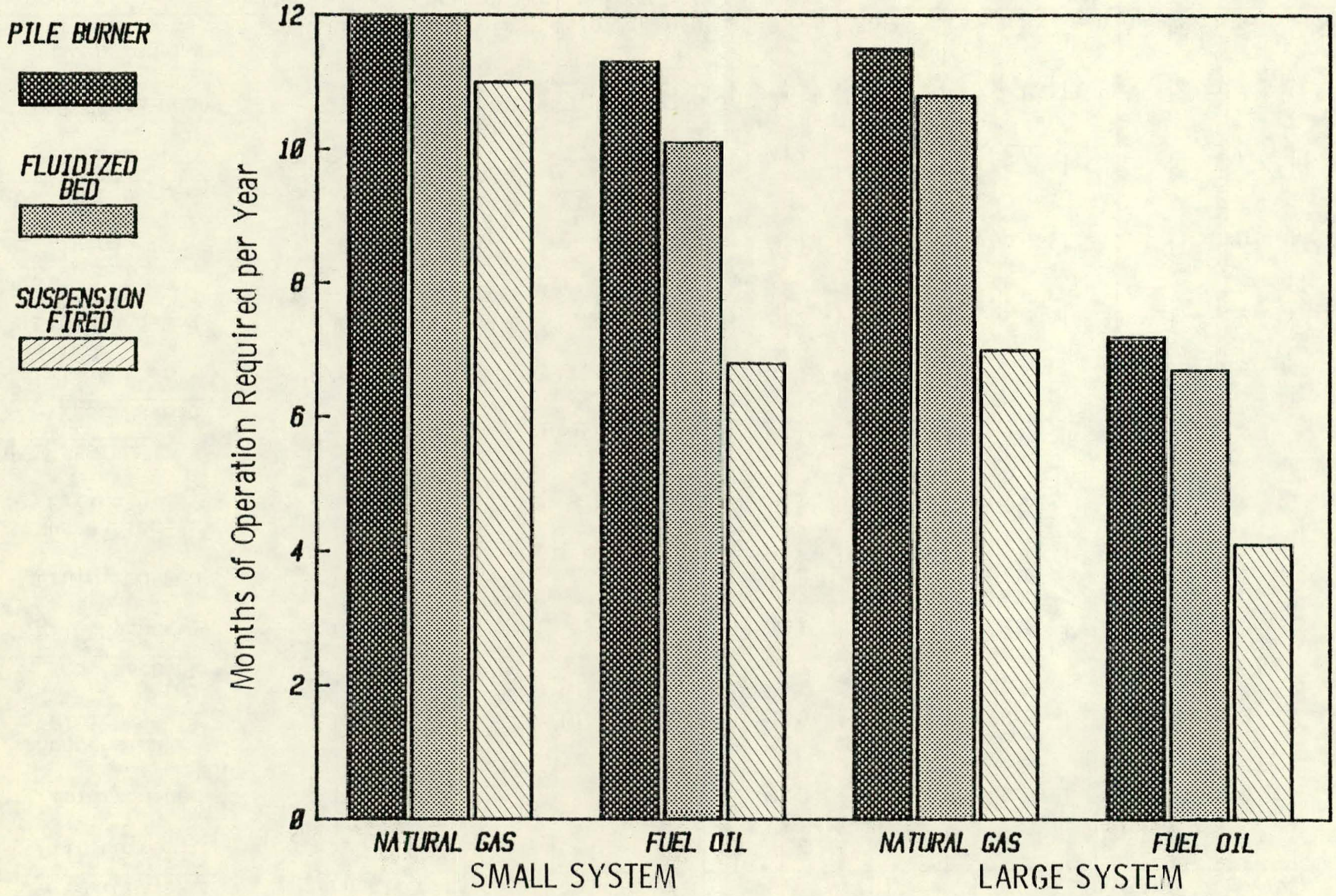

Figure 10. Operation on pomace required for payback of Average Annual Costs for Small and Large systems (16% interest rate).

Table 8. Length of operation on pomace required for payback of annual costs (at 16% interest rate).

		MONTHS OF OPERATION REQUIRED							
		Natural Gas Replaced				Fuel Oil Replaced			
SMALL SYSTEMS									
5 - Year Payback	Annual Cost*	A	B	C	D	A	B	C	D
Pile Burner	220,318	* *	* *	9.4	7.4	11.3	8.8	5.7	4.4
Fluidized-Bed	194,260	* *	* *	8.3	6.3	9.9	7.5	5.0	3.8
Suspension-Firing	127,594	10.9	6.8	5.5	3.4	6.5	4.1	3.3	2.2
10 - Year Payback									
Pile Burner	165,917	* *	10.1	7.1	5.0	8.5	6.0	4.3	3.0
Fluidized-Bed	145,939	* *	8.4	6.3	4.2	7.2	5.0	3.7	2.3
Suspension-Firing	97,303	8.3	4.2	4.1	2.1	5.0	2.5	2.5	1.3
LARGE SYSTEMS									
5 - Year Payback									
Pile Burner	401,782	11.4	7.2	5.7	3.6	6.9	4.4	3.5	2.2
Fluidized-Bed	367,674	10.4	6.3	5.2	3.2	6.3	3.8	3.2	1.9
Suspension-Firing	234,948	6.7	2.5	3.4	1.3	4.0	1.5	2.0	0.8
10 - Year Payback									
Pile Burner	294,451	8.4	4.3	4.2	2.1	5.0	2.5	2.5	1.3
Fluidized-Bed	270,229	7.7	3.5	3.9	1.7	4.6	2.1	2.3	1.1
Suspension-Firing	175,744	5.0	0.9	2.5	0.5	3.0	0.5	1.5	0.3

A-Analysis at current fuel prices.
B-Analysis including disposal costs.
C-Analysis at double fuel prices.
D-Analysis including disposal costs and double fuel prices.
*Annual costs = loan + operating costs
** Infeasible, since more than 1 year payback required for Average Annual Costs.

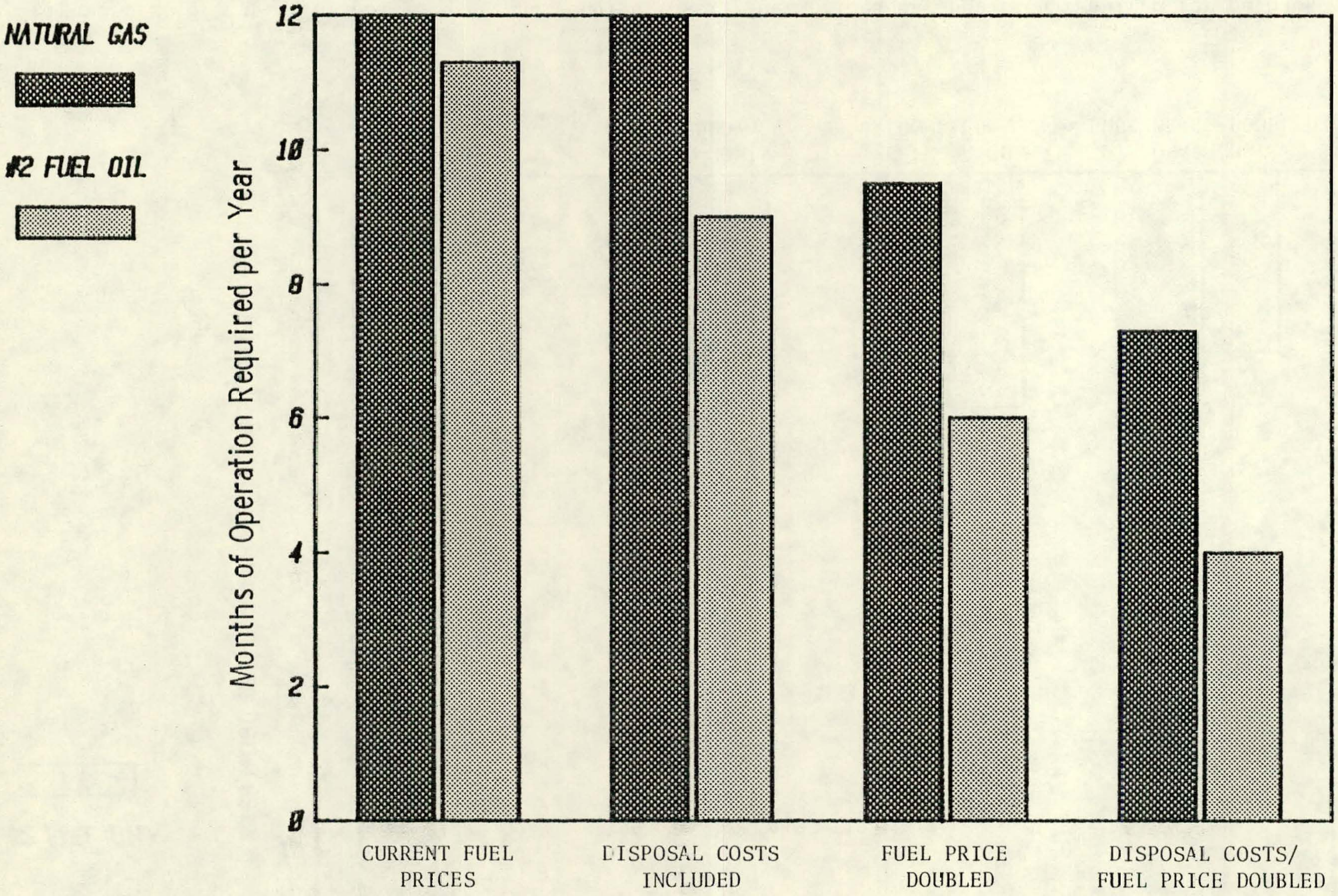

Figure 11. Effect of disposal costs and doubled fossil fuel prices on operation required for payback of Average Annual Costs (for Small Pile Burner System).

