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Wood Fuel Use in Papua New Guinea

An Assessment of Industrial Combustion Equipment

The MITRE Corporation

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An Assessment of Industrial Combustion Equipment

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Department of Minerals and Energy
Papua New Guinea

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ABSTRACT

This report presents the results of an engineering and economic assessment of new and retrofit industrial combustion equipment for wood fuel use in Papua New Guinea. Existing industrial combustion equipment and practices in Papua New Guinea is appraised. Potential industrial wood fuel systems that utilize wood, wood wastes, charcoal and pyrolytic oils and which are particularly applicable to Papua New Guinea are identified. An economic assessment of wood fuel systems is conducted for eleven case studies which are representative of a cross-section of Papua New Guinea industry. Conclusions and recommendations are presented to aid both government and industry in Papua New Guinea in fostering the development of appropriate wood fuel technologies and thereby help displace the consumption of imported petroleum.

FOREWORD

This study was performed for the Government of Papua New Guinea (PNG), Department of Minerals and Energy. The study was sponsored by the United States Agency for International Development, Office of Reimbursable Development Programs, and managed by the United States Department of Energy, Pittsburgh Energy Technology Center (PETC).

A two-week mission to Papua New Guinea, in April 1980, was conducted to assess existing industrial combustion equipment and practices in PNG. The mission members included:

Mr. Mathew Mendis - The MITRE Corporation
Mr. Edward Sharp - The MITRE Corporation
Mr. Robert Chronowski - Cleaver-Brooks Division, Aqua-Chem Inc.
Mr. Charles McCann - U.S. Department of Energy, PETC.

While in PNG, both Mr. Larry Weick and Dr. Kenneth Newcombe of the Energy Planning Unit, Department of Minerals and Energy, provided assistance in coordinating and guiding the mission. Their assistance in providing data continued throughout the duration of the study.

Several MITRE staff contributed to various efforts in this study. Most notable are Mr. Alberto Sabadell, Ms. Lisa Kenkeremath, and Ms. Barbara Williams.

The information and views expressed in this report are those of the authors and do not necessarily constitute the views of the U.S. Department of Energy, the U.S. Agency for International Development, or the Government of Papua New Guinea. Use of trade names does not necessarily constitutes endorsement or preference of products or equipment. Estimates of the equipment costs and performance characteristics are based on vendor data and the best judgement of the authors. They are not attributable to a single manufacturer, vendor, or individual with proprietary interests.

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ABBREVIATIONS

BBL	barrels
BTU	British thermal unit
COM	charcoal-oil mixture
d	day
°F	degree Fahrenheit
ha	hectare
HP	horse power
hr	hour
i*	discount rate
K	Kina (= U.S. $1.48; 1980 dollars)
KW	kilowatt
LBG	low-Btu gas
LPG	liquefied petroleum gas
M	men
MM	million
NPV	net present value
ODT	oven dried tonne
PNG	Papua New Guinea
SCF	standard cubic feet
T	tonne
t	toea (100 t = K1; one Kina)

CONVERSION FACTORS

UNITS:

1 BTU = 1,055 joules = 252.0 calories

1 tonne = 2,200 lbs

1 BBL = 42 U.S. gallons = 35 Imperial gallons

1 hectare = 2.471 acres

1 kilometer = 0.6214 miles

FUELS:

	UNITS	MMBTU/UNIT	TONNES/UNIT	MMBTU/TONNE
Residual Oil	BBL	6.29	0.149	42.2
Distillate Oil	BBL	5.28	0.133	39.7
Kerosene	BBL	5.67	0.128	44.3
Wood	ODT	18.70	1.000	18.7
Charcoal	TONNE	27.50	1.000	27.5
Pyrolytic Oil	TONNE	26.40	1.000	26.4

MONEY:

1 Kina = U.S. $1.48

1 Kina = 100 toea

EXECUTIVE SUMMARY

This report presents the results of an engineering and economic assessment of new and retrofit industrial combustion equipment for wood fuel use in Papua New Guinea (PNG). The purpose of the report is to provide information to aid both government and industry in PNG to develop and adopt appropriate wood fuel technologies. Industry presently accounts for 40 percent of the total national energy consumption, of which 75 percent is imported petroleum. The Government of PNG wants to foster use of wood wastes and wood resources to replace much of the petroleum consumption in industry. This report identifies and evaluates new and retrofit technologies, applicable in PNG, that use wood and wood-derived charcoal and pyrolytic oils. Industrial wood fuel technologies potentially applicable in PNG are listed below:

- Pyrolytic oil-petroleum mixture combustion
- Pyrolytic oil combustion
- Lump or crushed charcoal combustion
- Hogged or chipped wood combustion
- Crushed charcoal gasification
- Hogged or chipped wood gasification
- Pulverized charcoal-oil mixture combustion.

These technologies were selected as a result of a match between existing combustion equipment and practices in PNG (see Chapter 2.0) and an assessment of the state-of-the-art and commercial availability of industrial wood fuel use systems.

The primary recommendation of this study is that the use of wood fuels by industry, in many instances, is economically attractive and should be encouraged. Specific recommendations are summarized below.

Recommendations

- Encourage the use of wood, pyrolytic oils, and charcoal as industrial fuels, especially when new industrial combustion equipment is contemplated.

- Encourage the use of wood and pyrolytic oil retrofits for existing, heavily used and well maintained industrial equipment.

- Establish guidelines for standardizing new wood fuel technologies introduced to PNG. This will minimize diversity and thereby reduce spare part supply problems and maintenance problems. Standardization will enhance the manufacture of some components in PNG and permit a wider application of the present short supply of trained technical personnel.

- Develop a financial or tax assistance program to aid small industry in securing the substantial capital investment required to implement wood fuel technologies.

- Provide technical assistance to small operators to help "tune up" existing combustion equipment and thereby help conserve fuel.

- Encourage alternative renewable energy technologies where applicable, such as solar energy for crop drying, fuels from biomass, and wind energy for electricity.

A brief summary of key observations made as a result of an information gathering mission to PNG is presented below.

Observations

- With a few exceptions, industrial combustion equipment in PNG is relatively small in size.
- The majority of industrial petroleum consumption is for steam generation or process air heating.
- The efficiency of most small combustion equipment is much less than optimum.
- There is a shortage of technical trained labor to properly operate and maintain existing combustion equipment.
- There has been a tendency to overdesign equipment capacity.
- There is a major concern, on the part of industry, about future fuel supply reliability and costs.
- The PNG Government is committed to deterring the rapid growth of petroleum use in industry by fostering the use of alternative fuels.

Details of potential technical, institutional and economic barriers to the successful growth of wood fuel use in PNG industry are discussed in Chapter 2.0.

Subsequent to the site visit, an engineering and economic assessment was conducted of the wood fuel technologies applicable in PNG. Eleven case studies, representative of a cross-section of PNG industry fuel systems, were selected. In each case study, new or retrofit alternative fuel systems (generally wood based) were compared against the existing fuel systems (generally petroleum based). The basis for the economic assessment was a comparison, within each case study, of the net present value (NPV) of expenditures for

capital, fuel, operation and maintenance of each system.[1] The NPV was evaluated for discount rates of 11 percent and 20 percent to represent a range of returns on investments for PNG industry. The wood and petroleum fuel prices used in the study are presented below:

FUEL	KINA/TONNE	KINA/10^6 Btu
Residual oil	176	4.17
Distillate oil	310	7.81
Kerosene	332	7.49
Wood logs	25[2]	1.34
Lump charcoal	75	2.73
Pyrolytic oil	85	3.22

Estimates of the capital and operating costs assumed for each fuel system are presented in Chapter 4.0. The main conclusions of the technical and economic analysis, outlined in Chapters 3.0 and 4.0, are listed below.

[1] In the economic analysis, presented in Chapter 4.0, the criteria used is NPV of savings in expeditures of the alternative fuel system when compared against the expenditures of the existing fuel system. This approach permits accounting for the tax implications of each alternative. Thus, the system with the highest NPV of savings in expenditures is the most economical.

[2] Price in Kina per oven dry tonne.

Conclusions

- Wood fuel systems are attractive for industries that have a high use factor. Systems with low use factors do not realize sufficient fuel cost savings to offset the high initial capital investments required.[1]

The following conclusions are based on systems with annual use factors greater than 0.5.

- Alternative wood fuel systems generally have a positive NPV of expenditure savings when used to displace petroleum-fueled systems. The economics of the wood fuel systems are more attractive when displacing distillate fuel (#2 oil) than residual fuel (#6 oil).

- Pyrolytic oil systems, when applicable, are the most economically attractive alternative. This advantage is maintained over a wide range of discount rates.

- For a 250 HP boiler retrofit, the pyrolytic oil option yields the highest NPV. The 70/30 pyrolytic oil-petroleum mixture, the LBG wood gasifier, and the 50/50 charcoal-oil mixture systems all yield a positive but slightly lower NPV. The LBG charcoal gasifier is economical when displacing the higher priced distillate fuel but not economical for displacing residual fuels.

- New automatic stoker wood and charcoal boilers are more attractive economically than either new distillate or residual-fueled boilers. In general, the NPV of wood boilers increases relative to that for charcoal boilers with increasing boiler size and decreasing discount rates.

- The pyrolytic oil retrofit system yields the highest NPV in expenditure savings for an existing distillate-fired hot air furnace. The 70/30 pyrolytic oil-petroleum mixture and LBG wood and charcoal gasifiers also yield positive NPVs.

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[1]Use factor is determined as the percentage of time the system is used.

- Neither automatic nor wood charcoal stoker systems nor LBG gasifiers provide positive economic returns when compared to improving the efficiency of the existing, manually-stoked wood furnace and utilizing it for its remaining service life.

- Both new automatic wood and charcoal package hot air furnaces are more economically attractive than an equivalent new distillate oil furnace.

The following conclusions are based on an assessment of six specific cases in PNG visited by the study team.

- Utilization of charcoal or a charcoal-coal mix for BCL's (Bougainville Copper Limited) proposed power plant expansion is not an economically attractive option. However, the proposed power plant expansion utilizing coal should be encouraged. Coal-based power generation can be used to displace present oil consumption both at the power plant and at other locations on Bougainville Island.

- The use of both pyrolytic oils and fuel conservation measures can provide substantial savings to BCL's ore concentrate operation.

- The potential use of pyrolytic oils in the A.C.I. Glass furnace at Lae should be encouraged, pending positive combustion research and test results.

- Electricification of the Arawa Hospital boilers should be considered.

- Solar crop drying techniques for the tea withering and tobacco curing processes should be investigated in more detail.

General information on wood fuel technologies, manufacturers, vendors and approximate costs are presented in Chapter 3.0 and Appendices A through D. Chapter 3.0 identifies the wood combustion and conversion technologies most appropriate for PNG, and discusses specific aspects of these technologies that are germane to PNG.

Appendix A presents a general survey of wood combustion and conversion equipment manufacturers and a state-of-the-art discussion of wood fuel technologies. Appendix B presents the list of equipment suppliers contacted for purposes of this study. Appendix C presents average prices quoted for typical wood fuel equipment, and Appendix D lists U.S. suppliers and manufacturers of wood fuel preparation, handling and storage systems.

The economic assessment of alternative fuel options was based on the NPV of savings in expenditures when compared to the expenditures of the existing fuel system. A presentation of the basic equations used for the NPV analysis is outlined in Appendix E. A FORTRAN computer program, based on these equations, was developed to facilitate the calculations and sensitivity analysis. The program is presented in Appendix F. Finally, Appendix G presents the PNG itinerary of the mission members.

1.0 INTRODUCTION

1.1 Background

The objective of this study is to evaluate the feasibility of utilizing wood and wood-derived fuels to displace imported petroleum in industrial and commercial combustion equipment in Papua New Guinea (PNG). To accomplish this objective, existing industrial combustion equipment and practices in PNG were appraised during a two-week site visit. A subsequent engineering and economic analysis of wood fuel combustion technologies, appropriate for use in PNG, was performed. The results of observations during the site visit and findings of the subsequent engineering and economic assessment are presented in this report. The report is intended to aid both government and industry in PNG in evaluating those wood fuel technologies most appropriate for PNG.

1.2 Outline of Analysis

An outline of the analysis path used for this study is presented in Figure 1-1. To gain an understanding of current industrial combustion equipment and practices in PNG, the study team spent two weeks visiting over 25 installations throughout PNG. The areas visited are shown on the map in Figure 1-2. The appraisal of existing conditions, practices and concerns of industry relating to fuel use and combustion equipment is discussed in Chapter 2.