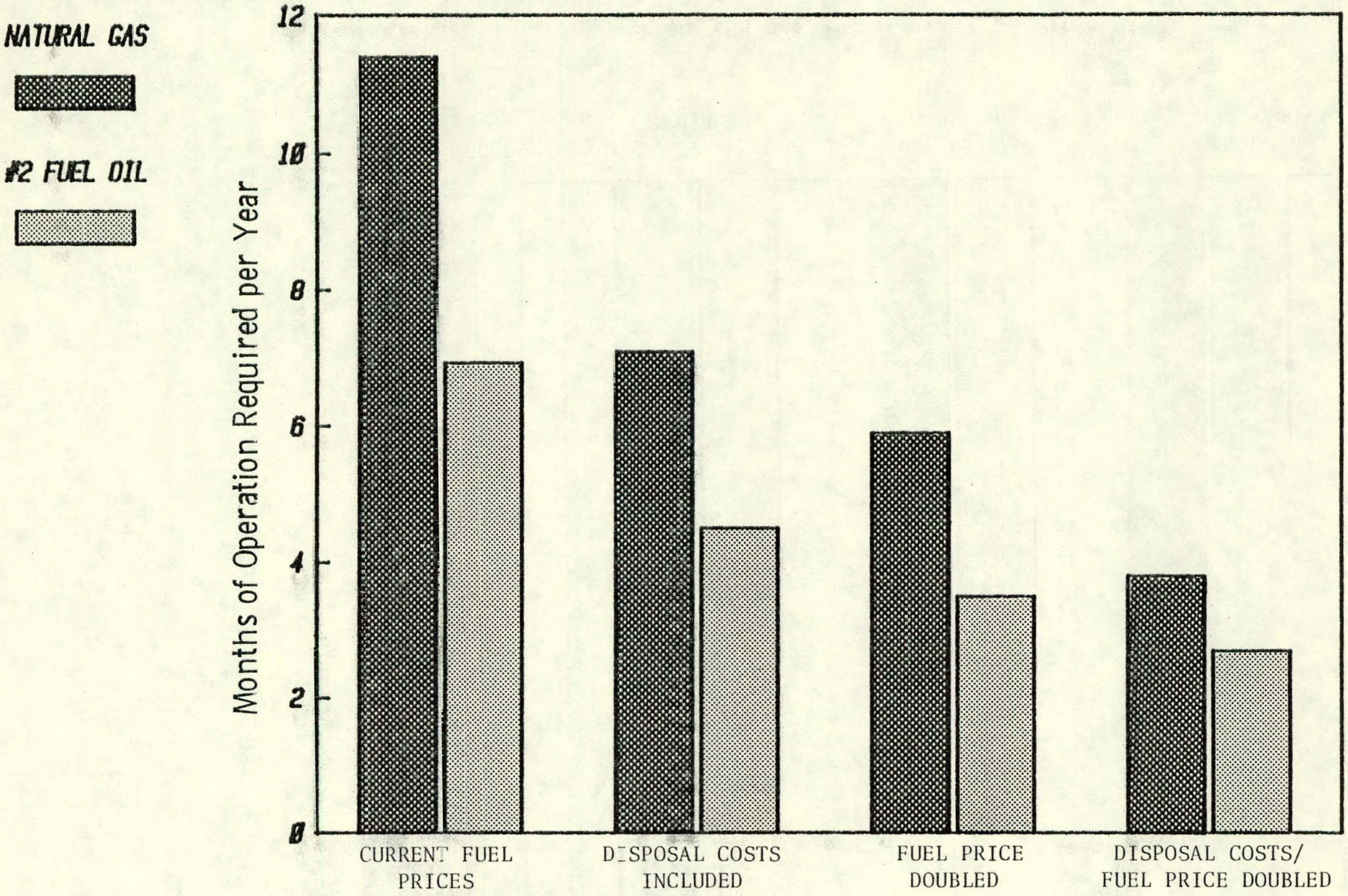

Figure 12. Effect of disposal costs and doubled fossil fuel prices on operation required for payback of Average Annual Costs (for Large Pile Burner System).

alternative for applications permitting a dry (15% MC) and particulate solid fuel. The PB and FBC systems have a higher capital investment, but can burn fuels up to 60% MC. For applications in which pomace could be combusted immediately, storage would not be required. The pomace would require little drying, thus reducing the size (and cost) of the rotary drier and eliminating the need for the storage bin and accompanying handling equipment. Also, the PB and FBC systems can burn non-uniform solid fuels, permitting greater flexibility and possibly eliminating the need for the hammermill, which would further reduce investment costs. These systems (PB and FBC) which require higher capital investments may prove cost-effective at current fossil fuel prices with reductions in investment costs.

4.2 Sensitivity Analysis

Average Annual Costs decreased by 11% when the cost of capital was lowered from 16% to 10%, and increased by 8% when the rate was raised from 16% to 20% (Table 9). However, these changes did not significantly alter the break-even period from that calculated at the 16% interest rate (Table 8). The impact of fluctuating interest rates was tempered by the use of AAC spread over the 5-year payback period. Also annual operating costs, which were not affected by the loan interest rates, accounted for 18 and 21.2% of the AAC (see Figure 9). Therefore, the analysis is only slightly sensitive to interest rate changes in the range of 10-20%. These results are graphically presented in Figure 13. The tabulations for 10 and 20% interest rates on

Table 9. Sensitivity of Average Annual Costs to changes in the loan interest rate (5-year payback period).

	Average Annual Costs			Percent Change in AAC from 16% Interest	
Small Systems	10%	16%	20%	10-16%	16-20%
Pile Burning	$197,338	$220,318	$236,317	-10	+7
Fluidized-Bed	173,843	194,260	208,471	-11	+7
Suspension Fired	114,799	127,594	136,502	-10	+7
Large Systems					
Pile Burning	$356,865	$401,782	$433,052	-11	+7
Fluidized-Bed	326,511	367,674	396,331	-11	+8
Suspension Fired	209,938	234,948	252,359	-11	+7

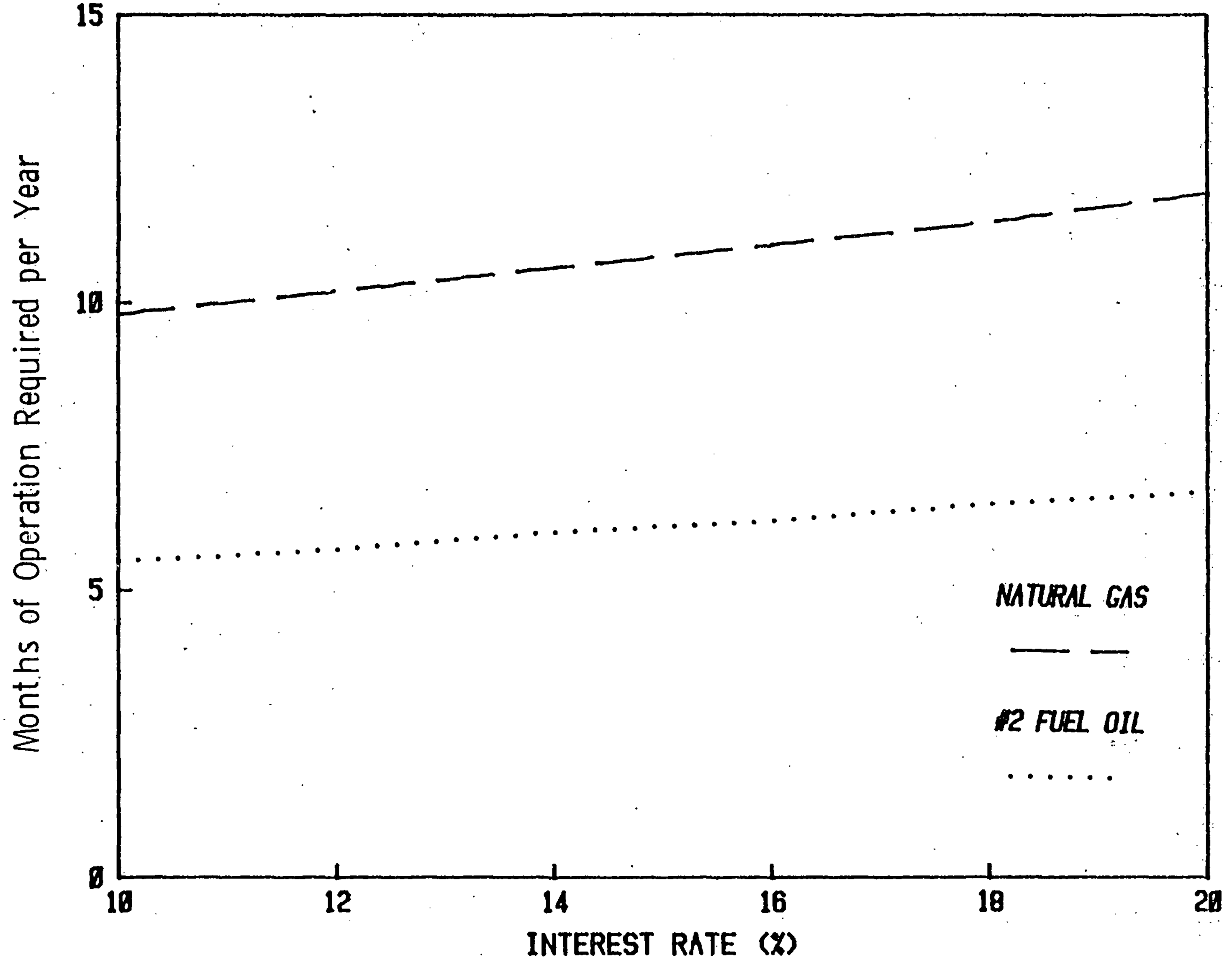

Figure 13. Sensitivity of average annual costs to interest rate changes (Large Pile Burner System).

the break-even period for AAC are contained in Appendices 4 and 5.

Average Annual Costs were calculated after increasing electrical costs by 25, 50 and 100% (Table 10). At 100% increase, AAC rose by a maximum of 16% (for SF). For a 25% increase in utility costs, annual costs increased by only 2-4%. However, increases in utility rates are often based on increased fuel costs to the generating plant. Since the pomace net savings (in $) is based on the value of the fossil fuel it replaces, most likely the savings from pomace will be higher, offsetting the increased utility costs. As with the results from interest rate changes, the analysis would be at most slightly sensitive to changes in utility rates.

Extending the loan payback period to 10 years would reduce the AAC approximately 25%, and permit small processors currently using fuel oil to substitute with pomace using the SF system (Table 8). This is the only difference from the 5-year payback analysis. The SF system would continue to be cost-effective, with annual costs recovered after 4.0 months of operation on pomace. It is doubtful that a firm would consider a 10 year payback period for equipment, especially a small processor.

The analysis is most sensitive to fossil fuel prices and disposal costs, which have direct bearing on the break-even period. Fossil fuel reductions and elimination of pomace disposal costs mean direct savings for the firm. Also a variety of inter-actions are possible between loan interest rates, utility

Table 10. Sensitivity of Average Annual Costs to increases in electrical utility costs of 25, 50 and 100%.

SMALL SYSTEM - (5 - year payback period)

		% Increase in AAC for Increasing Utility Costs		
	AAC*	25	50	100
Pile Burner	220,318	3	6	12
Fluidized-Bed	194,260	3	6	12
Suspension-Firing	127,594	4	8	16
LARGE SYSTEM - (5 - year payback period)				
Pile Burner	401,782	2	4	8
Fluidized-Bed	367,674	2	4	8
Suspension-Firing	234,948	3	6	12

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*ACC = Average Annual Costs, July 1982 prices, 16% Loan interest rate.

costs, payback period and fuel/disposal costs which vary from firm to firm. These interactions might reduce or increase the length of operation on pomace required to recover Average Annual Costs. Therefore the approach used in this analysis must be applied to individual firms in order to best evaluate the potential for pomace utilization.

4.3 Potentials for Improving Cost-Effectiveness

Other means of cost reduction at the plant may play important roles in the economic feasibility of pomace combustion. The availability of other in-plant wastes with fuel value (waste paper, shipping material, used pallets and such processing wastes as cherry and peach pits) would allow a processor to combust for more than 16 hours/day or beyond the 5-month processing season used in this analysis. Local sources of solid fuel might also be available. If a processor could burn solid fuels for 7 months/year, small processors could purchase the SF system substituting fuel oil, while large processors could purchase any of the 3 systems economically (Figure 10).

A processor may also have a lower steam demand than that associated with the pomace producton rates assumed in the analysis. In this case AAC would be lower since a smaller sized boiler could be purchased. By storing excess pomace, combustion could be extended beyond the 5-month process season, reducing fossil fuel costs further. Other potential sources of savings include recovery of waste stack heat to offset fossil fuel costs in pomace drying and recycling of the rice hull press aid by air classification. The latter source would reduce purchase costs of rice hulls and permit pneumatic handling of dry pomace.

5. Conclusions

Given conditions representative of the Michigan apple juice industry, this evaluation has identified the folllowing:

1) Direct combustion is the most efficient means of converting apple pomace for production of process steam and hot water. Package boilers capable of combusting pomace are available to the industry. These boilers employ pile burning, fluidized-bed combustion and suspension-firing technologies, and permit conversion of existing fossil fuel systems to combination biomass/fossil fuel systems.

2) Drying pomace from 65-15% MC is justifiable since a net energy gain is realized from combustion. Drying facilitates handling, permits storage and increases the net heat content. The amount of drying for specific applications is dependent upon the method of combustion used, the period of pomace storage required and the volume of pomace produced.

3) From results of the Break-Even Economic Analysis, a large processor producing 88,998 kg/day (194,000 lb/day) of fresh pomace and requiring 8793 kW (30 million Btu/hr) of power, would be justified in substituting pomace for #2 fuel oil in a suspension fired boiler. Average Annual Costs could be recovered after 4.0 months of operation on

pomace. If fuel oil prices were to double, conversion would become economical for all 3 solid fuel boilers. Substitution of natural gas would become cost-effective only for the suspension-fired boiler with a doubling in natural gas prices.

4) For a small processor producing 29,030 kg/day (64,000 lb/day) of pomace, substitution would become feasible only if fuel prices were to double; for natural gas systems, only suspension-fired boilers would be economical, while for fuel oil systems, all 3 boiler types could be considered.

5) Combustion of pomace reduces disposal volume by approximately 96%. For processors with disposal costs, this translates to direct savings and reduces the break-even period for the Average Annual Costs by 40%. While not currently a major problem, changes in enviromental or disposal regulations could significantly increase disposal costs.

6) The analysis was slightly sensitive to increased electrical costs or fluctuations in the interest rate from 10-20%. Extending the loan payback period from 5 to 10 years would permit a small processor currently burning fuel oil to convert to a suspension-fired system substituted by pomace.

Combustion of fuel sources other than apple pomace would reduce fossil fuel costs further and make the proposed systems more cost-effective for processors. A Special Addendum involving identification of these sources and application to the economic approach, is attached.

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7. Appendices

Appendix 1. Drying and flow rate calculations for pomace.*

a) Amount of Water dried: From 65% to 15% Moisture Content (wet basis):

75% of fresh weight pressed as juice, 25% remains as pomace @ 65% MC. (Kranzler and Davis, 1981).

Dry weight : 1 lb. - .65 lb water = .35 lb dry matter per lb of fresh pomace.

Weight at 15% MC:

$$\frac{x - .35}{x} = .15$$

$$x = .35/.85$$

$$= .4118 \text{ lb or approximately } 41\%$$

For 1 lb pomace, 1.00 - .41 = .59 lb water to be removed or 59% of weight.

b) Heat required to dry, based on a drying efficiency of approximately 60%

$$\frac{1700 \text{ Btu}}{1 \text{ lb water}} = \frac{x}{.59 \text{ lb water}}$$

x = 1003 Btu/lb pomace @ 65% or approximately 1000 Btu/lb.

c) Pomace required at 15% MC/million Btu's generated

$$\frac{1 \text{ million Btu}}{6000 \text{ Btu/lb}} = 166.7 \text{ lbs. pomace}$$

d) Pomace required at 65% MC/million Btu generated

$$\frac{166.7 \text{ lbs.}}{.4118} = 404.8 \text{ lbs.}$$

e) Flow Rates Used in Calculations

1) 10 million Btu/hr generation:
   10 (404.8 lb) = 4048 lb/hr @ 65% MC (64,768 lb/16-hr day)
   10 (166.7 lb) = 1667 lb/hr @ 15% MC

2) 30 million Btu/hr generation:
   30 (404.8 lb) = 12,144 lb/hr @ 65% MC (194,394 lb/16-hr day)
   30 (166.7 lb) = 5001 lb/hr @ 15% MC

---

* All calculations in the Appendix are in English units.