Subsequent to the site visits, an engineering and economic assessment of appropriate wood fuel conversion and combustion

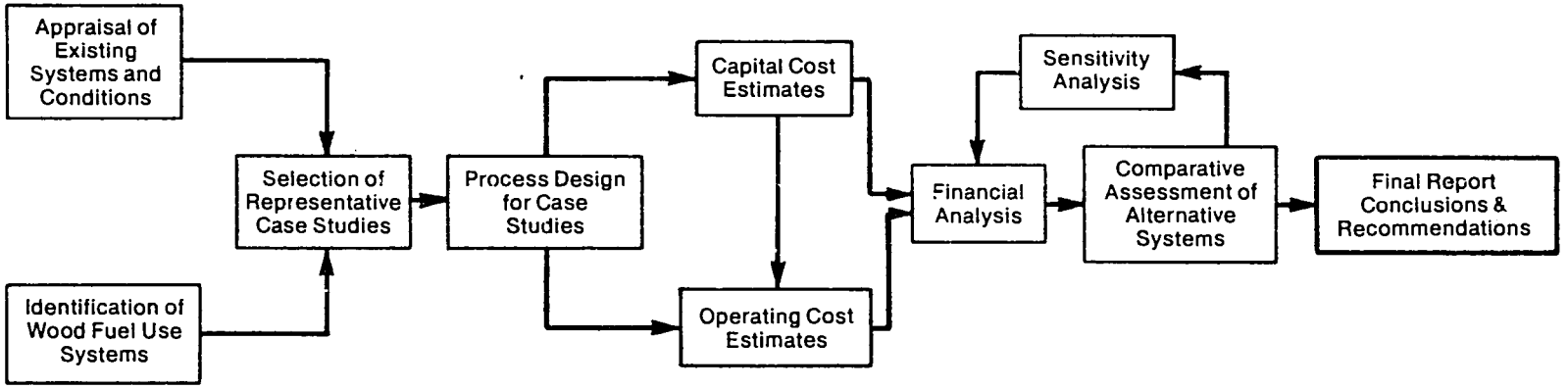
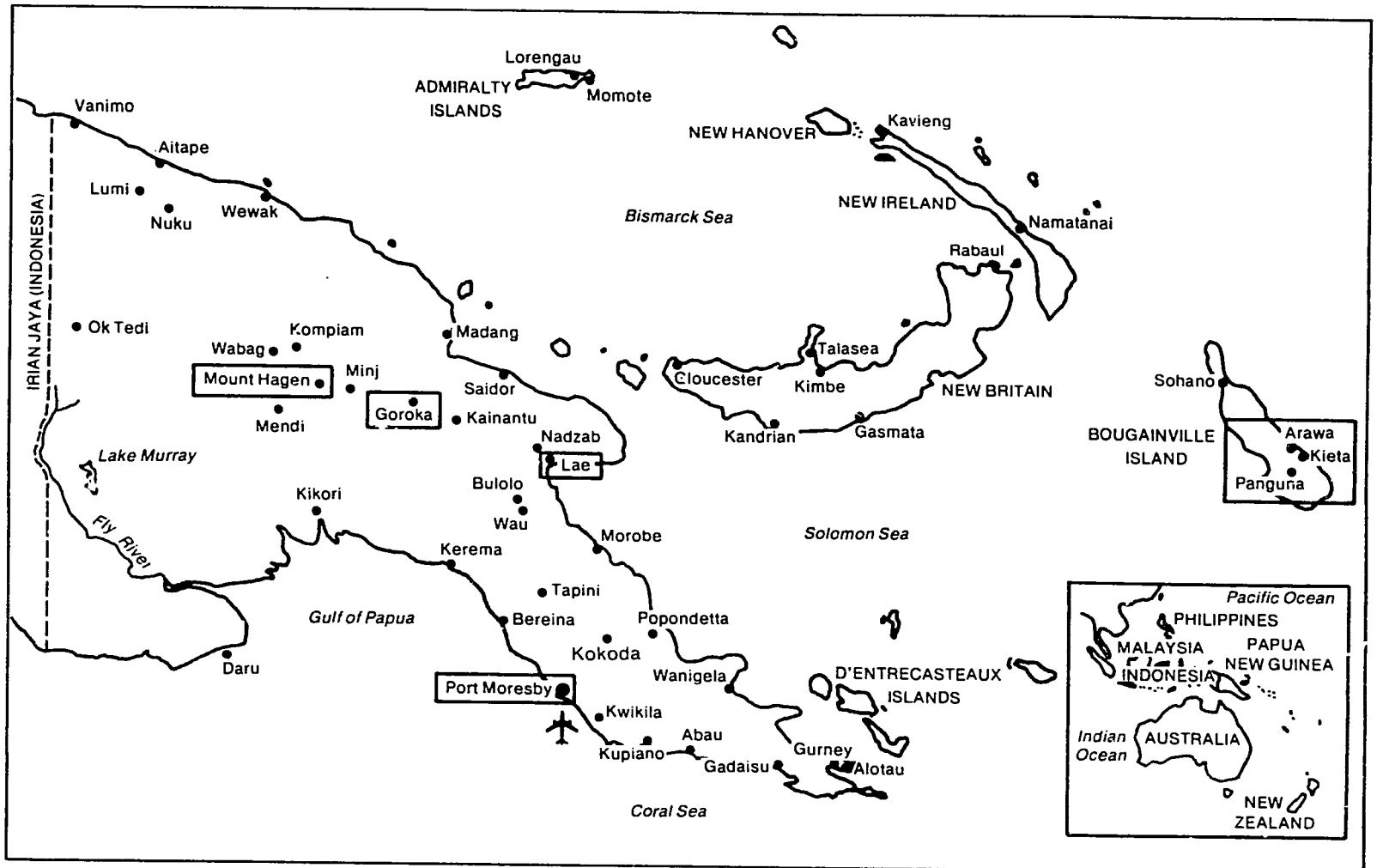


FIGURE 1-1
PROJECT ANALYSIS PATH



areas visited

FIGURE 1-2
MAP OF PNG

technologies was conducted. Current process developers and vendors were contacted and general cost and performance data were obtained. A discussion of industrial wood fuel technologies is presented in Appendix A.

Based on the state-of-the-art wood fuel technologies and the appraisal of industrial equipment and practices in PNG, the following wood fuel technologies were identified as potentially applicable in PNG:

- Pyrolytic oil-petroleum mixture combustion
- Pyrolytic oil combustion
- Lump or crushed charcoal combustion
- Hogged or chipped wood combustion
- Crushed charcoal gasification
- Hogged or chipped wood gasification
- Pulverized charcoal-oil mixture combustion.

A discussion of the technical aspects of these technologies, as they relate to conditions in PNG, is presented in Chapter 3.

A detailed economic assessment was conducted for several generic and specific case studies of wood fuel technologies that are relevant to PNG. The case studies and associated economic assessments are presented in Chapter 4. Equipment cost and operating parameter estimates were derived from discussions with current commercial vendors. A list of the vendors contacted is presented in Appendix B. The average quoted costs for major equipment were determined and

these are listed in Appendix C. A list of the major suppliers and manufacturers of wood fuel preparation, handling, and storage systems is presented in Appendix D.

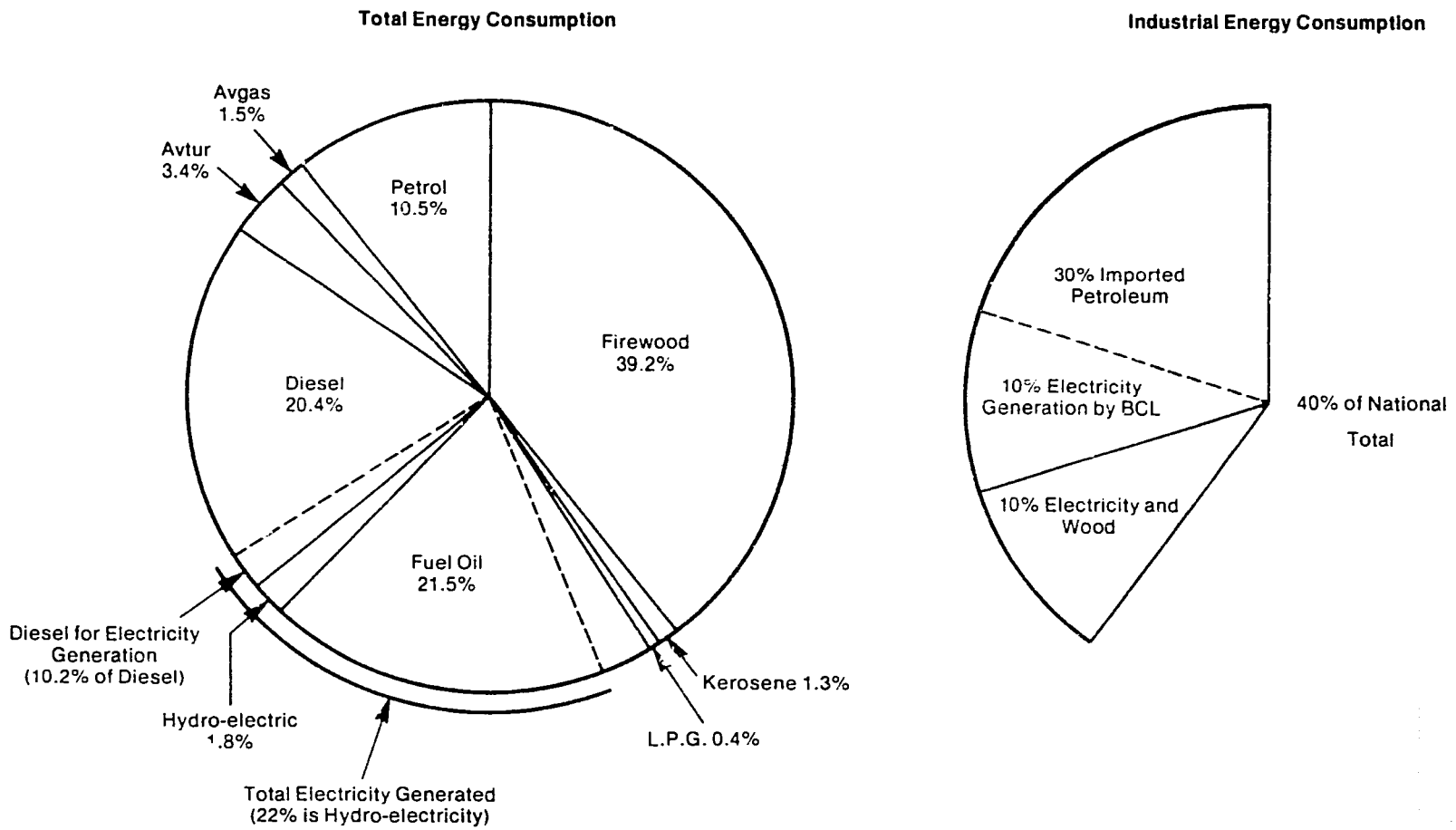
The economic assessment was based on a comparison of the net present value (NPV) of the savings in expenditures of alternate technologies when compared to the existing technology (see Appendix E for NPV equation).[1] Two discount rates were used: 11 percent to reflect those industries which place a high value on fuel supply reliability and, as such, are willing to forego normal target returns; and, 20 percent to reflect a reasonable rate of return for industry in PNG.

Inflation rates between wood fuels, petroleum fuels, labor, utilities and maintenance costs are incorporated in the analysis. Along with the basic economic assessment, an extensive sensitivity analysis was conducted and these results are presented in Chapter 4. A FORTRAN computer program to facilitate the NPV analysis, developed specifically for this project, is included in Appendix F.

1.3 Wood as an Industrial Fuel for Papua New Guinea

Industrial energy consumption in PNG accounted for 40 percent of the total national energy consumption in 1976 (see Figure 1-3). Of this, 75 percent (or 30 percent of the national total) is imported

[1]Savings in expenditures are used instead of gross expenditures in order to account for corporate tax effects.



Source: PNG Department of Minerals and Energy

FIGURE 1-3
THE PNG ENERGY PICTURE: 1976

petroleum, almost all being residual or distillate fuel. Imported petroleum in industry is used mainly for steam generation or process air heating.

Rapidly rising prices of petroleum fuels threaten the growth of industry in PNG. At present, there are no known economic reserves of oil, gas or coal. However, large forest resources are available. With the potential for tree farming, the expected rapid growth of the lumber industry and the increasing availability of wood waste, wood as a fuel resource for industry must be seriously considered.

Approximately 86 percent or 40 million hectares of the land area in PNG is covered by forests.[1] An estimated breakdown of the availability of these resources is presented in Table 1-I. As indicated, present logging operations account for a harvest of 1.2 million cubic meters of timber per year. A large volume of logging waste is generated in the process of harvesting this timber. Estimates of the logging waste range as high as 40 percent of the harvested timber. Although the production of logging wastes is high, availability is limited because the wastes are dispersed in generally remote areas. Use of these wastes requires collection, transportation and processing. The economics of such a proposition must be

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[1]The discussion of wood and wood waste resource in PNG presented here is extracted from References 1, 2, and 3. The discussion is not intended to be comprehensive but is presented to illustrate the abundant availability of wood and wood wastes as a potential resource for industrial fuel.