Appendix 2. Net savings realized from pomace combustion.

a) Drying costs/lb. pomace @ 65% MC (Based on July 1982 prices)

Natural gas @ \$4.615/million Btu.

$$\frac{\$4.615}{\text{i mil. Btu}} = \frac{X}{1000\ \text{Btu}}$$

$$X = \$.004615/\text{lb pomace}$$

#2 Fuel oil @ \$8.20/million Btu

$$\frac{\$8.20}{1\ \text{mil. Btu}} = \frac{X}{1000\ \text{Btu}}$$

$$X = \$.0082/\text{lb pomace}$$

b) Drying Costs

Natural gas: (\$.004165/lb pomace) x (404.8 lbs) = \$1.686/million Btu generated.

#2 Fuel oil: (\$.0082/lb pomace) x (404.8 lbs) \$3.319/million Btu generated.

c) Net Savings from Pomace Combustion

Fuel Replaced	Fuel Saving/Mil. Btu		Drying Costs/Mil. Btu		Net Savings
Nat. Gas	\$4.615	-	\$1.686	=	\$2.929/million Btu
#2 Fuel Oil	\$8.20	-	\$3.319	=	\$4.881/million Btu

d) Net Value of Pomace @ 65% MC

Natural gas: $$\frac{\$2.929/\text{million Btu}}{404.8\ \text{lbs/million Btu}} = \$.0072/\text{lb}$$

#2 Fuel Oil: $$\frac{4.881/\text{million Btu}}{404.8\ \text{lbs/million Btu}} = \$.0121/\text{lb}$$

By burning pomace, 64% of the fuel costs can be reduced (36% would be used for drying the pomace from 65-15% MC).

Appendix 2. Power output, required pomace flow rates and net savings over fossil fuels.

Million Btu/hr.*	Pomace Flow Rate (lbs/hr) 15% MC	Pomace Flow Rate (lbs/hr) 65% MC	Net Fuel Savings/hr Operation Nat. Gas	Net Fuel Savings/hr Operation #2 Fuel Oil
**10	1667	4,048	$29.29	$48.81
15	2500	6,071	43.93	73.21
20	3333	8,094	58.58	96.62
25	4167	10,119	73.23	122.03
**30	5000	12,142	87.87	146.43
35	5833	14,165	102.51	170.83
40	6667	16,190	117.16	195.24
45	7500	18,213	131.81	219.60

---

*Based on net heat value for pomace at 15% MC of 6000 Btu/lb.

**Power values used in the analysis.

Appendix 3. Calculation of waste disposal costs.

Pomace volume @ 65% MC = approximately 40 lbs/ft^3 ($1080\ lbs/yd^3$)

BULK CAPACITY (private carrier)

Capacity

18 cubic yd: $1080\ lbs/yd^3 \times 18\ yds^3 = 19{,}440$ lbs or 9.72 tons

40 cu. yd.: $1080\ lbs/yd^3 \times 40\ yds^3 = 43{,}200$ lbs or 21.6 tons

Cost/ton pomace (65% MC)

18 cubic yd: $\dfrac{\$167/day}{9.7\ tons} = \$17.22/ton$

40 cubic yd: $\dfrac{\$233/day}{21.6\ tons} = \$10.79/ton$

To remove 30 tons/day

$1\text{-}18\ yd^3,\ 1\text{-}40\ yd^3 = \dfrac{\$400/day}{31.31\ tons} = \$12.50/ton$

Yearly disposal costs

To remove 32 tons/day: ($1\text{-}18\ yd^3$, $1\text{-}40\ yd^3$)

= ($12.50/ton) (32 tons/day) (125 days/yr.)

= $50,000/yr

To remove 100 tons/day ($5\text{-}40\ yd^3$ containers)

= ($233/day) (5 containers) (125 days)

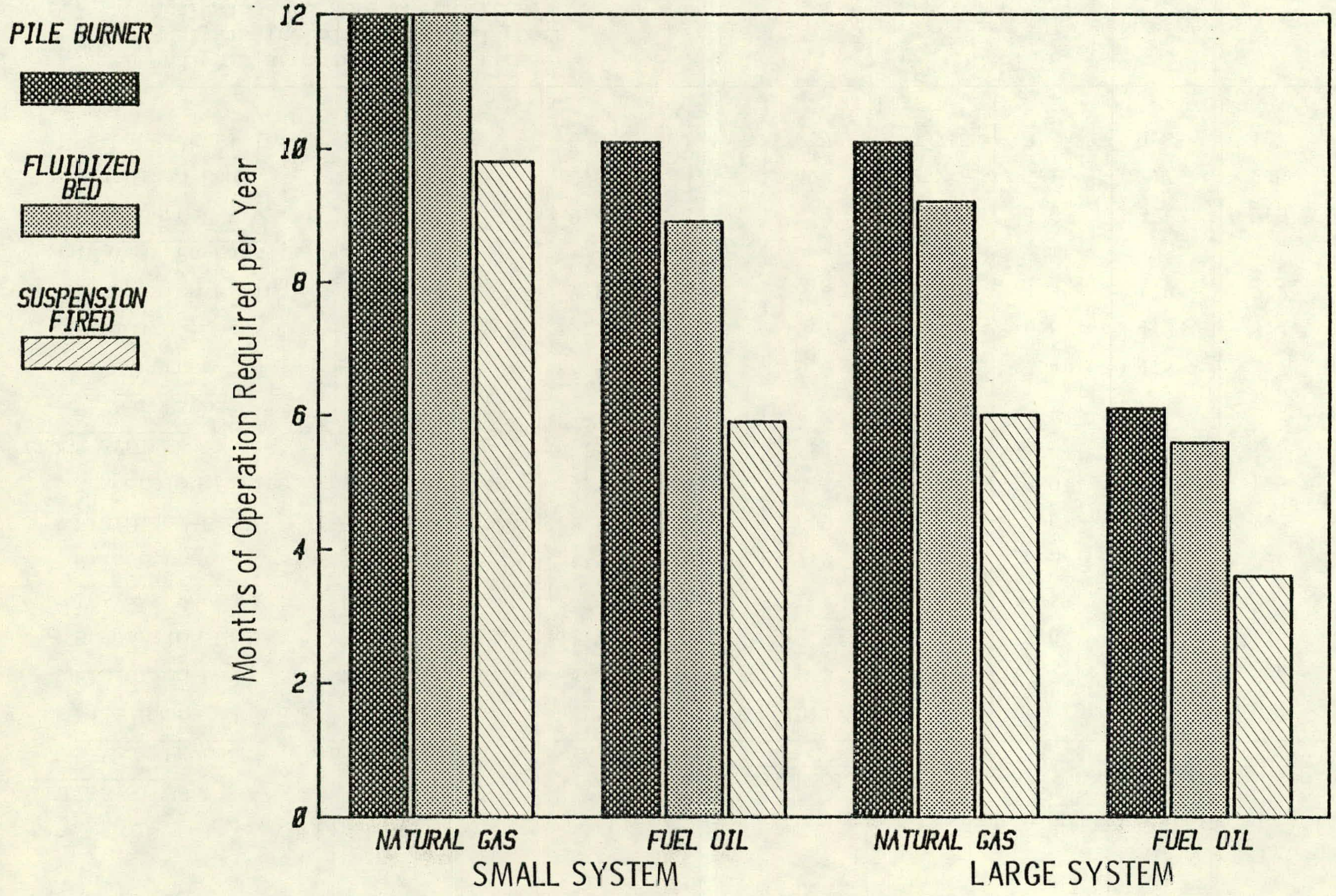
= $145,625/yr

Appendix 4. Sensitivity of Analysis to 10% Loan Interest Rate

Effects of disposal costs and increased fossil fuel costs on length of operation on pomace (per year) required for payback. (10% interest rate)

		MONTHS OF OPERATION REQUIRED							
		Natural Gas Replaced				Fuel Oil Replaced			
SMALL SYSTEMS									
5-Year Payback	Annual Costs*	A	B	C	D	A	B	C	D
Pile Burner	197,338	**	**	8.4	6.35	10.1	7.7	5.0	3.9
Fluidized-Bed	173,848	**	10.7	7.4	5.4	8.9	6.5	4.5	3.3
Suspension Firing	114,799	9.8	5.7	4.9	2.9	5.9	3.4	3.0	1.7
10-Year Payback									
Pile Burner	141,531	12.0	8.0	6.0	4.0	7.2	4.8	3.6	2.4
Fluidized-Bed	124,280	10.6	6.5	5.3	3.25	6.4	3.9	3.2	1.9
Suspension Firing	83,726	7.1	3.1	3.5	1.5	4.3	1.8	2.1	0.9
LARGE SYSTEMS									
5-Year Payback									
Pile Burner	356,365	10.1	6.0	5.1	3.0	6.1	3.6	3.1	1.8
Fluidized-Bed	326,511	9.2	5.1	4.6	2.6	5.6	3.1	2.8	1.6
Suspension Firing	209,938	6.0	1.8	3.0	0.9	3.6	1.1	1.8	0.5
10-Year Payback									
Pile Burner	247,789	7.0	2.9	3.5	1.9	4.2	1.7	2.1	0.9
Fluidized-Bed	226,550	6.4	2.3	3.2	1.1	3.9	1.4	1.9	0.7
Suspension Firing	149,206	4.2	0.1	2.1	0.1	2.5	0.1	1.3	0.1

A-Analysis at current fuel prices.
B-Analysis including disposal costs.
C-Analysis at double fuel prices.
D-Analysis including disposal costs and double fuel prices.
* Annual costs = loan + operating costs
** Infeasible, since more than one year payback required for Average Annual Costs.



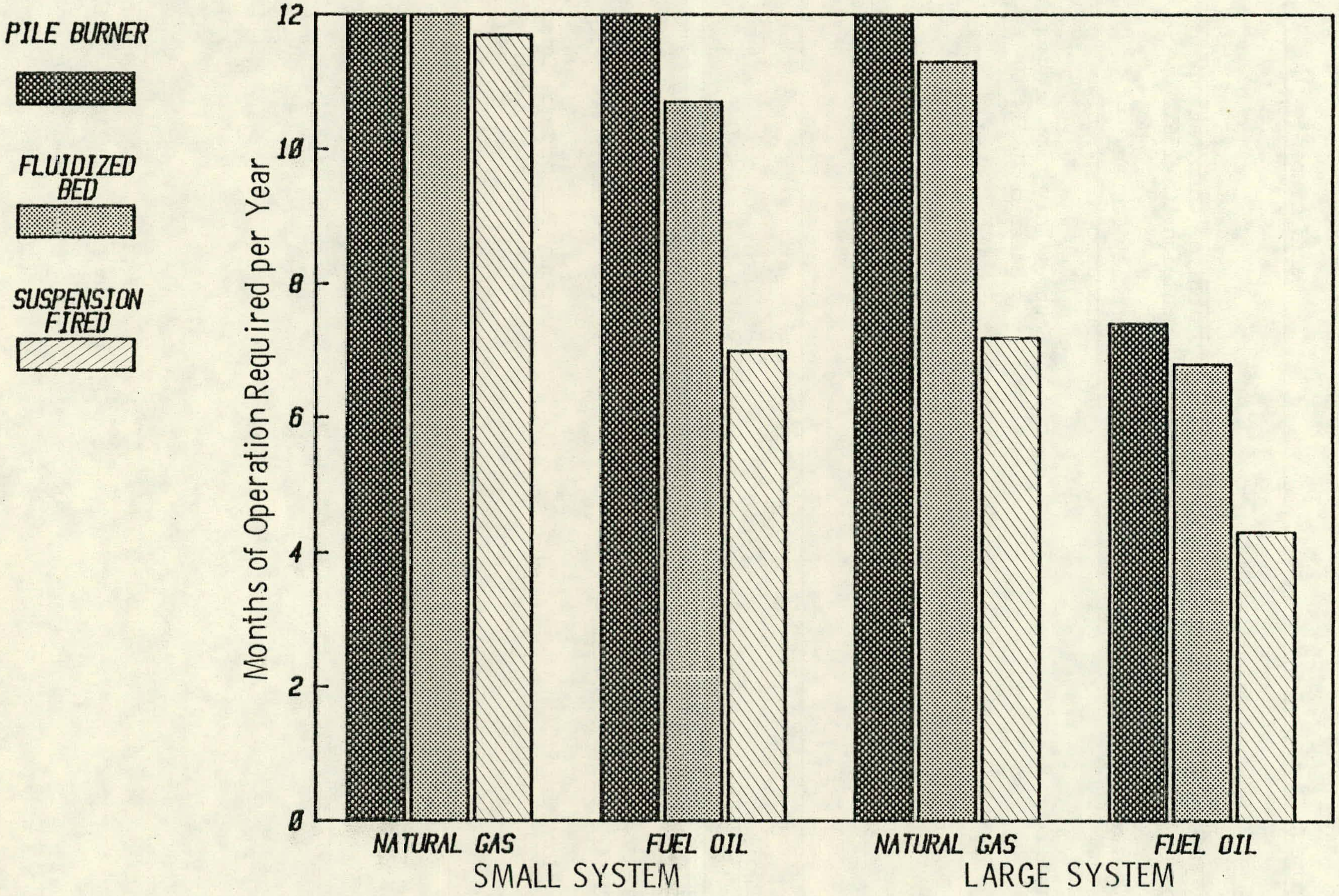
Appendix 4. Operation on pomace required for payback of Average Annual Costs for Small and Large systems (10% interest rate).

Appendix 5. Sensitivity of analysis to 20% loan interest rate

Effects of disposal costs and increased fuel costs on length of operation on pomace (per year) requireed for payback (20% interest rate)

		MONTHS OF OPERATION REQUIRED							
SMALL SYSTEMS		Natural Gas Replaced				Fuel Oil Replaced			
5-Year Payback	Annual Costs[4]	A	B	C	D	A	B	C	D
Pile Burner	236,317	* *	* *	10.1	8.1	* *	9.7	6.1	4.8
Fluidized-Bed	208,471	* *	* *	8.9	6.8	10.7	8.2	5.4	4.1
Suspension Firing	136,502	11.7	7.6	5.8	3.8	7.0	4.5	3.5	2.3
10-Year Payback									
Pile Burner	183,380	* *	11.6	7.9	5.8	5.2	3.9	2.6	1.9
Fluidized-Bed	161,450	* *	9.7	6.9	4.9	4.6	3.2	2.3	1.6
Suspension Firing	107,027	9.1	5.1	4.5	2.5	3.0	1.7	1.5	0.9
LARGE SYSTEMS									
5-Year Payback									
Pile Burner	433,052	* *	8.2	6.2	4.1	7.4	4.9	3.7	2.5
Fluidized-Bed	396,331	11.9	7.1	5.7	3.6	6.8	4.3	3.4	2.2
Suspension Firing	252,359	7.2	3.0	3.6	1.5	4.3	1.8	2.2	0.9
10-Year Payback									
Pile Burner	329,584	9.4	5.2	4.7	2.6	5.6	3.1	2.8	1.5
Fluidized-Bed	301,509	8.6	4.4	4.3	2.2	5.1	2.7	2.5	1.9
Suspension Firing	194,749	5.5	1.4	2.7	0.7	3.3	0.8	1.7	0.4

A-Analysis at current fuel prices.
B-Analysis including disposal costs.
C-Analysis at double fuel prices.
D-Analysis including disposal costs and double fuel prices.
* Annual costs = loan + operating costs.
** Infeasible, since more than one year required for payback of Average Annual Costs.



Appendix 5. Operation on pomace required for payback of Average Annual Costs for Small and Large systems (20% interest rate).

Appendix 6. Equipment and manufacturers of system components used in the anlysis.

Component	Manufacturer
Handling System	
Rotary Drier	Aeroglide Corporation Raleigh NC 27611
Belt Conveyors (high, low MC)	Dunckley Company Kalamazoo MI 49001
Hammermill	Shutte Pulverizer Comapny, Inc. Buffalo NY 14240
Bucket Elevator Screw Auger	Laidig Silo Michiwauka IN 46544
Storage Bin	IMCS, Inc. Zeeland MI 49464
Package Boilers	
Suspension/Pile Burning (Ray Biomass Boiler)	Ray Burner Company San Francisco CA 94112
Fluidized-Bed Combustion (Fluid-Fire Package Boiler)	Johnston Boiler Company Ferrysburg MI 49409
Suspension Firing ROEMMC Burner System)	Guaranty Performance Company, Inc. Independence KS 67301

Appendix 7. Technical and economic feasibility of utilizing apple pomace <u>and supplemental wastes</u> as a boiler feedstock.

SPECIAL ADDENDUM TO U.S. DEPARTMENT OF ENERGY

GRANT NO. DE-FG02-81R510307

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1. Introduction

The use of apple pomace as a supplemental boiler feedstock for processors was shown to be cost-effective only under fairly restrictive conditions. Other solid wastes, besides pomace, are also generated by apple juice processors. These wastes, if feasible for use as boiler feedstocks, could further offset fossil fuel and disposal costs improving the cost effectiveness of biomass combustion systems.

Conversion of industrial solid wastes to useful energy is growing in acceptability. In 1977 it was estimated that approximately 15% of non-wood process wastes were converted into energy equivalent to 94.9 x 10^{12} kJ (90.0 x 10^{12} Btu) (Tillman, 1977). In 1980 a plant in Cheboygan, Michigan began conbusting plastics, cellulose fibers and factory and office trash, generating up to 65 million kJ/hr (28 million Btu/hr) and saving over $350,000/year in fossil fuel costs and over $550,000/year in disposal costs (Reason, 1982).

Municipal solid wastes (MSW) are converted to produce approximately 43.4 x 10^{12} kJ (41.2 x 10^{12} Btu) per year in the U.S. (Tillman, 1977). MSW was estimated to contain 80% organic combustibles (food wastes, paper, plastics, leather, rubber, wood) and 20% inorganic non-combustibles (glass, metal) (Baum and Parker, 1973). Conversion of MSW requires extensive presorting to remove the inorganic residues and has proven cost-effective on a municipal scale basis.

The purpose of this special addendum is to report on the results of a study in which solid wastes were identified and evaluated for use as boiler feedstocks in addition to apple pomace in the apple processing plant. The physical parameters and economic model model from the main body of the current report (henceforth refered to as the Main Report) were employed to measure the effects of incorporating these alternate feedstocks on the break-even period for Average Annual Costs of the three handling/combustion systems considered, i.e., the pile-burner, fluidized bed and suspension-fired systems.