TABLE 1-I

PAPUA NEW GUINEA FOREST RESOURCES (1976)

	Million Ha	Million m^3
Inaccessible Forest	21.5	
Accessible Forest	19	
Operable Forest	15	1480

EXISTING ANNUAL (1976) RESOURCE USE ($1000m^3$)

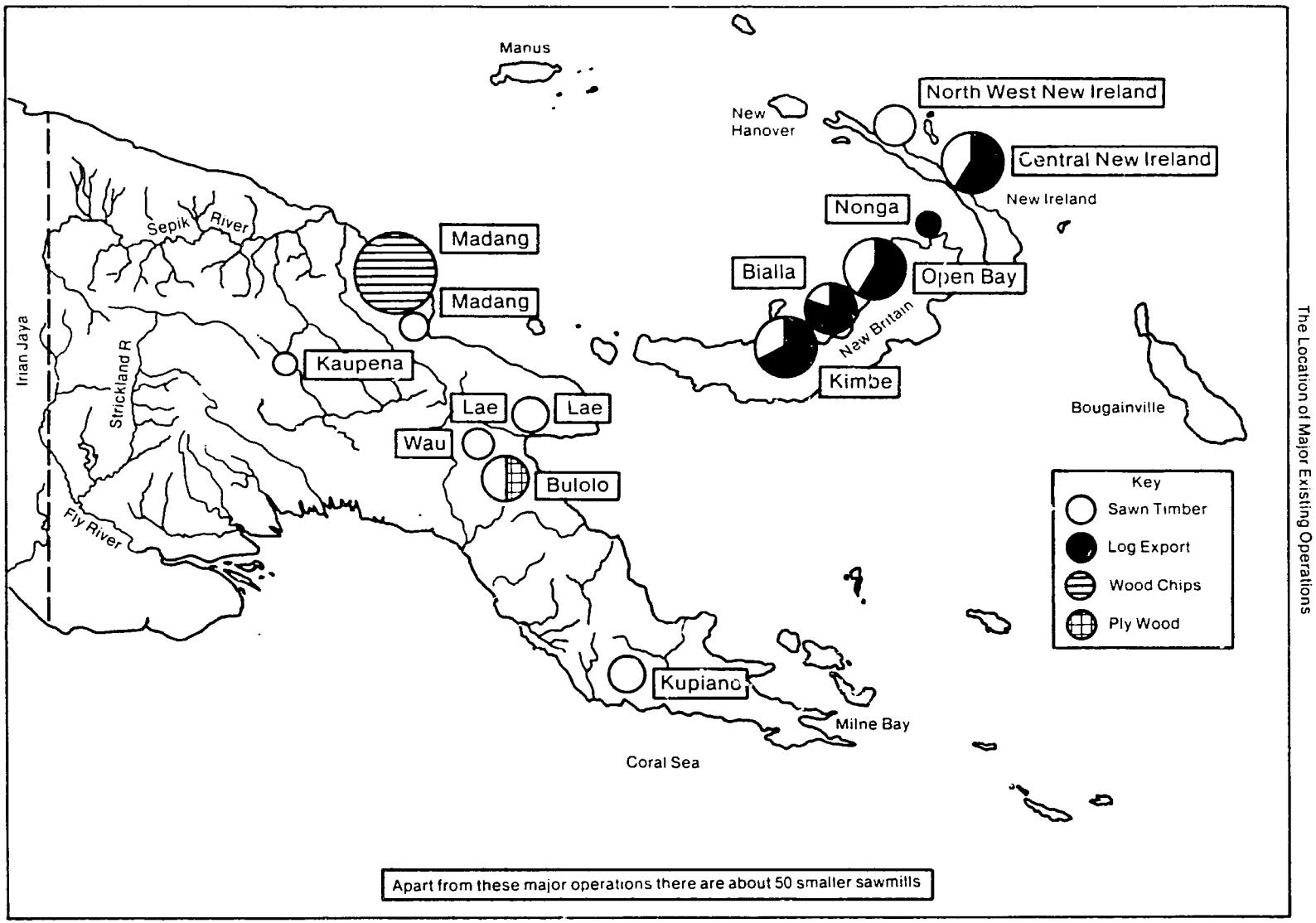
Log Export	520
Sawmill	438
Chipmill	250
Total	1208*

*Note: At this rate, PNG could operate in virgin timber for 1,225 year.

weighed against the costs of other available resources. However, the negative environmental and future land use costs of leaving logging residues in place also must be evaluated.

Alternatively, sawmill residues are presently an economically attractive source of wood waste. Sawmill residues typically include sawdust, shavings, offcuts, bark, veneer cores, pulpwood fines, and condemned timber. Additionally, these wastes are available in a central location, generally near industrial centers and/or navigable water, thus minimizing potential transportation costs (see Figure 1-4).

Present sawmill wastes alone are estimated at over 400,000 m^3/yr. In most cases, the wastes are burned in open burners or discarded, causing serious environmental problems and presenting an economic burden to sawmill operators. In some instances, the wastes are used at the sawmills to fire boilers or to make charcoal. This, however, accounts for only a small fraction of the wastes produced. Assuming that 90 percent of the sawmill wastes are available and assuming a 45 percent moisture content (on a wet basis) and a 65 percent conversion efficiency, the energy equivalent of the wood waste amounts to 425,000 BBL of oil or about 25 percent of PNG's 1976 industrial fuel use. With present estimates of logging residues added to the sawmill wastes, the equivalent energy is more than sufficient to meet total industrial fuel use or approximately 45 percent of PNG's 1976 petroleum imports.



The Location of Major Existing Operations

Source. Timber Trade Mission. Papua New Guinea. Department of Forests. 1979

FIGURE 1-4
EXISTING TIMBER OPERATIONS

2.0 APPRAISAL OF EXISTING INDUSTRIAL COMBUSTION EQUIPMENT IN PAPUA NEW GUINEA

2.1 Major Observations

Several key observations were made as a result of a two-week site visit to PNG. During this period, the study team observed over 25 applications of industrial combustion equipment and interviewed over 40 individuals involved in various aspects of these operations (see Appendix G for study team itinerary). A summary of these observations is presented below.

1) Technical

- With the exception of two industrial consumers, Bouganville Copper Limited and A.C.I. Glass, PNG industries use combustion equipment that is relatively small in size. Boilers range from 30 HP to 300 HP. Hot air furnaces average from 2.0 to 3.0 MMBtu/hr.

- A majority of petroleum consumption by industry is for steam generation or process air heating.

- The efficiency of most small combustion equipment appears to be below optimum. In many cases, fuel consumption could be cut by 15 to 25 percent simply by tuneup of equipment and proper operating and maintenance procedures.

- There is a shortage of necessary equipment, instrumentation, etc., to keep present systems in optimum operating condition.

- A general tendency for greater capacity than required was apparent with respect to industrial boilers. The norm appears to be a mismatch between burner (sized to the load) and boiler (oversized with respect to the load). This has resulted in both operational and maintenance problems plus reduced boiler efficiency.

- A majority of the combustion equipment was manufactured in Australia.

2) Labor

- Trained technical labor required to operate, repair and maintain industrial combustion equipment is in short supply in PNG.

- The reliability of general labor in the use of combustion equipment is a major concern to industry. These concerns were projected in discussions relating to equipment deterioration.

- There currently is no coordinated program to train general labor in the use of equipment. However, several isolated instances of training in specific tasks were observed.

3) Industry

- Industry is concerned about the uncertainty of fuel supply and costs. This concern is presently directed at petroleum fuels but is also displayed with respect to future use of alternative fuels.

- In general, industry indicated a willingness to consider alternative wood fuel systems. Smaller industries were less demonstrative of this commitment than larger industries.

- There is general concern about the lack of an established technical infrastructure to support alternative wood fuel systems. There is need for trained combustion engineers and greater availability of replacement parts and equipment for new and existing systems.

4) Government

- The PNG government is committed to fostering the use of wood fuels by industry. It is projecting this commitment through the establishment of the government-financed Energy Development Corporation (EDC).

- The present tax structure does not provide any major financial incentives for industry to convert to alternative wood fuel systems.

- The government has indicated its intention to end its fuel price equalization policy which has in the past distorted the economics of petroleum use in relatively

inaccessible regions of the country. The elimination of this policy will enhance the use of wood- and wood-derived fuels.

2.2 Description of Existing Equipment

Industrial combustion equipment in PNG varies in size from the 45 MWe wall-fired, watertube boilers at Bouganville Copper Limited's power plant at Anewa Bay to the 30 KW boiler viewed at a bottler in Lae. In general, the majority of boiler equipment ranges between 30 HP (294 KW) and 300 HP (2,940 KW). Boilers in this size range were generally package fire-tube boilers. A dutch oven/locomotive boiler retrofit was observed at South Pacific Timbers in Lae, but such exotic systems are the exception rather than the rule.

The age of most boilers ranged from brand new (the Goodyear re-treading facility at Panguna) to over 15 years old. The condition of the boilers was not necessarily an indication of their age. An illustrative example is the boilers at the Arawa Hospital versus those of the Goroka Base Hospital. The three boilers at Arawa were installed in 1972; two are presently beyond repair and the third has a tenuous service life at best. The three boilers at the Goroka Base Hospital, installed in 1966, presently look like and function as brand new boilers.[1]

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[1]The overwhelming reason for this general exception to boiler equipment of this age in Papua New Guinea must be credited to the Technical Supervisor for Municipal Services in Goroka. His technical skills and strict operating code have resulted in this exception.

Most boilers observed were manufactured in Australia. The most common were:

- Tomlinson-built Cleaver Brooks
- George and George Steam-O-Matic.

Others observed included:

- Murray Maxitherm (Australia)
- Loas-Offenback, Mains (Germany)
- Hardee Bloomer (Australia)
- Cleaver Brooks (United States).

Combustion equipment for process heat varies in size from the 15 MMBtu/hr[1] glass furnace of A.C.I. Glass in Lae to the 250,000 Btu/hr[2] kerosene-fired, pot-type stoves used for curing tobacco. The tea industry in Mt. Hagen presently employs 24 wood and distillate-fired furnaces in the 2.0 to 2.5 MMBtu/hr size range. Combustion equipment used in the coffee industry and copra industry were not observed by the study team.

2.3 Major Equipment Related Concerns

The major concerns of combustion equipment users in PNG can best be summarized as:

- Lack of spare parts
- Lack of trained personnel for maintenance
- Lack of reliable labor to operate equipment.

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[1]Estimate based on fuel consumption data obtained from A.C.I. Glass.

[2]Estimate based on fuel consumption data obtained from Rothmans Tobacco.

In general, the concern for downtime due to delays in spare parts delivery was a key reason for redundancy and overcapacity in design. This, and an insufficient cadre of technically trained personnel, were identified as the reasons for the apparent lack of more complicated multi-fuel burner systems. The future introduction of any alternative combustion equipment must take these factors into consideration.

2.4 Potential for Retrofit

The prime requisites for retrofit of combustion systems to utilize wood and wood-derived fuels are with industries characterized by:

1) Large, well maintained equipment
2) Technical staff to monitor, operate and maintain the new technology
3) An available backup system
4) Sound financial backing.

Currently in PNG, several industries can be identified in this category. Among those observed by the study team that fall in this category were:

- South Pacific Brewery, Lae
- A.C.I. Glass, Lae
- Tea industry in Mt. Hagen
- Bouganville Copper Ltd., Panguna
- Goodyear Tire, Panguna.

The economics of retrofit for these and other candidate combustion systems in PNG are addressed in Chapter 4.

Hospitals, as a generic class of boiler users, are not prime candidates for wood-derived alternative fuels. Their operation and maintenance records show rapid boiler deterioration with age. A notable exception, discussed earlier, was the Goroka Base Hospital which has an outstanding operating and maintenance record and staff. Hospitals, in general, eventually should be converted to less complicated, self-sustaining systems.

Small and old oil-fired combustion equipment should be addressed in the context of replacement rather than retrofit of equipment.

3.0 POTENTIAL INDUSTRIAL WOOD FUEL SYSTEMS FOR PAPUA NEW GUINEA

3.1 Summary

Industrial wood or wood-derived fuel systems potentially applicable in PNG are:

- Pyrolytic oil-petroleum mixture combustion
- Pyrolytic oil combustion
- Lump or crushed charcoal combustion
- Hogged or chipped wood combustion
- Crushed charcoal gasification
- Hogged or chipped wood gasification
- Pulverized charcoal-oil mixture combustion.

These wood fuel systems are germane to PNG industry for three essential reasons:

1) Compatibility with existing industrial combustion equipment presently consuming petroleum.

2) Use of wood resources that can be centrally converted to a fuel (charcoal or pyrolytic oil) which minimizes transportation and storage costs.

3) Use of raw wood or wood wastes by direct combustion or through conversion to a combustible gas.

These systems were identified as a result of a match between existing combustion equipment and practices in PNG (see Chapter 2.0) and an assessment of the state-of-the-art and commercial availability of industrial wood fuel systems (see Appendix A). The processing steps for using wood and wood waste as industrial fuel are shown in Figure 3-1. As indicated, several alternative routes for utilizing

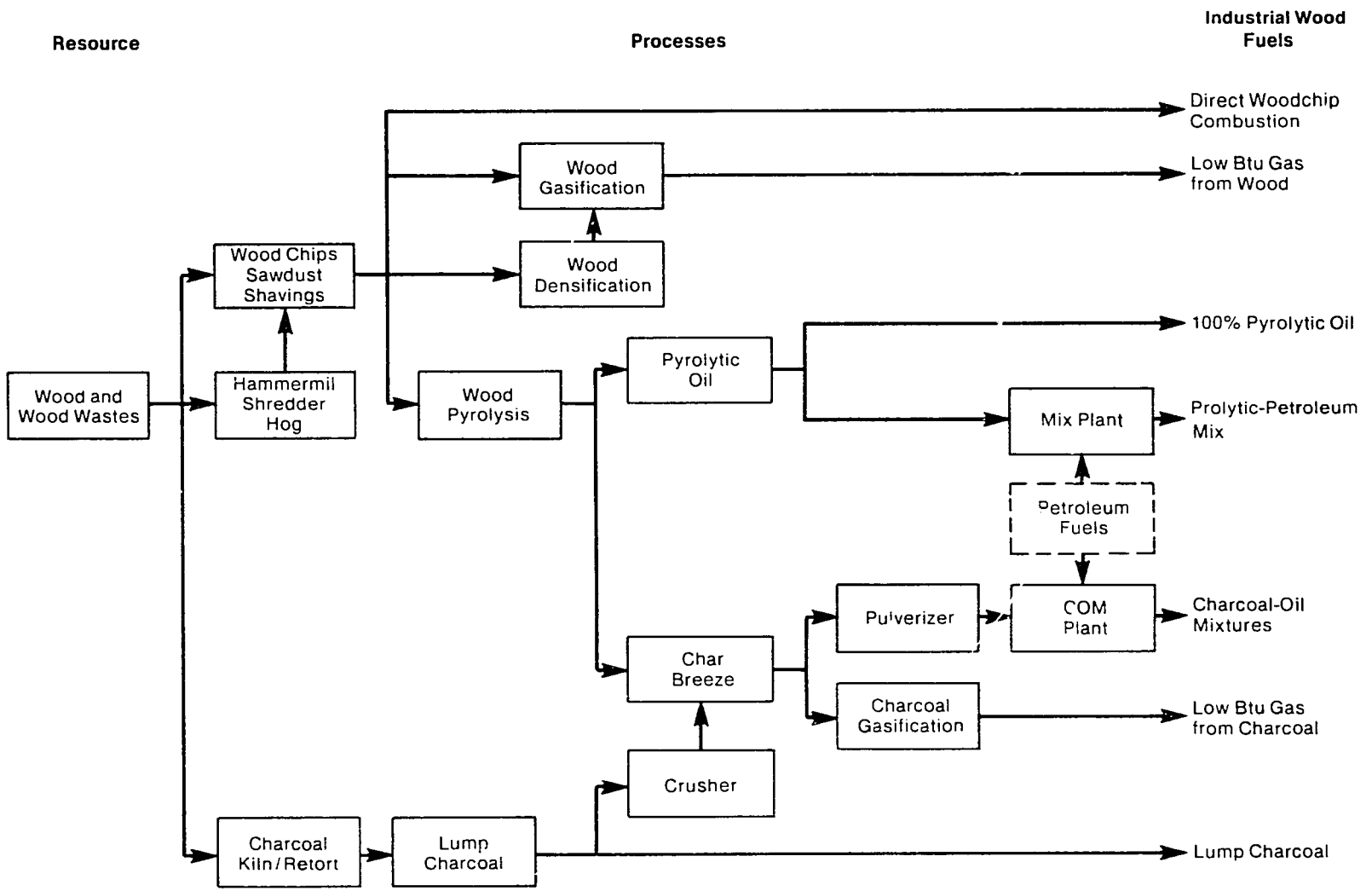

FIGURE 3-1
WOOD CONVERSION TO INDUSTRIAL FUELS

wood as an industrial fuel are available. An assessment of the economics of these alternatives, within the context of retrofit and new applications in Papua New Guinea, is presented in Chapter 4. Recommendations for appropriate wood fuel systems for PNG are based on this assessment.

3.2 State-of-the-Art of Industrial Wood Fuel Technologies

A discussion of the state-of-the-art and lists of the present manufacturers of industrial wood conversion and combustion equipment are presented in Appendix A. The discussion addresses:

- Direct wood and charcoal combustion
- Wood and charcoal low Btu gasification
- Wood pyrolysis
- Charcoal-oil mixture (COM) combustion.

3.3 Definition of Fuel Systems for Papua New Guinea

Wood fuel systems potentially applicable to PNG are briefly discussed below. The discussion highlights the technical and equipment considerations that were incorporated in the economic assessment of these systems.

3.3.1 Pyrolytic Oil-Petroleum Mixture Combustion Systems

Tests indicate that pyrolytic oils can be burned in existing residual oil systems without any major modification to the burner. However, due to the lower heating value of pyrolytic oils when compared to conventional fuel oils, derating of the combustion system may be required. In some cases, more frequent maintenance of burner

nozzles is required due to periodic buildup of gummy material. Mixing pyrolytic oils with residual oils is expected to minimize this problem (References 4 and 5).

The viscosity of pyrolytic oils resembles that of #6 fuel oil. The oils contain water soluble components and may contain from 10 to 25 percent water. The oils are somewhat acidic having a pH of approximately 3.5 (Reference 5). The net result is the requirement of storage and feed systems that are resistant to corrosion. Thus, stainless steel, fiberglass or epoxy-coated tanks are required for storage, and stainless steel pipes and pumps are needed for the fuel delivery system.

Combustion products from pyrolytic oils are not corrosive and contain CO_2 and H_2O. Pyrolytic oils have a major advantage over most residual oils in that they contain essentially no sulfur. Additionally, the presence of a small percentage of water in the pyrolytic oil can actually improve the combustion efficiency of the mixture. Suspended water droplets in the oil explode into steam as the mixture enters the boiler and thus improves the atomization and combustion of the fuel (Reference 5).

Pyrolytic-petroleum oil mixtures either can be mixed at a central location prior to delivery or can be fed by separate feed systems to the burner. The advantage of a central mix system is that only one feed system (pipes, pumps, and tanks) is required at the boiler. However, because of the different specific gravities and

immiscibility of pyrolytic and residual oil, the mixture will tend to separate. Chemical additives and stirring can help minimize separation. However, for purposes of this analysis, a separate feed system was selected (see Figure 3-2). Two advantages are inherent in this system. First, for retrofit or for new systems, the corrosion resistant tanks and pumps required will be of a lower capacity than if a single tank system is used. Second, the ratio of pyrolytic to residual oil can be controlled by the users according to the characteristics of their combustion system and their inventory of pyrolytic and petroleum fuels. A pyrolytic oil feed system is presented schematically in Figure 3.3.

3.3.2 Wood and Charcoal Direct Combustion Systems

There are several commercially available wood and charcoal direct combustion systems (see Appendix A). The Wellons Cyclo-Blast Boiler System burns logs, wood chips, or wood residues on water-cooled grates with a carefully controlled air flow. Waste heat is recovered from the stack gases by a heat exchanger. The Coen suspension burner can be used to retrofit existing oil- and gas-fired boilers so that wood fines can be burned directly. Wood suspension burners also can be designed to fire fine wood material in combination with oil or gas, thus adding to their versatility. The fluidized-bed boiler uses a design in which combustion occurs in the presence of a mass of mineral particles which are kept in turbulent motion. This design increases the heat-transfer rate, provides

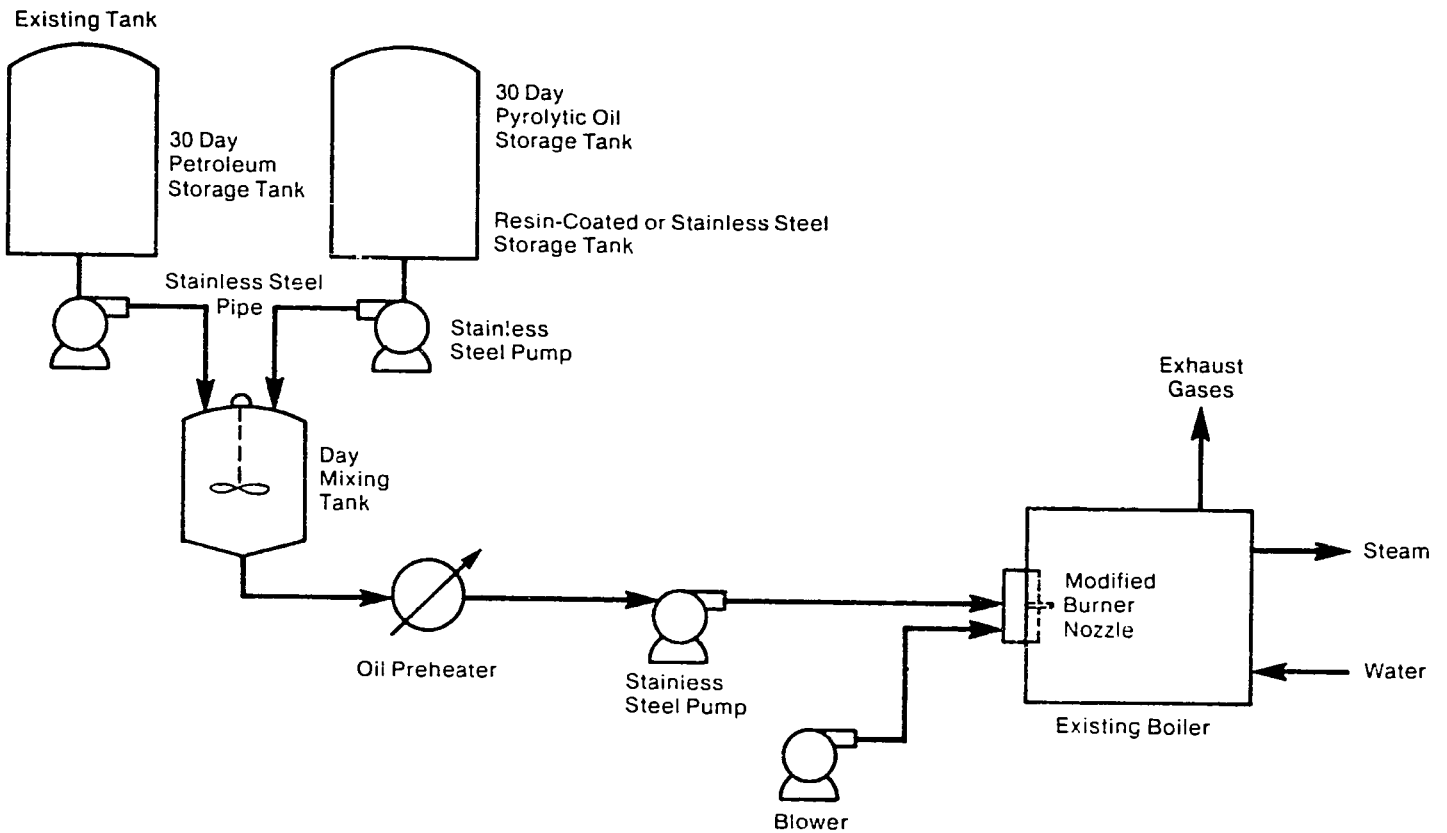

FIGURE 3-2
PYROLYTIC OIL-PETROLEUM MIXTURE FEED SYSTEM

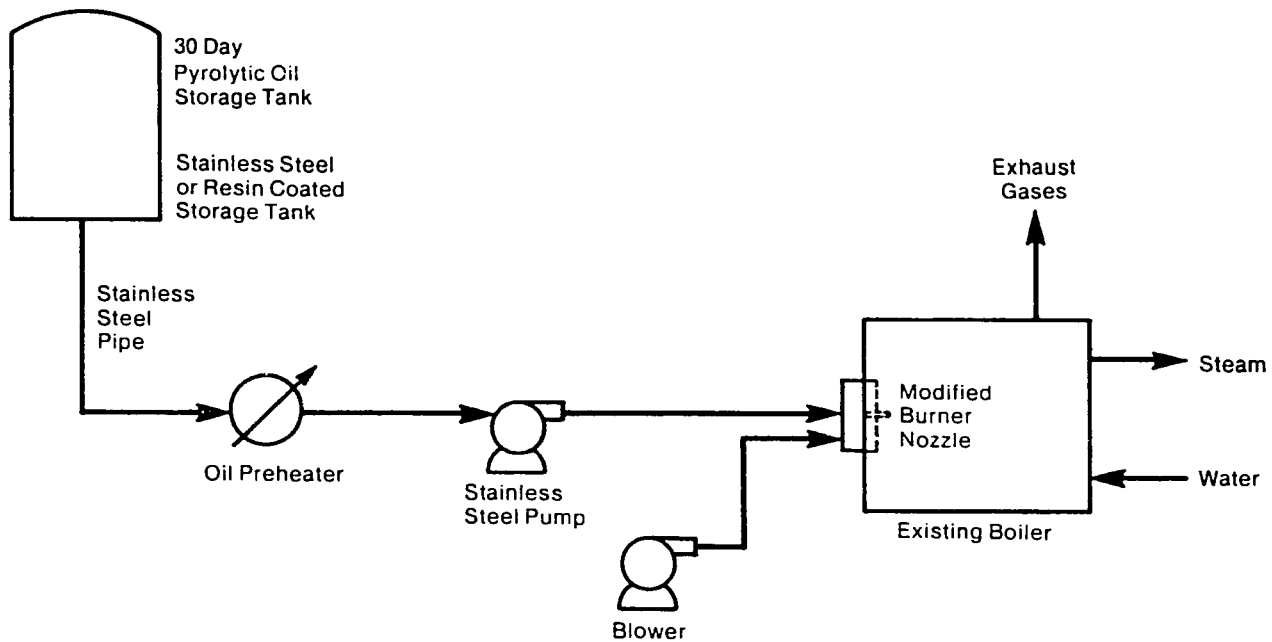

FIGURE 3-3
PYROLYTIC OIL SYSTEM

multifuel capability, and enables high combustion efficiency at low combustion temperatures. Commercial and industrial wood and charcoal-fueled boiler systems can be designed with varying degrees of automation. The spreader-stoker type is a completely automated system designed to achieve continuous or intermittent disposal of unburned residue.

Figure 3-4 shows a retrofit wood waste conversion system using a suspension burner. Costs for suspension burners and automatic stoker systems vary according to capacity and the amount of fuel preparation required. For example, suspension burners require dry, fine fuel. If wood logs are used, they must be hammermilled and dried to the required specification of the burner. If planer shavings or sawdust is used, fuel preparation requirements will be reduced significantly.