2. Generation of Processing Wastes

2.1 Fruit and Vegetable Wastes

The Office of Solid Waste Management, U.S. Environmental Protection Agency, conducted a national survey of processors of canned, frozen, and dehydrated foods, and arrived at the following conclusions (Hudson, 1978):

1. The food processing industry produces approximately 8,437 million kg (18,600 million lb) of solid residual per year.
2. Of this amount, fruit and vegetable processors generate 93% of the residuals or 7,802 million kg (17,200 million lb). Specialty processors (baby foods, soup, stew, TV dinners, spaghetti) account for 4% or 336 million kg (740 million lb) and seafood processors account for 3% or 254 million kg (560 million lb).
3. For the industry as a whole, 79% of the residuals or 6,622

million kg (14,600 million lb) are utilized as by-products, with the remaining 21% or 1,814 million kg (4,000 million lb) disposed of as waste.

4. About 97% of the residuals utilized as by-products are fed to animals or, 6,441 million kg (14,200 million kg).
5. Of the 1,814 million kg (4,000 million lb) of solid waste, 50% is placed in landfills, 49% is spread on the land and 1% is burned on-site.

The leading processed crops for Michigan are shown in Table 1, in terms of amounts processed in 1981 (Michigan Agricultural Reporting Service, 1982). The MC for fresh fruits and vegetables produced in Michigan can be over 90%, wet basis, while that for pomace ranges from 52% (grape) to over 65% (apple pomace), depending upon the method and efficiency of the press used. Processing residue estimates for each crop were calculated by multiplying the total production amount for each crop by the corresponding waste fraction. The total amount of residues was estimated to have been 3,316.2 million kg (7,310.9 million lbs), fresh weight. This translates to approximately 530.6 million kg (1,169.7 million lbs), dry weight, assuming 16% average dry matter (or 84% MC).

2.2 Other Processing Plant Wastes

Non-food process wastes are generated from shipping, canning, maintenance and office operations. Typical wastes include: 1) packaging materials (paper, wood crates, plastics, glass,

Table 1. Major processed commodities and solid process waste estimates for Michigan, 1981.

COMMODITY			AMOUNT PROCESSED (million kg/ fresh wt.)	MOISTURE CONTENT (%, wet wt)	PROCESS WASTE FRACTION	SOLID PROCESS WASTE ESTIMATE (million kg/fresh wt)
1)	Sugar beet	- root	2,086.5	84[3]	.64[7]	1,335.4
		- top (animal feed)	2,086.5	84	1.00[7]	2,086.5
2)	Potato	- processed & chips	222.3	79	.05	11.1
3)	Apple	- juice	98.0	84	.25[6] (pomace)	24.5
		- canned, frozen	92.5	84	.35	32.4
4)	Tomato		107.0	94	.33	35.3
5)	Pickling cucumber		91.4	96	.05[5]	4.6
6)	Cherry	- tart & sweet	58.5	86	.05[2] (pit)	2.9
7)	Grape	- juice & wine	46.6	77	.12[6] (pomace)	5.6
8)	Snap bean		32.8	89	.07	2.3
9)	Carrot		22.0	89	.33	7.3
10)	Prune, plum		7.8	81	.05[2] (pit)	0.4
11)	Asparagus		5.3	94	.30	1.6
12)	Peach		2.4	89	.08[2] (pit)	0.2
13)	Strawberry		1.8	86	.10	0.2
		TOTALS	4,961.4			3,550.3

---

[1] Michigan Agricultural Reporting Service, 1982; [2] Winton and Winton, 1935;

[3] White and Plaskett, 1981; [4] Ben-Gera and Kramer, 1969; [5] Hudson, 1978;

[6] Kranzler and Davis, 1981; [7] Stewart, 1981

wire, fasteners); 2) assorted solid wastes (office trash, floor sweepings, garbage); and in some cases 3) field residues from cleaning operations or nearby harvest operations.

The type and quantity of wastes available to the individual apple juice processor varies from plant to plant. Therefore, a list of fuel candidates was compiled for firms in the industry.

3. Physical Properties of Processing Plant Wastes

3.1 Compositional and Handling Characteristics

In this analysis the supplemental fuel candidates were assumed to be subjected to the same handling and storage conditions as for apple pomace. They would be shredded and dried, if necessary, to 15% MC and stored prior to combustion.

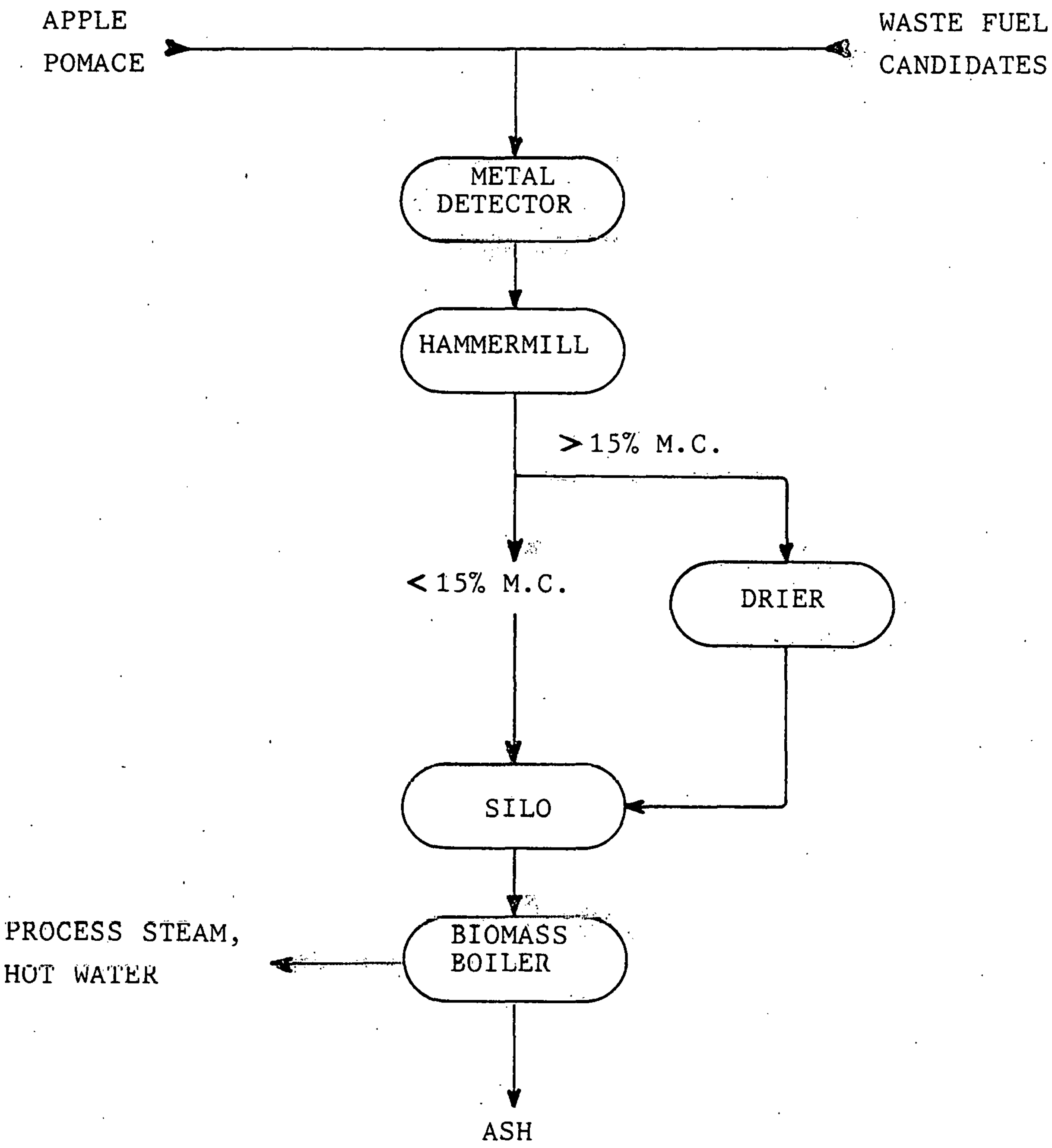
The hammermill would need to be selected according to the size and characteristics of the waste to be shredded. Organic residues from food process operations would have shredding characteristics similar to those of pomace. Pits from plums, peaches and cherries could be sent directly to the drier for pile burning and fluidized-bed combustion systems. For suspension fired systems these would require shredding. Fruit wastes from trimming and peeling operations would be somewhat dewatered due to the chopping action of the hammermill. For these wastes above 80% MC, the energy required for drying is higher than the energy released from the remaining dry matter and therefore not a viable feedstock.