There are three types of stokers: underfeed, crossfeed and overfeed (i.e., spreader-stoker) which differ mainly in the relative directions of the flows of fuel and air. Of these three types of stokers, spreader-stokers are now the most widely used because they can burn all types of solid feedstocks, respond rapidly to load changes and operate efficiently with comparatively low excess air. Figure 3-5 shows an automatic stoker-fired combustion system. In spreader-stoker firing, wood feed is delivered to the stoker at a controlled rate. The wood is propelled by the stoker into the furnace where some of it burns in suspension and the rest lands and burns on a grate. The relative position of the grate with respect to the stoker determines the amount of feed predrying, the percentage of

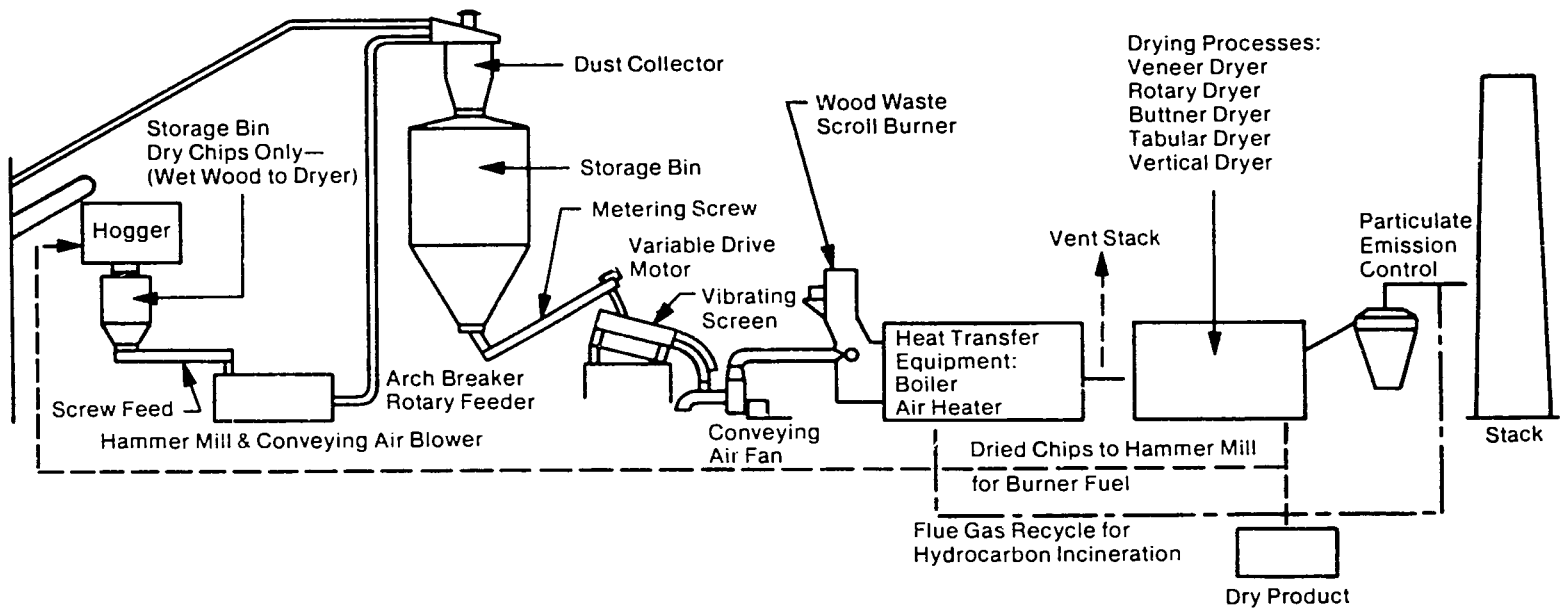

FIGURE 3-4
WOOD WASTE CONVERSION SYSTEM USING SUSPENSION BURNER

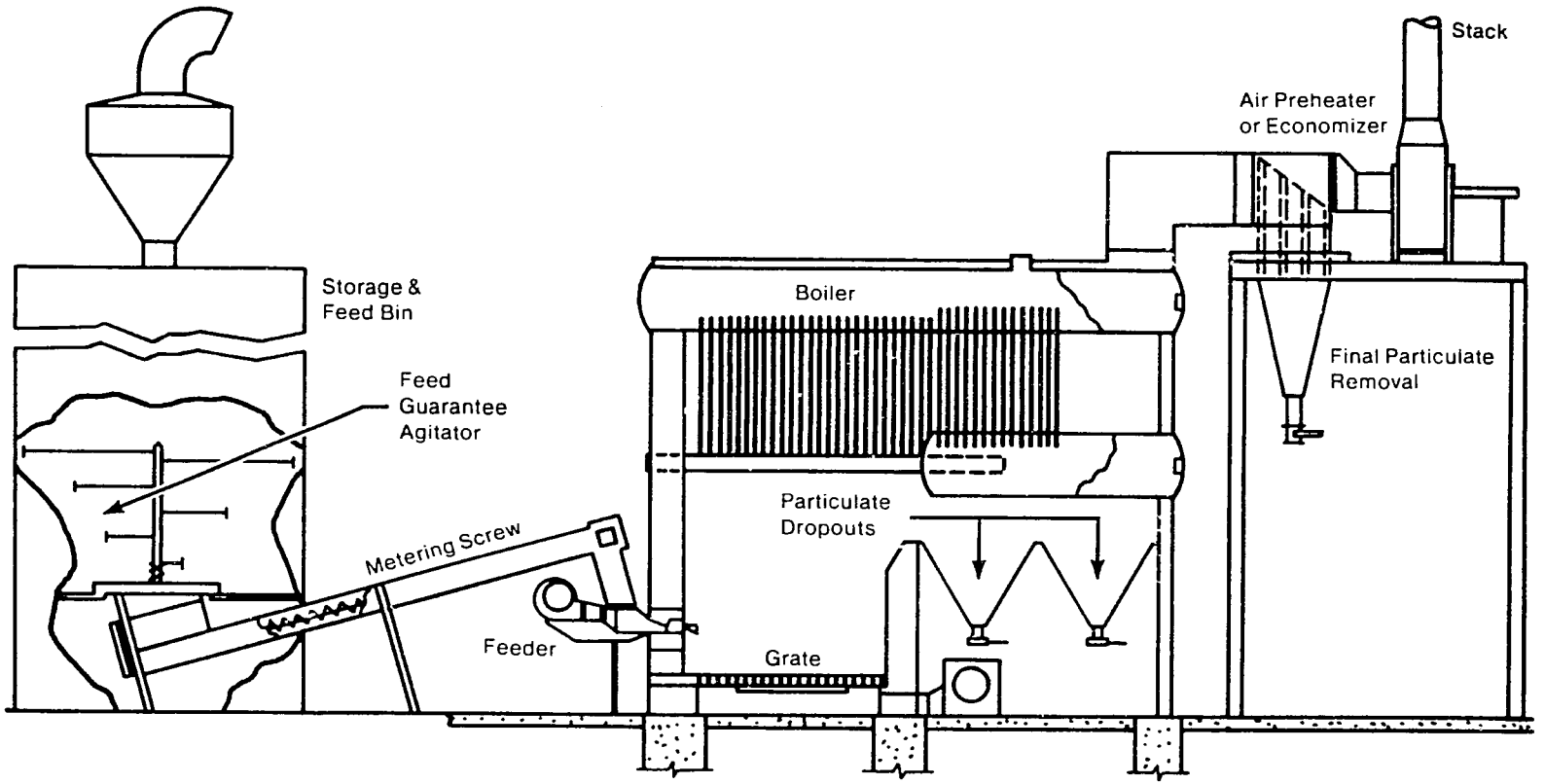

FIGURE 3-5
AUTOMATIC STOKER DIRECT COMBUSTION SOLID FUEL BOILER

wood burned in suspension, and the extent of carryover of fly ash and char out of the furnace.

Manufacturers of wood-fired equipment are listed in Appendix A. Suppliers and manufacturers of wood fuel preparation, handling and storage systems are listed in Appendix D.

Boiler derating, due to combustion volume limitations, is a major disadvantage of retrofitting existing oil- and gas-fired boilers with wood-fired systems. For firetube boilers, suspension burners are the only reasonable system for retrofit.[1] The complexity of suspension burner systems, which require a dry, fine feed, makes their use for the small boilers (less than 300 HP) both expensive and unattractive. Thus, for the analysis in Chapter 4, retrofit of direct wood combustion systems for boilers is not considered. However, new wood and charcoal package boilers and hot air furnaces are evaluated as well as retrofit spreader stokers for existing manually stoked wood and charcoal furnaces.

3.3.3 Wood and Charcoal Gasification

Gasification of wood and wood residues using air and steam as the gasifying medium to produce a low-Btu (100 to 200 Btu/scf) gas is a technology which has been commercially available since the turn of the century.

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[1]Spreader stoker systems can be retrofitted to large oil and gas boilers but with many more modifications to the boiler front than with the suspension burner system.

The gasification process converts a solid carbonaceous feed to a gaseous fuel. The gaseous fuel can be burned directly or upgraded to higher quality fuels or used as a feedstock for manufacturing chemicals such as ammonia or methanol. However, the gas produced from an air and steam blown gasifier contains large amounts of nitrogen (more than 40 percent by volume), and it is primarily suitable for onsite combustion.

Wood and charcoal gasifiers are well suited for retrofit to oil or gas fired combustion systems. Such retrofit gasifiers result in a smaller derating of boilers than do direct combustion systems and generally are less expensive than wood combustion systems (Reference 6).

Gasifiers classified by their reactor type are:

- Fixed bed
- Stirred moving bed
- Fluidized bed
- Entrained flow.

Of these configurations, only fixed-bed gasifiers have been commercially used for wood gasification. The most common design is an updraught fixed-bed reactor. A list of developers and the status of gasifiers is presented in Appendix A.

Figure 3-6 presents a diagram for a low-Btu gasifier-boiler retrofit system. The main cost components for the gasifier retrofit are the fuel storage, handling and preparation components, and the

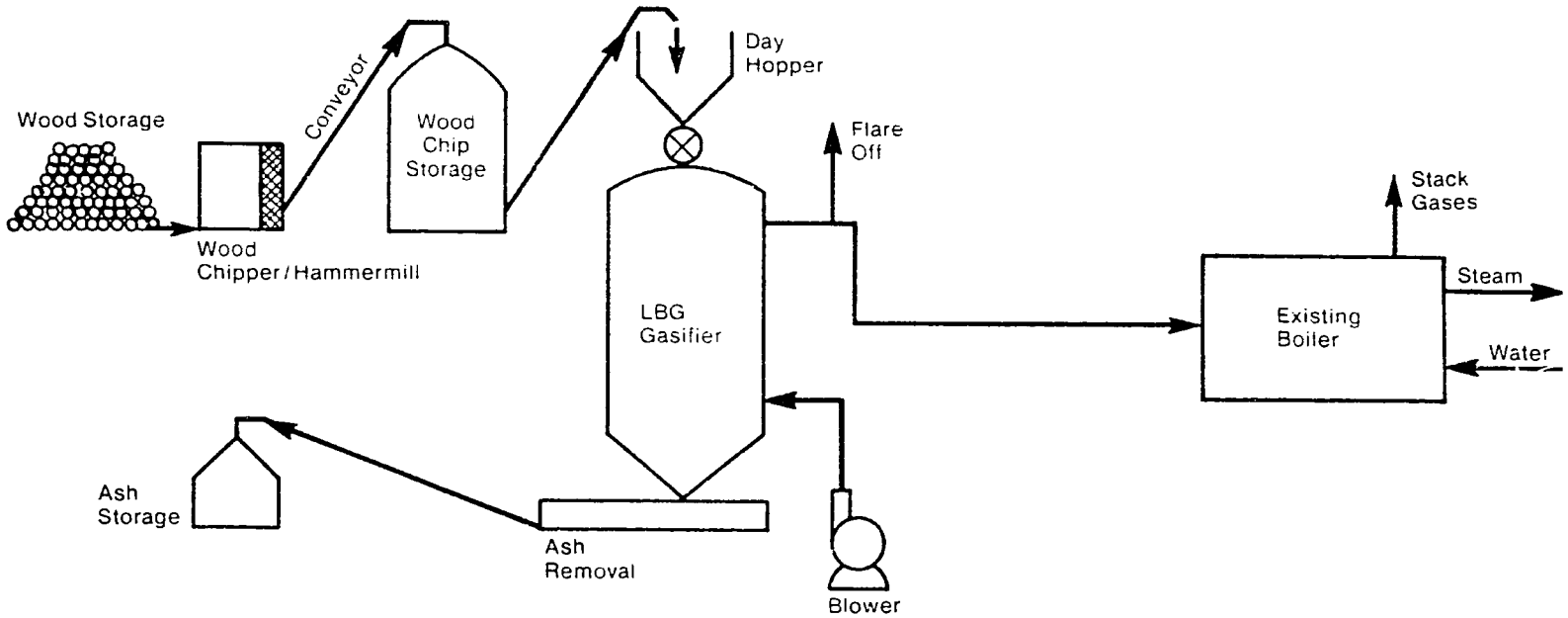

FIGURE 3-6
RETROFIT LOW-BTU GASIFIER

gasifier unit. For charcoal gasifiers, the volume and mass of material required for equivalent energy output is approximately one-third less than that for wood. No gasifiers specifically designed for charcoal were identified. Gasifier manufacturers contacted indicated that no major modifications would be required to convert a wood gasifier to utilize charcoal. However, the charcoal feed size, if too fine, could result in sparking problems.

3.3.4 Charcoal-Oil Mixtures

Charcoal-oil mixtures (COM), as the name implies, involve mixing finely pulverized charcoal (typically 90 percent through 200 mesh) with residual oil. The COM can be used in existing oil combustion systems that incorporate some necessary modifications. Charcoal-oil mixtures are an extension of the coal-oil mixture fuel currently being investigated by the U.S. Department of Energy, Pittsburgh Energy Technology Center (References 7, 8 and 9). Charcoal-oil mixtures were successfully tested at the Pittsburgh Energy Technology Center in 1977. The use of charcoal with residual oil helps conserve the more expensive residual oil.

A discussion of the preparation and use of COM is presented in Appendix A. For industrial users, the main consideration is that the economics and other requirements of on-site preparation are not attractive. Central preparation, potentially at the point of charcoal production, is more advisable. Figure 3-7 presents a COM fuel train retrofit for an existing boiler. The new components required in the fuel train include a storage tank with an agitator. In cold

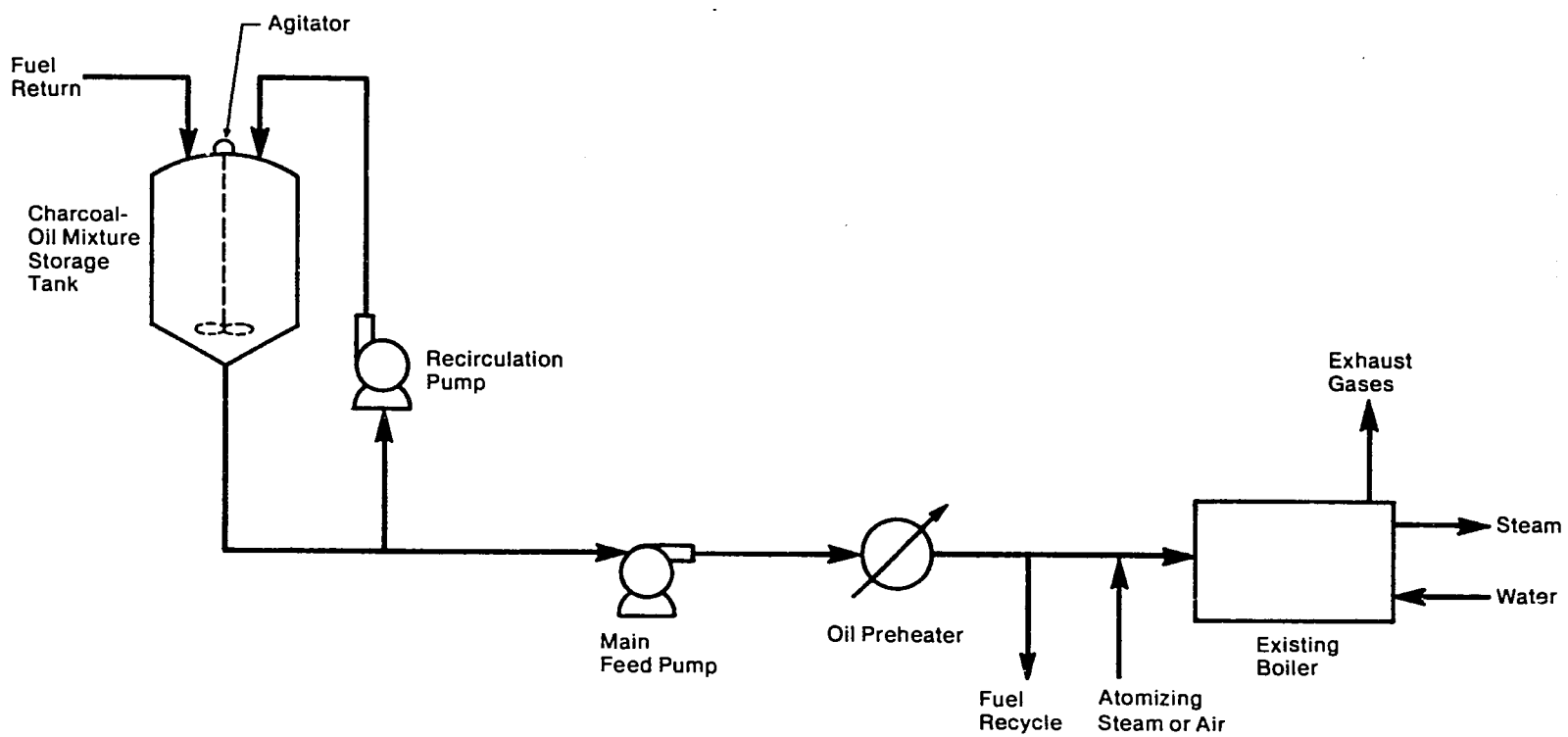

FIGURE 3-7
RETROFIT CHARCOAL-OIL MIXTURE FUEL SYSTEM

climates, a steam jacket or heating element is required for the storage tank to maintain the temperature (above 65°F) and, thus, the suspension of the fuel. In PNG this will not be required due to sufficiently high ambient temperatures. Abrasion-resistant slurry pumps and valves are required to deliver the COM to the burner. Long-radius elbows in piping are necessary to minimize erosion. A main focus of COM research has been the erosion of burner tips. Tungsten carbide inserts, in conjunction with low-pressure air atomization, have been used to minimize this problem.

The cost of preparing coal-oil mixtures has been extensively investigated by U.S. Department of Energy staff (Reference 7). Preparation costs are estimated at U.S. $6.50 per ton or equivalently K4.85 per tonne. For the purposes of the economic analysis of COM in PNG, preparation costs were doubled and a cost of K10 per tonne was assumed. This translates to a 5 percent increase in the price of COM over the combined cost of the charcoal and oil constituents. The selling price of a 50/50 COM[1] is thus K125.5 per tonne.

[1]A 50 percent charcoal, 50 percent oil by weight mixture was assumed because it is the limit for charcoal use where material handling and combustion problems of the COM are acceptable (Reference 7).

4.0 ECONOMIC ANALYSIS OF INDUSTRIAL WOOD FUEL COMBUSTION SYSTEMS

4.1 Summary

This chapter presents the economic analysis of wood fuel combustion systems appropriate for present and future industrial use in PNG. Five generic cases, representative of a large segment of PNG's industrial fuel use systems, are evaluated in detail. The generic cases are:[1]

- Retrofit fuel feed systems for existing oil-fired boilers (250 HP)
- New package boiler systems (250, 500 and 1000 HP)
- Retrofit fuel feed systems for existing oil-fired, hot air furnaces (two 2.0-MMBtu/hr)
- Retrofit fuel feed systems for existing manually stoked, wood-fired hot air furnaces (three 2.5-MMBtu/hr)
- New hot air furnace systems (4.0 MMBtu/hr).

In each of the above cases, the prevailing fuel use (i.e., distillate oil, residual oil, kerosene, or wood logs) is compared against the potential use of the following wood derived fuels:

- Pyrolytic oil-petroleum mixtures
- Pyrolytic oils
- Lump or crushed charcoal
- Hogged or chipped wood

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[1]Equipment size ranges were selected to be representative of existing industrial combustion equipment in PNG.

- Low Btu gas from a charcoal gasifier
- Low Btu gas from a wood gasifier
- Pulverized charcoal-oil mixtures.

Not all the above fuel categories are applicable in each case. The selection of the appropriate alternate fuels case is indicated in the analysis presented in Section 4.3.

A summary of the initial capital investments, annual operating costs and net present value (NPV) of the discounted savings in expenditures,[1] for the alternatives in each case study, is presented in Table 4-I. The results indicate that wood fuels as an alternative for petroleum use in PNG industry are, in most cases, economically attractive.[2] An analysis of the specific data in Table 4-I indicates that:

- Alternative wood fuel systems generally have a positive NPV of expenditure savings when used to displace petroleum fueled systems. The economics of the wood fuel systems are more attractive when displacing distillate fuel (#2 oil) than residual fuel (#6 oil).
- Pyrolytic oil systems, when applicable, are the most economically attractive alternative. This advantage is maintained over a wide range of discount rates.
- For a 250 HP boiler retrofit, the pyrolytic oil option yields the highest NPV. The 70/30 pyrolytic oil-petroleum mixture, the LBG wood gasifier, and the 50/50 charcoal-oil mixture

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[1]Savings in expenditures for the alternative technologies is based on a comparison with expenditures for the existing technologies.

[2]Fuel systems that yield a positive NPV of expenditure savings are considered economically attractive. Within a set of alternatives that are compared against a common base, the higher the NPV of expenditure savings the more relatively economic is the alternative.

TABLE 4-I

SUMMARY OF INITIAL CAPITAL INVESTMENTS, ANNUAL OPERATING EXPENDITURES AND NPV OF EXPENDITURE SAVINGS FOR SELECTED FUEL SYSTEM OPTIONS

CASE STUDY/FUEL SYSTEM OPTION	INITIAL CAPITAL INVESTMENT $x10^3$ KINA	INITIAL ANNUAL OPERATING EXPENDITURE $x10^3$ KINA	NPV OF EXPENDITURE SAVINGS $x10^3$ KINA	
CASE A: Retrofit fuel feed system for existing oil firetube boiler (250 HP)			$i^*=0.11$	$i^*=0.20$
Base Case 0-a: #6 residual fuel oil	26.9	280.6		
Base Case 0-b: #2 distillate oil	26.9	475.8		
Option 1: 70/30 pyrolytic oil-petroleum mix	44.7	248.6		
·compared to #6 oil			240	134
·compared to #2 oil			1740	1018
Option 2: 100% pyrolytic oil	39.3	227.0		
·compared to #6 oil			409	235
·compared to #2 oil			1909	1120
Option 3: LBG charcoal gasifier	191.8	287.7		
·compared to #6 oil			-111	-139
·compared to #2 oil			1389	745
Option 4: LBG wood gasifier	325.1	235.9		
·compared to #6 oil			236	7
·compared to #2 oil			1736	892
Option 5: 50/50 charcoal/oil mixture	57.7	256.7		
·compared to #6 oil			175	89
·compared to #2 oil			1675	974

TABLE 4-I (CONTINUED)

SUMMARY OF INITIAL CAPITAL INVESTMENTS, ANNUAL OPERATING EXPENDITURES AND NPV OF EXPENDITURE SAVINGS FOR SELECTED FUEL SYSTEM OPTIONS

CASE STUDY/FUEL SYSTEM OPTION	INITIAL CAPITAL INVESTMENT $x10^3$ KINA	INITIAL ANNUAL OPERATING EXPENDITURE $x10^3$ KINA	NPV OF EXPENDITURE SAVINGS $x10^3$ KINA	
CASE B: New Package Boiler System (250,500 and 1000 HP)			$i^*=0.11$	$i^*=0.20$
Base Case O-a: #6 residual fuel oil				
250 HP	92.7	290.4		
500 HP	140.5	563.8		
1000 HP	212.3	1101.4		
Base Case O-b: #2 distillate oil				
250 HP	92.7	485.7		
500 HP	140.5	954.3		
1000 HP	212.3	1882.4		
Option 1: Automatic Stokered Wood				
250 HP	391.2	240.8		
·compared to #6 oil			289	37
·compared to #2 oil			1789	922
500 HP	638.2	437.6		
·compared to #6 oil			829	265
·compared to #2 oil			3829	2034
1000 HP	1040.3	791.9		
·compared to #6 oil			2152	896
·compared to #2 oil			8152	4435
Option 2: Automatic Stokered Charcoal				
250 HP	169.8	239.6		
·compared to #6 oil			382	189
·compared to #2 oil			1882	1074
500 HP	245.4	452.5		
·compared to #6 oil			865	459
·compared to #2 oil			3866	2229
1000 HP	399.8	860.3		
·compared to #6 oil			1865	1009
·compared to #2 oil			7865	4548

TABLE 4-I (CONCLUDED)

SUMMARY OF INITIAL CAPITAL INVESTMENTS, ANNUAL OPERATING EXPENDITURES AND NPV OF EXPENDITURE SAVINGS FOR SELECTED FUEL SYSTEM OPTIONS

CASE STUDY/FUEL SYSTEM OPTION	INITIAL CAPITAL INVESTMENT $x10^3$ KINA	INITIAL ANNUAL OPERATING EXPENDITURE $x10^3$ KINA	NPV OF EXPENDITURE SAVINGS $x10^3$ KINA	
CASE C: Retrofit fuel feed system for existing oil-fired hot air furnaces (Two 2.0 MMBtu/hr units)				
Option 0: #2 distillate oil	22.7	132.0		
Option 1: 70/30 mix with #2 oil	37.2	88.7	326	186
Option 2: 70/30 mix with #6 oil	37.2	72.7	449	259
Option 3: 100% pyrolytic oil	31.8	67.3	494	287
Option 4: LBG charcoal gasifier	103.4	90.4	287	134
Option 5: LBG wood gasifier	169.6	84.3	303	115
CASE D: Retrofit fuel feed system for existing manually-stoked wood-fired hot air furnaces (three 2.5 MMBtu/hr units)				
Option 0: Improve existing system efficiency	12.7	119.0		
Option 1: Automatic charcoal stoker	85.5	150.8	-318	-215
Option 2: Automatic Wood Stoker	108.8	122.2	-91	-93
Option 3: LBG charcoal gasifier	158.4	176.1	-552	-384
Option 4: LBG wood gasifier	245.5	144.7	-352	-303
CASE E: New package hot air furnace (4.0 MMBtu/hr)				
Option 0: #2 distillate oil	50.7	136.2		
Option 1: Automatic wood stoker	176.7	84.3	359	155
Option 2: Automatic charcoal stoker	119.2	86.0	366	185

systems all yield a positive but slightly lower NPV. The LBG charcoal gasifier is economical when displacing the higher priced distillate fuel but not economical for displacing residual fuels.[1]

- New automatic stokered wood and charcoal boilers are more attractive economically than either new distillate or residual oil fueled boilers. In general, the NPV of wood boilers increases relative to that for charcoal boilers with increasing boiler size and decreasing discount rates.

- The pyrolytic oil retrofit system yields the highest NPV in expenditure savings for an existing distillate-fired hot air furnace. The 70/30 pyrolytic oil-petroleum mixture and LBG wood and charcoal gasifiers also yield positive NPVs.

- Neither automatic wood nor charcoal stoker systems nor LBG gasifiers provide positive economic returns when compared to improving the efficiency of the existing, manually-stoked wood furnace and utilizing it for its remaining service life.

- Both new automatic wood and charcoal package hot air furnaces are more economically attractive than an equivalent new distillate oil furnace.

Details of the NPV analysis including sensitivity analysis of key variables are presented in Section 4.3.4.

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[1]The capital costs, used in this study, for the LBG charcoal gasifier does not consider the costs as suggested by the Cleaver-Brooks Division of Aqua-Chem, Inc. It was suggested by Cleaver-Brooks that their gasifier, currently being developed and which is targeted at the small industrial boiler (less than 400 HP) market, will have much more favorable economics than is assumed in this study. This claim cannot be substantiated as Aqua-Chem, Inc. does not have commercial units in operation and will not quote formal prices. Informal estimates like $12 per pound of steam generated have been discussed as an installed price for the gasifier with controls and feeders in the USA. Commercial availability of such a product would substantially change the attractiveness of this case. However, the presence of technical difficulties relating to handling variations in fuel characteristics has been cited as the reason for the product being held from the market.

The potential use of wood or wood-derived fuels for three specific cases in PNG is also evaluated. These include:

- Charcoal use for Bougainville Copper Limited's (BCL's) proposed power plant expansion
- Charcoal-oil mixtures or pyrolytic oils for BCL's ore concentrate dryer
- Pyrolytic oils for A.C.I.'s glass furnace.