Packaging wastes typically have a moisture content below 15% and as such require no drying. This results in a higher net heat content, since drying energy is eliminated; however, other problems arise. Nails, staples and wire must be removed from pallets, crates and paper boxes in order to avoid excessive wear on the hammermill. Metallic objects can damage pneumatic transfer tubes and even ignite dry biomass from friction created while passing through the hammermill (Kut and Hare, 1981). Removal of metal fasteners would also increase hand labor costs. A metal detector/removal system should be placed in-line prior to shredding to remove any loose objects. Larger packaging pieces would also require size reduction in order to pass through the hammermill inlet opening. Plastics likewise require no drying although temperatures in the feed auger must be maintained below the melting point of the plastics being metered in order to prevent blockage. Figure 1 illustrates the mass flows for the various products.

Drying a mixture of wastes with different initial MC would pose a problem in terms of producing uniform exit MC of 15%, since the retention time would be different for each waste. In order to prevent over-drying of some wastes and a potential fire hazard, it would be desirable to separately dry wastes with different MC. After drying there should be no problem in handling, temporary storage and combustion of the waste mixtures.

Bulk densities for wastes must be known for sizing of conveyor systems. Values for several wastes range from 16.0 kg/m^3

Figure 1. Mass flow scheme for waste fuel candidates.



(1.0 lb/ft^3) for expanded polystyrene to 770.0 kg/m^3 (48.1 lb/ft^3) for oak (Table 2). Those wastes with high initial MC (such as uncompacted vegetable waste) will have significantly lower bulk densities after the drying stage.

3.2 Combustion Considerations

Residue MC is a major factor in combustion efficiency, as detailed in the main report. The higher the MC, the more drying will be required prior to storage and combustion, thus lowering the net heat content of the residue. The approximate net heat content for a fuel per unit mass can be calculated by subtracting the amount of heat necessary to dry the fuel from the heat content of the fuel. A drying efficiency of roughly 50% is commonly assummed for wet agricultural products, or 3954 kJ/kg of water present (1700 Btu/lb).

Process by-products and wastes contain significant energy potential, as shown in Table 3. Most cellulosic residues have heat contents in the range of 13,956-23,260 kJ/kg (6000-10,000 Btu/lb) dry weight, which includes paper and wood packaging wastes, nut shells, fruit pits and field residues. However, plastics, rubber and fats and oils have higher heat contents due to the higher proportion of hydrogen and carbon per unit. The presence of high amounts of oxygen in biomass materials reduces the heat content of the material since the carbon and hydrogen are already partly oxidized (White and Plaskett, 1981).

Combustion of plastics increases heat recovery substantially

Table 2. Bulk densities for selected industrial wastes.

		kg/m^3	lb/ft^3
1)	Folded newspapers, cardboard packed or baled	500	31.2
2)	Loosely crumpled paper	50	3.1
3)	Loose waste paper (in sacks)	20	1.2
4)	Uncompacted vegetable waste, separated food wastes (70-80%)	200	12.5
5)	Cotton gin trash[2]	56	3.5
6)	Oak, 14% MC	770	48.1
7)	Pine, 15% MC	570	35.6
8)	Polystyrene, expanded	16	1.0

---

[1] Kut and Hare, 1981; [2] Beck and Halligan, 1980

Table 3. Combustion characteristics of selected processing wastes and residues.

		Heat Content (dry basis)		Ash
		kJ/kg	Btu/lb	%
A.	Packaging Wastes[1]			
**1)	Corrugated paper boxes	17,280	7,429	5.3
2)	Brown paper	17,924	7,706	1.1
3)	Paper food cartons	17,980	7,730	6.9
4)	Waxed milk cartons	27,289	11,732	1.2
5)	Plastic coated paper	17,917	7,703	2.8
6)	Newspaper (packing)	19,724	8,480	1.5
**7)	Polyethylene, polypropylene	44,194	19,000	0.0
8)	Polystyrene	40,123	17,250	---
9)	Polyamides (nylon)	29,657	12,750	---
10)	Polyesters	27,912	12,000	---
11)	Polyurethane	26,749	11,500	---
12)	Polystyrene foam	42,147	18,120	---
13)	Polyvinyl chloride (PVC)	19,189	8,250	2.1
14)	Vinyl	20,539	8,830	0.0
15)	Softwood (pine)	21,283	9,150	0.1
16)	Hardwood (oak)	20,194	8,682	0.1
B.	Field Residues[2]			
1)	barley straw (spring)	18,000	7,739	5.3
2)	barley straw (winter)	17,800	7,653	6.6
3)	bean straw	18,000	7,739	5.3
4)	oat straw	17,900	7,696	5.7
5)	pea straw	17,900	7,696	7.7
6)	potato haulme	17,300	7,438	13.5
7)	rape straw	18,000	7,739	4.5
8)	rye straw	18,200	7,825	3.0
9)	sugar beet tops	15,400	6,621	21.2
10)	wheat straw	17,600	7,567	7.1
11)	corn stover (35% MC, w.b.)[3]	10,730	4,613	4.0
12)	corn cob (15% MC, w.b.)[3]	18,600	7,997	1.4
13)	cotton gin trash (12.5% MC)[4]	18,775	8,072	---
C.	Nut Shells and Fruit Pits[5]			
1)	almond (soft)	19,445	8,360	3.1
2)	black walnut	18,608	8,000	0.3
3)	chestnut	18,375	7,900	n.a.*
4)	English walnut	18,608	8,000	0.8
5)	filbert	19,306	8,300	0.7
6)	peanut	20,469	8,800	8.8
7)	pecan	20,818	8,950	1.8
8)	apricot	19,817	8,520	0.7
9)	cherry	18,143	7,800	0.8
10)	peach	19,073	8,200	0.4

Table 3. (continued)

		MOISTURE CONTENT (as received, wet basis)	HEAT CONTENT (dry basis)	
D.	Assorted Solid Wastes[1]		kJ/kg	Btu/lb
1)	Paper	10.2	17,612	7,572
2)	Wood	20.0	20,033	8,613
3)	Grass	65.0	17,894	7,693
4)	Brush	40.0	18,375	7,900
5)	Greens	62.0	16,461	7,077
6)	Leaves	50.0	16,505	7,096
7)	Leather	10.0	20,585	8,850
8)	Rubber	8.2	26,353	11,330
9)	Plastics	2.0	33,420	14,368
10)	Oils, paints	0.0	31,168	13,400
11)	Linoleum	2.1	19,329	8,310
12)	Rags	10.0	17,798	7,652
13)	Dirt	3.2	8,815	3,790
**14)	Wet fruit wastes	80.0	19,734	8,484
15)	Fats	0.0	38,844	16,700

---

[1] Baum and Parker, 1973; [2] White and Plaskett, 1981; [3] Claar, et al, 1979; [4] Oursborn, et al, 1978; [5] Mantell, 1975; *not available; ** used in this analysis.

due to higher net heat contents but requires special attention. A typical pile burner boiler cannot efficiently combust more than 10% plastic since sudden flare-ups can occur, disrupting combustion air. Also, interference in under grate air flow can be caused by drippings falling through the grate and igniting, and waste residence time in inclined grate systems can be reduced by the melted plastic causing the pile to slide down the chamber. However through proper combustor design and control of combustion air, up to 90% plastic fuel can be combusted (Kut and Hare, 1981). A problem caused by combustion of PVC (poly-vinyl chloride) plastic is the release of chlorine which combines with hydrogen to form hydrochloric acid (HCl). Severe corrosion occurs in the heat exchanger when HCl condenses on the surfaces. Chlorine is also released from the burning of salt in food processing wastes and paper products. As long as the temperature in the heat exchanger and stack is maintained above the HCl condensation point (150-350°C) corrosion problems will be minimized. The sulfur content is not significant for plastics at 1-2% nor for the cellulosic materials (Baum and Parker, 1973).

The highest ash contents were 21.2 and 13.5% for sugar beet tops and potato haulme, respectively. All other reported values were below that for peanut shells at 8.8%. The most likely fuel candidates for Michigan processing firms are within the range for adequate emission control; values for cherry and peach pits are less than 1% (Table 3).

Ash fusion temperatures must not be reached during combustion in order to prevent slagging. Under normal operating conditions in a biomass boiler, ash from cardboard, paper, textiles and plastics will not reach the minimum fluid temperature of 1205° (2201°F) and therefore will produce little or no slag (Table 4).

Table 4. Ash fusion temperatures for selected process wastes.*

ASH	C	F
Mixed waste	1,205	2,201
Cardboard, textiles	1,227	2,241
Plastics, rubber, leather	1,261	2,302
Coal	1,330	2,426
Apple pomace	1,482	2,700

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*from Kut and Hare, 1981 and Kranzler, et al., 1983.

Combustion of these residues would require the same emission standards as those for waste-fueled combustors listed in Table 4 of the Main Report. Limits for HCl emission have not been set at the federal level; however, the State of Michigan allows a maximum of 0.07 mg/ m^3 when measured at the property line of the plant. These requirements have been easily met by all waste-fuel facilities in Michigan (Tilesz, 1983). Fly ash absorbs some HCl while being carried in the flue gas, and any excess HCl can be satisfactorily removed by water scrubbers (Baum and Parker, 1973).