These three particular cases account for over 50 percent of the industrial petroleum consumption in PNG. However, they do not lend themselves to a generic analysis and therefore are dealt with individually. The details of this analysis are presented in Section 4.4. The main conclusions are:

- Utilization of charcoal or a charcoal-coal mix at BCL's proposed power plant expansion is not an economically attractive option
- The use of pyrolytic oils and fuel conservation measures can provide substantial savings to BCL's ore concentrate operation
- Combustion of pyrolytic oils in the A.C.I. Glass process furnace should be encouraged pending positive research and test results.

Finally, three specific cases that were observed by the study team while in PNG are best addressed by non-wood fuel technologies. These cases and the appropriate technologies are:

- Electrification of the Arawa Hospital boilers
- Solar crop drying techniques for the tea withering process
- Solar crop drying techniques for the tobacco curing process.

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discussed in Case C are modeled after the tea drying furnaces at Bunum-Wo. The manually-stoked wood furnaces discussed in Case D are modeled after those of the Kindeng tea factory. Cases that consider new combustion systems, while not being modeled after specific facilities, incorporate observations made by the study team while in PNG.

The following generic cases and associated fuel options were evaluated.

Case A. Retrofit fuel feed system[1] for existing oil-fired boilers (250 HP).

- Option 0-a: Maintain the existing #6 residual fuel oil system.
- Option 0-b: Maintain the existing #2 distillate fuel oil system.
- Option 1: Modify the existing fuel system to use a 70/30 pyrolytic oil-petroleum mixture.
- Option 2: Modify the existing fuel system to use pyrolytic fuel oil.
- Option 3: Retrofit a charcoal gasifier to produce low-Btu gas for combustion in the existing boiler.
- Option 4: Retrofit a wood gasifier to produce low-Btu gas for combustion in the existing boiler.
- Option 5: Modify the existing fuel system to use a 50/50 charcoal-oil mixture (COM).

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[1]Fuel feed system is defined here to include on-site fuel storage, handling, conversion (if necessary) and burner.

Case B. New package boiler systems[1] (250, 500, and 1000 HP).

Option 0-a: Install a new #6 residual fuel oil-fired, package boiler system.

Option 0-b: Install a new #2 distillate fuel oil-fired, package boiler system.

Option 1: Install a new automatic stoker, wood-fired, package boiler system.

Option 2: Install a new automatic stoker, charcoal-fired, package boiler system.

Case C. Retrofit fuel system for existing oil-fired hot air furnaces (two 2.0-MMBtu/hr units).

Option 0: Maintain the existing #2 distillate oil system.

Option 1: Modify the existing fuel system to use a 70/30 pyrolytic-distillate oil mixture.

Option 2: Modify the existing fuel system to use a 70/30 pyrolytic-residual oil mixture.

Option 3: Modify the existing fuel system to use pyrolytic fuel oil.

Option 4: Retrofit one charcoal gasifier to produce low-Btu gas for combustion in the two existing furnaces.

Option 5: Retrofit one wood gasifier to produce low-Btu gas for combustion in the two existing furnaces.

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[1]Package boiler systems are discussed in Appendix A. The boiler system is defined to include both the fuel feed system, grate (if necessary), combustion chamber, ash removal (if necessary), and boiler tubes.

Case D. Retrofit fuel systems for existing manually stoked wood-fired, hot air furnaces (three 2.5-MMBtu/hr units).

Option 0: Maintain the existing manually stoked system, implement some recommended design improvements,[1] and continue to use split wood logs.

Option 1: Retrofit automatic charcoal stoker units, modify grates and use lump charcoal.

Option 2: Retrofit automatic wood stoker units, modify grate and use chipped or hogged wood.

Option 3: Retrofit one charcoal gasifier to produce low-Btu gas for combustion in the three existing furnaces.

Option 4: Retrofit one wood gasifier to produce low-Btu gas for combustion in the three existing furnaces.

Case E. New package hot air furnace (4.0 MMBtu/hr).

Option 0: Install a new distillate-fired, hot air furnace.

Option 1: Install a new automatic stoker, wood-fired hot air furnace.

Option 2: Install a new automatic stoker, charcoal-fired hot air furnace.

Overall system designs, cost estimates and financial analyses for each fuel option were conducted for these five generic cases. Results of these analysis are presented in Section 4.3.

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[1] Recommendations for improved combustion efficiency for manually-stoked wood-fired furnaces used by the PNG tea industry are outlined in a report by Ian Gilmour entitled: Energy Requirements for Tea Drying Operatins in the Western Highlands, submitted to the Minerals and Energy Department of the Government of Papua New Guinea, July 1980.

As a result of site visits by the study team, six specific cases were identified for a preliminary economic assessment of using wood, wood-derived fuels or alternative non-petroleum fuels. These case studies are listed below:

Case F. Proposed expansion of Bougainville Copper Limited's (BCL) power plant.

- Use of imported Australian coal.
- Use of domestically produced charcoal alone or mixed with coal.

Case G. BCL's ore concentrate dryer.

- Concinue the use of #6 residuel fuel oil.
- Convert to the use of pyrolytic oil.
- Convert to the use of charcoal-oil mixtures.

Case H. A.C.I.'s glass furnace.

- Continue the use of #6 residual fuel oil.
- Convert to a 70/30 pyrolytic-residual oil mixture.

Case I. Arawa Hospital Boilers.

- Install new oil-fired package boilers.
- Install new wood-fired package boilers.
- Install new solar hot-water/low-pressure steam boilers.
- Install new electric hot-water/low-pressure steam boilers.

Case J. Tea withering process at Mt. Hagen tea estates.

- Continue the use of distillate or split log fired furnaces.
- Retrofit a wood gasifier to the existing furnace.

- Retrofit an automatic wood stoker to the existing furnace.

- Install solar crop drying facilities to supplement the existing furnace systems.

Case K. Tobacco curing process of Rothman's tobacco.

- Continue the use of kerosene pot burners.

- Install a central wood-fired, hot air furnace.

- Install solar crop drying facilities in conjunction with the existing kerosene system.

Only a preliminary economic analysis was conducted of the options associated with each of these specific cases. However, this assessment provides an insight to some of the potential options available. The results of this assessment are presented in Section 4.4.

4.2.2 Criteria for Selection

The criteria for selecting both the generic and specific cases can be summarized as follows:

- The cases are representative of industrial petroleum combustion systems in use in PNG.

- The combined industrial petroleum fuel use represented by both the generic and specific cases accounts for more than 70 percent of the present industrial petroleum consumption in PNG.

- It is technically feasible to replace the existing petroleum combustion systems in each of the cases with a new or retrofit wood-fuel system.

In addition to the above criteria, the cases selected were the result of knowledge of existing combustion systems in PNG, and a technical assessment of feasible wood or wood-derived fuel systems.

4.3 Assessment of Generic Case Studies

4.3.1 Assessment Outline

The assessments of the five generic cases are presented, by case study, in the following format.

- System Description - The system and appropriate options are described as an introduction to the case.
- Results - Results of the financial and sensitivity analysis are presented and discussed.
- Estimated Equipment Costs, Fuel Consumption, and Operating Requirements - Costs, fuel and operating parameters for each option are summarized in tabular form.
- NPV and Cash Flow Analysis - The net present value of capital investments and operating expenditure savings are summarized in tabular form.
- Sensitivity Analysis - The sensitivity of the NPV of each fuel option to key parameters are illustrated by tables and figures.[1]
- Fuel Option Flow Diagrams - Major equipment components and mass/energy flows for each fuel option are presented in box flow diagrams.

This format permits the reader to systematically evaluate the fuel options in each case study. With the data provided, the reader can alter the basic assumptions or estimates of each fuel option to determine the changes in the NPV of each option. In addition, any variation in data beyond that covered by the sensitivity analysis can be evaluated by utilizing the NPV FORTRAN program developed specifically for this study (Appendix F).

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[1]Sensitivity analysis data are more extensive for Case A than in all other case studies. Subsequent analyses focus only on the most sensitive variables identified in Case A.

4.3.2 Assessment Methodology

An assessment of the net present value (NPV) of the flow of capital investments and the savings in annual operating expenditures was used as the basis for determining the economic attractiveness of each fuel option.

Two basic discount rates (i^*) are used throughout the analysis. The first rate, 11 percent, is used to reflect those industries that place a high value on fuel supply reliability and, therefore, are willing to forego normal target returns in exchange for a reliable, domestic fuel supply. The second rate, 20 percent, reflects a reasonable target rate of return for industry in PNG.[1] The equation used to determine the NPV is:

$$NPV^A\ (i^*,n) = \sum_{t=1}^{n} \left(SAD_t^A \times PWF_t^{i^*} \right) + \left(ACB_n^A \times PWF_n^{i^*} \right) - ATICI_o^A$$

where:

$NPV^A\ (i^*, n)$	= net present value of option A for a given discount rate, i^*, and an analysis period n.
SAD_t^A	= net savings in annual disbursements in year t of option A over that of the base option.
$PWF_t^{i^*}$	= present worth factor for a given discount rate, i^*, in year t.
ACB_n^A	= additional cash balance of option A over that of the base option due to a salvage value for equipment, income from land sales and a recovery of working capital at the end of the analysis period n.

[1]The specification for these discount rates was stated in the "Terms of Reference" for this study.

$ATICI_o^A$ = additional initial capital investment of option A over that required for the base option.

The net savings in annual disbursements, SAD , incorporates the effects of differing inflation rates for wood fuels, petroleum fuels, labor costs, utility costs, and maintenance costs. A complete presentation of the NPV equation used in this analysis is given in Appendix E.

The basic inputs required for the financial analysis can be categorized as follows:

- Data pertinent to estimating the required initial capital investment such as equipment costs, installation costs, engineering design fees, contingency costs, land purchases, etc.
- Data pertinent to estimating the annual operating and maintenance expenditures such as primary fuel costs, labor costs, utilities, maintenance, etc.
- Data pertinent to financial parameters such as the expected discount rate, number of years of cash flow analysis, average annual inflation rates, corporate income tax rates, etc.

A complete list of the basic data inputs required to conduct the financial analysis is presented in Table 4-II.

Estimates of the data items for each case study in Table 4-II were obtained from:

- A survey of related equipment manufacturers. The survey was performed as part of this study and also draws on surveys of previous MITRE studies (References 6, 10 and 11; see Appendix B for the list of manufacturers contacted).
- An engineering analysis of the operating characteristics of each system (i.e., efficiencies, energy/mass balances, utility requirements, etc.).

TABLE 4-II

BASIC DATA INPUTS FOR FINANCIAL ANALYSIS

- Data for Estimating Initial Capital Investments

EQUIP	=	estimated delivered price of equipment, Kina
ADLC	=	estimated cost of required additional land, Kina
INSTAL	=	assumed factor for installation costs
ENGIN	=	assumed factor for engineering design fees
CONTIN	=	assumed factor for contingency costs

- Data for Estimating Annual Operating and Maintenance Expenditures

FIH	=	fuel input, tonne per hour (T/hr)
FUELC	=	fuel cost, Kina per tonne (K/T)
SUVPL	=	supervisor labor required, men per hour (M/hr)
SUWAGE	=	supervisor labor wage rates, Kina per hour (K/hr)
GENL	=	general labor required, men per hour (M/hr)
GLWAGE	=	general labor wage rates, Kina per hour (K/hr)
OHR	=	estimated overhead rate for labor
MAINT	=	annual maintenance costs as a percentage of the total initial capital investment
ELI	=	electricity requirements, kilowatts (KW)
ELECT	=	electricity costs, Kina per KW-hr (K/KW-hr)
HRIND	=	average operating hours per day (hr/d)
ALOAD	=	average annual load factor
PCOIL	=	percent of the annual fuel input that is petroleum based
DEPF	=	annual depreciation factor allowed

- Financial Parameters

i^*	=	assumed discount factor
η	=	analysis period in years
TR	=	corporate income tax rate
f_o	=	average annual inflation rate for petroleum-based fuels
f_w	=	average annual inflation rate for wood and wood-based fuels
f_{ol}	=	average annual inflation rate for labor wages
f_{ut}	=	average annual inflation rate for cost of utilities
f_{ma}	=	average annual inflation rate for maintenance costs

- Data obtained during site visits in PNG (see Appendix G for summary of site visits).

The final estimates incorporate information from numerous sources gathered for this study and are adjusted to reflect costs or conditions expected for PNG.

4.3.3 Baseline Assumptions

To establish a baseline for the NPV analysis, several financial parameters, base year, commodity prices and cost estimating factors were defined. The base year was taken as 1980. Parameters and their baseline values are presented in Table 4-III. These baseline estimates were varied in the sensitivity analysis.

4.3.4 Case Studies

Case A. Retrofit fuel system for existing oil-fired boilers (250 HP).

- System Description

The boiler is base loaded at 200 HP, operates 24 hours per day and has an annual utility of 85 percent. Seven fuel systems were analyzed including two base case petroleum fuel options.

Option 0-a: An existing #6 residual fuel oil system (see Figure 4-1).

Option 0-b: An existing #2 distillate fuel oil system (similar to Figure 4-1).

Option 1: A retrofit 70/30 pyrolytic-residual oil mixture fuel system (see Figure 4-2).

Option 2: A retrofit pyrolytic fuel oil system (see Figure 4-3).

Option 3: A retrofit LBG charcoal gasifier (see Figure 4-4).