4. Break-Even Analysis

4.1 Fuel Values for Selected Wastes

From the list of waste fuel candidates (Table 2) three were selected for analysis of economic feasibility: polyethylene, corrugated paper box and wet fruit waste. Criteria for selection of these wastes were the likelihood of availability to the processor and application of a range of wastes from better candidates (polyethylene which requires no drying and has a high heat value) to worst candidates (wet fruit waste at 80%).

The Break-Even Period for payback of Average Annual Costs was determined in the Main Report for each of the three handling/combustion systems. Under the economic constraints defined for those systems the only feasible option was for a large processor to supplement fuel oil with pomace in a suspenson-fired combustor. In this addendum, the amount of wastes were estimated which would be required in addition to apple pomace in order for the Average Annual Costs of the three systems to break-even. These estimates were based upon fuel values for polyethylene, corrugated paper box and fruit waste (in dollars). The wastes could logistically be stored and combusted to meet steam demands during different process seasons. Seasonal wastes, such as fruit pits, would be available as well during these seasons.

The values of the waste materials as feedstocks are dependent upon the savings realized from reductions in fossil fuel usage less the costs of preparing the waste for use as a fuel, e.g. drying. For the three wastes considered in the addendum analysis, fuel values ranged from $0.004/kg ($0.0018/lb) for substitution of natural gas with wet fruit waste to $0.3439/kg ($0.156/lb) for substitution of fuel oil with polyethylene (Table 5). The low values for wet fruit waste reflect the energy costs for drying from 80-15% MC prior to firing. Corrugated paper box has a heat content equivalent to those of apple pomace and wet fruit waste on a dry basis; however, the value for corrugated paper is higher since no drying is required. The differences in values for a waste replacing natural gas or fuel oil is due to the cost of fuel oil being almost twice that of natural gas (see Appendix 2, Main Report). The values of the wastes for use as fuel supplements permit comparison with other values (or costs) of the wastes for different uses, such as animal feed value or disposal costs.

4.2 Required Flow Rates for Break-Even of Average Annual Costs

The contribution of apple pomace toward payment of the Average Annual Costs (AAC) for the combustion systems was limited by the amounts of pomace available to the processor (29,030 kg/day for a small processor and 88,998 kg/day for a large processor). In this Break-Even Analysis the balance of AAC which was not met by pomace combustion was assumed to be met by combustion of either polyethylene, corrugated paper box or wet fruit waste. The amount of additional waste necessary to pay AAC was calculated as follows.

The AAC for each combustion system was converted into an hourly cost figure, based upon a production schedule of 16 hours/day, 25 days/month over a 5 month process season, as

Table 5. Net fuel values for selected solid wastes.*

	Initial Moisture Content (%, w.b.)	Net Value For Fuel Replaced ($/kg)		Relative Value In Comparison to Apple Pomace ($)
		Natural gas	Fuel oil	
Apple pomace	65	0.0159	0.0267	1.00
Corrugated paper box	10	0.0749	0.1345	4.71
Polyethylene	2	0.1940	0.3439	12.20
Fruit waste	80	0.0040	0.0064	0.25

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[*] Net fuel value based on savings in fossil fuel costs (July 1982 prices) less drying costs.

assumed in the Main Report. The contribution of apple pomace (in $/hr fuel value) was substracted from the hourly cost for each system to yield the hourly deficit (Table 6). For example the small pile burner system would incur purchase costs equivalent to $110.16/hr operation over the 5-year payback period. In this case apple pomace would contribute $29.29 when substituting for natural gas, resulting in an hourly deficit of $80.87. The only feasible system was the large suspenson-fired system substituting for fuel oil, which would result in savings of $28.96/hour of operation.

The amount of additional waste fuel required for break-even of the Average Annual Costs was calculated by dividing the hourly deficit for each system by the fuel value of the waste substituted for natural gas or fuel oil. Required flow rates increased when changing from polyethylene to corrugated paper box or wet fruit waste, which reflected the relative fuel values of the wastes (Table 7). An interesting result of this analysis was that the required flow rates of the additional wastes were similar for the two system sizes. AAC of the larger systems increased approximately 85% over the respective smaller systems while required flow rates for wastes replacing natural gas increased only about 40%. For wastes replacing fuel oil, the required flow rates actualy decreased 11 and 23% for the larger PB and FBC systems, respectively.

The fact that required flow rates did not increase proportionally with AAC for the larger systems was due to the contribu-

Table 6. Contribution of apple pomace toward break-even of Average Annual Costs for the combustion systems.

	Average Annual Costs ($)[1]	Hourly Costs ($)[2]	Pomace Contribution[4] Fuel Substituted		Hourly Deficit ($) Fuel Substituted	
			Natural gas	Fuel oil	Natural gas	Fuel oil
A. Small Systems						
1) Pile Burner	220,318	110.16	29.29	48.81	80.87	61.35
2) Fluidized Bed	194,260	97.13	29.29	48.81	67.84	48.32
3) Suspension Fired	127,594	63.80	29.29	48.81	34.51	14.99
B. Large Systems						
1) Pile Burner	401,782	200.89	87.87	146.43	113.02	54.46
2) Fluidized Bed	367,674	183.84	87.87	146.43	95.97	37.41
3) Suspension Fired	234,948	117.47	87.87	146.43	29.60	(-28.96)[3]

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[1] A.A.C. based on 16% loan interest rate for 5-year payback period.

[2] Hourly costs of combustion systems based on 16 hr/day, 25 days/month, 5 month process season.

[3] Net gain/hr operation - only system economical with supplementation of apple pomace.

[4] $/hr.

Table 7. Required flow rates of process wastes in addition to apple pomace for break-even of Average Annual Costs for the combustion systems.*

Required Flow Rates Of Wastes Substituting For Fossil Fuels (kg/hr operation)

	Polyethylene		Corrugated Paper Box		Wet Fruit Waste (fresh weight)	
	Natural gas	Fuel oil	Natural gas	Fuel oil	Natural gas	Fuel oil
A. Small Systems						
1) Pile Burner	417	178	1,080	456	20,217	9,586
2) Fluidized Bed	350	141	906	359	16,960	7,550
3) Suspension Fired	178	43	461	111	8,627	2,342
B. Large Systems						
1) Pile Burner	583	158	1,509	405	28,255	8,509
2) Fluidized Bed	495	109	1,281	278	23,993	5,845
3) Suspension Fired	153	* *	395	* *	7,400	* *

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* Based on 5-year payback period, 16% loan interest rate, July 1982 fuel prices.

* * Combustion of apple pomace is sufficient for break-even of Average Annual Costs.

tion of apple pomace toward payment of the AAC. The flow rate for pomace increased 300% for the larger systems, significantly offsetting the increases in AAC of 85%. Thus the required flow rates for the three wastes were similar for the two system sizes. The slight reductions in required flow rates for replacement of fuel oil reflected the 67% difference in purchase costs for fuel oil and natural gas.

Dry packaging wastes, particularly plastics, have the greatest potential for use as boiler feedstocks supplementing apple pomace. Corrugated paper box and polyethylene had relative fuel values of 471% and 1220%, respectively, that for apple pomace. Fruit wastes with MC below 65%, such as seeds and pits, have potential fuel value roughly equivalent to that of pomace.

Utilization of high MC process wastes requires careful analysis, due to the large amounts of water which must be removed prior to combustion. This analysis assumed wet fruit waste dried from 80-15% MC, which resulted in a net heat content of only 784 kJ/kg (337 Btu/lb). As previously mentioned some dewatering would occur during the shredding operation and further dewatering could be accomplished by use of a vibratory screening conveyor during tranport to the rotary drier. Recovery of waste heat for drying the wastes would also reduce costs. The extent of dewatering by these options was not investigated in this analysis.

5. Conclusions

Supplementing apple pomace with other process wastes for use as a boiler feedstock, was considered for handling/combustion systems employing pile burning, fluidized-bed and suspension firing combustion methods. Technical and economic analyses were performed on polyethylene plastic (PP), corrugated paper box (CPB) and wet fruit waste (WFW) with the following conclusions:

1) The relative fuel values for PP, CPB and WFW (calculated in dollars) were approximately 1220%, 471% and 0.25%, respectively, that for apple pomace. WFW at 80% moisture content or more, is not practical as a feedstock due to excessive drying requirements.

2) Small processors--those producing 29,030 kg apple pomace per day--could economically supplement #2 fuel oil in a suspension-fired system if 43 kg/hr (95 lb/hr) of PP, or 111 kg/hr (25 lb/hr) of CPB were available.

3) Large processors--those producing 88,998 kg apple pomace per day--could economically supplement #2 fuel oil with a fluidized-bed system if 109 kg/hr (240 lb/hr) of PP or 278 kg/hr (613 lb/hr) of CPB were available.

4) Required flow rates for the feedstocks supplementing natural gas were 300-400% higher than for #2 fuel oil systems.

5) Use of packaging material would require special attention in the removal of metals prior to shredding and combustion. State and federal emission standards can be maintained for hydrochloric acid (from combustion of vinyl plastic) and flyash through proper combustion control and scrubbers.

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