TABLE 4-III

BASELINE VALUES FOR FINANCIAL ANALYSIS

- Cost Estimating Factors

INSTAL	=	0.20	: installation costs are 20% of total equipment costs
ENGIN	=	0.20	: engineering design and construction fees are 20% of total equipment costs plus installation
CONTIN	=	0.10	: start up contingency costs are 10% of total equipment costs plus installation costs plus engineering fees
OHR	=	0.30	: operating labor overhead rate
MAINT	=	0.15	: annual maintenance costs are 15% of total initial capital investment

- Base Year Commodity Prices (in 1980 Kina)

FUELC	=	K176/tonne	#6 residual fuel oil
	=	K310/tonne	#2 distillate oil
	=	K332/tonne	kerosene
	=	K175/tonne	charcoal
	=	K185/tonne	pyrolytic oil
	=	K25/tonne	wood on a dry basis

SUWAGE	=	K2.5/hr	: supervisory labor wage rates
GLWAGE	=	K1.0/hr	: general labor wage rates
ELECT	=	K0.05/KW-hr	: electricity costs per kilowatt hour
ADLC	=	K20,000/hectare	: average land costs per hectare

- Baseline Financial Parameters

TR	=	0.365	: corporate tax rates of 36.5% for companies incorporated in PNG (Reference 19).
f_o	=	0.08	: average annual inflation rate of 8.0% for petroleum products.*

TABLE 4-III

BASELINE VALUES FOR FINANCIAL ANALYSIS

(Concluded)

f_w	= 0.08	:	average annual inflation rate of 8.0% for wood and wood-derived fuels.*
f_{ol}	= 0.05	:	average annual inflation rate of 5.0% for labor wage rates.
f_{ut}	= 0.05	:	average annual inflation rate of 5.0% for utility rates.
f_{ma}	= 0.05	:	average annual inflation rate of 5.0% for maintenance costs,

*These inflation rates are varied in the analysis of all cases because of their importance in the analysis.

Option 4: A retrofit LBG wood gasifier (see Figure 4-5).

Option 5: A retrofit 50/50 charcoal-oil-mixture fuel system (see Figure 4-6).

The analysis compares the NPV of the five retrofit fuel systems against the two existing petroleum fuel systems. The analysis does not account for existing boiler components. It is assumed that replacement decisions and costs for the boiler components are independent of the fuel system. Because the boiler is operated at a base load of 200 HP but has a rating of 250 HP, boiler derating is not considered. Initial costs and operating parameters were estimated for the existing petroleum options and for each retrofit option. These are presented in Table 4-IV. In the case of land costs, only incremental costs over that of the existing petroleum options were accounted for.

- Results

Under the baseline assumptions, all the retrofit wood fuel systems, except the LBG charcoal gasifier that displaces residual oil, yields a positive NPV. The pyrolytic oil system provides the largest NPV of savings in expenditures. Over a 15-year period and for a discount rate of 11 percent, the NPV of these savings amounts to over 400,000 kina when displacing residual oil and over 1.9 million kina when displacing distillate oil. With a discount rate of 20 percent, the NPV of savings are over K235,000 for replacing residual oil use and K1,120,000 for replacing distillate oil use. The economics of

the 70/30 pyrolytic oil-residual oil system, the LBG wood gasifier and the 50/50 charcoal-oil mixture system are equally attractive though slightly less so than the pyrolytic oil system. The LBG charcoal gasifier yields the lowest NPV.

Tables 4-V and 4-VI and Figures 4-7 through 4-15 present the baseline NPV analyses and sensitivity analyses for each of the wood-derived fuel systems when compared to the petroleum systems. The sensitivity of the NPV of each retrofit system to changes in the baseline estimate of a parameter is reflected by the slope of the respective plots in Figures 4-7 through 4-15. The greater the slope the more sensitive is the NPV to the parameter indicated on the horizontal axis of the graph.[1] Thus, in Figure 4-7, the NPV of the LBG wood gasifier is the most sensitive to changes in the baseline estimate of equipment costs.

The sensitivity analysis indicates that the retrofit wood fuel systems that replace distillate oil remain attractive under some extreme conditions. For example, Figure 4-7 indicates that the NPV of the retrofit systems remains positive even when the initial equipment costs are increased by more than 75 percent. These NPVs are

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[1]The slope is defined as the ratio of a change in the value of the parameter on the horizontal axis (i.e., fuel costs, equipment costs, etc.) to the resulting change in the value of the parameter on the vertical axis (i.e., the NPV). The steeper the slope of a fuel option the more sensitive is its NPV to the parameter on the horizontal axis. The scales for the graphs vary between figures and therefore visual comparisons of slopes between figures is not possible.

also positive when initial year wood fuel price estimates[1] are raised by more than 75 percent (see Figure 4-8). In the case of existing residual oil systems, the economics of retrofit wood fuel systems are less attractive. Figure 4-7 indicates that only the pyrolytic oil systems and the 50/50 charcoal-oil mixture system have positive NPVs when initial equipment cost estimates are 75 percent greater than the baseline estimate. Figure 4-8 shows that an increase of more than 30 percent in the initial price estimate of wood derived fuels results in negative NPVs for all the retrofit wood fuel systems.

Figure 4-9 presents the NPV of the retrofit systems as a function of the discount rate (i*). The plots show that the NPV decreases with increasing discount rates. Because of the larger annual cash flows, the sensitivity of the NPV is greater for the retrofit systems replacing distillate oil than for those replacing residual oil.

The effects of different inflation rates for petroleum fuels versus wood fuels are presented in Figures 4-10 and 4-11 for the LBG wood gasifier and in Figures 4-12 and -13 for the pyrolytic oil system. The NPV of the retrofit wood systems is most sensitive to relative changes in the inflation rates of petroleum fuels versus wood-derived fuels. Thus, if the inflation rate of petroleum were to

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[1]The initial price indicates the assumed base price from which inflated prices over the analysis period are calculated.

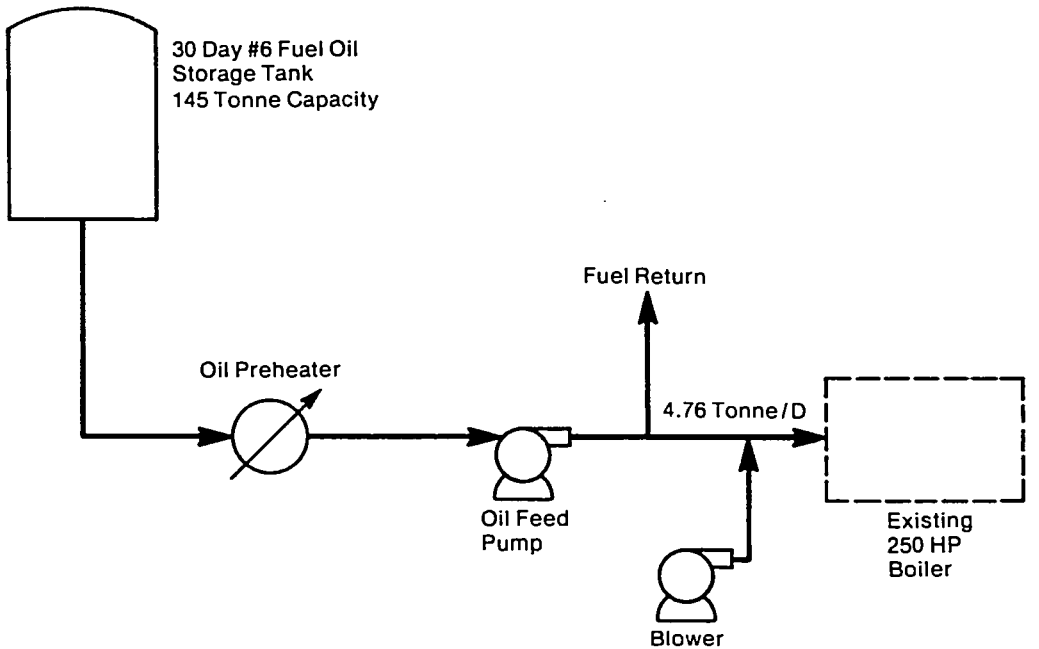
increase relative to that of wood-derived fuels, the NPV of the retrofit systems would increase. This would be a likely situation in PNG, given the availability of a large wood resource base and no known domestic petroleum.

Figures 4-14 and 4-15 show the effect of changing the NPV cash-flow analysis period for the wood gasifier and pyrolytic oil options. The point at which the NPV becomes positive can be interpreted as the discounted payback period. The results show that in the case of the retrofit LBG wood gasifier replacing a residual oil system, the NPV, discounted at 20 percent, is positive only after 14 years. At a discount rate of 11 percent, the NPV is positive after 8 years. Figure 4-15 indicates that the payback periods are extremely short (less than four years) when the retrofit systems are used to replace distillate oil systems.

Additional data for the sensitivity analysis, presented in Tables 4-V and 4-VI, indicate that the NPV is quite sensitive to the estimated fuel input rate. The fuel input rate reflects the efficiency at which a fuel system operates. If the fuel input rate increases by 25 percent, this reflects a decrease in the efficiency of the system of 25 percent (e.g. from 0.80 to 0.60). System efficiencies were not varied (i.e., allowed to decline) through the life of each system. However, the importance of maintaining maximum efficiency is most critical for fuel systems where the input fuel costs are highest. Thus, the analysis indicates that if there is a decline

in the fuel system efficiencies, the NPV of the wood gasifier declines relatively slower than the other four fuel options. This is an especially important consideration in the case of the residual oil, pyrolytic oil and charcoal-oil mixture systems where burner systems, if not maintained, can result in drastic declines in fuel efficiencies.

The data in Tables 4-V and 4-VI show that the NPV of the fuel options is not very sensitive to the installation, engineering, maintenance and contingency cost factors. They also indicate, for Case A, that wage rates are not a sensitive variable. This is because labor costs are a low percentage of annual costs in all the fuel options.



Fuel System Equipment:

30 day storage tank
Fuel feed pumps
Pipe and valves
Electrical and instrumentation
Oil burner
Estimated Delivered Costs—K17,000

Labor Requirements:

Supervisory	0.25 M/hr
General	1.0 M/hr

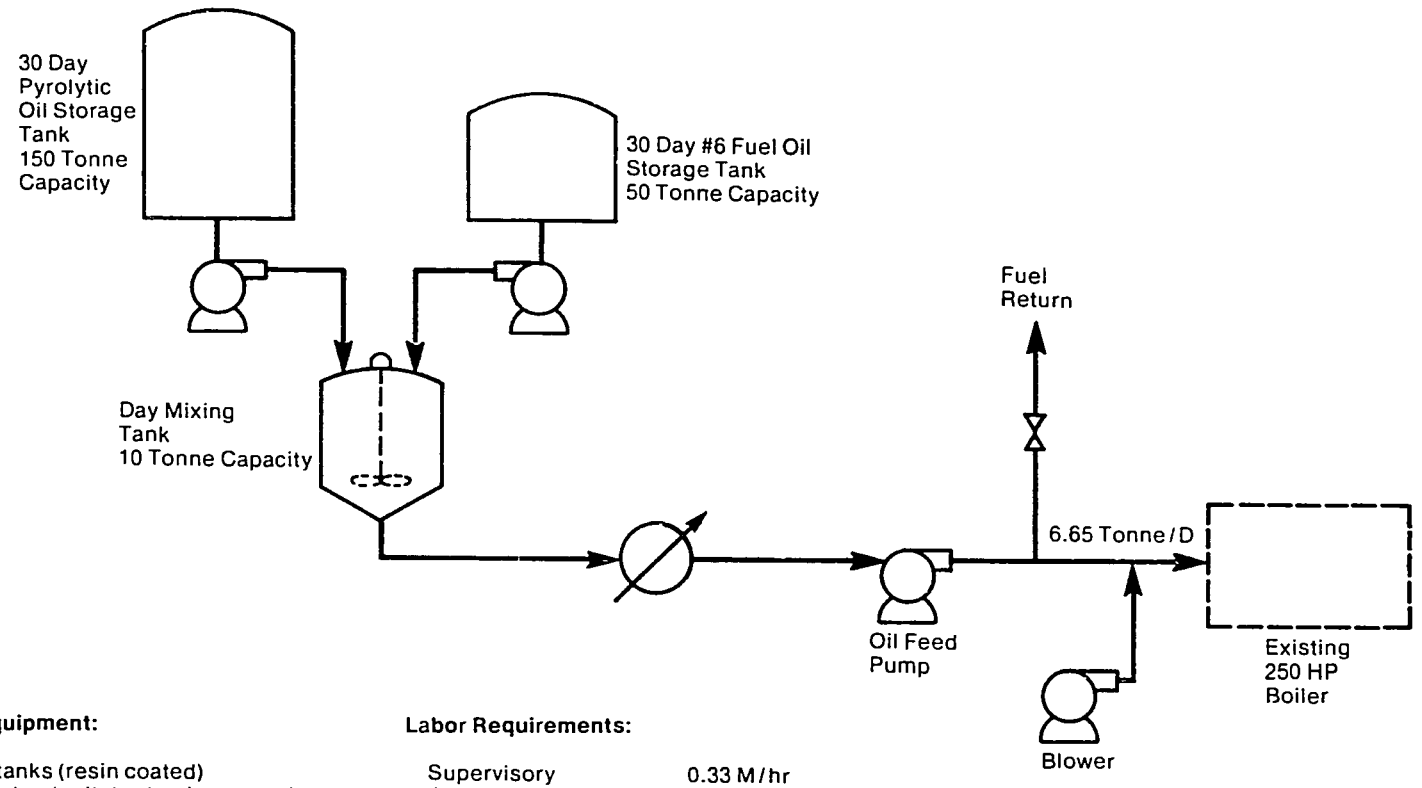
Utilities:

Electricity	5.0 kw

H.V. of Fuel: 42.2 MM Btu/tonne #6 fuel oil

Boiler Efficiency: 0.80

FIGURE 4-1
OPTION 0:
#6 FUEL OIL FEED SYSTEM—250HP BOILER



Fuel System Equipment:

Fuel storage tanks (resin coated)
Day mixing tank w/agitator (resin coated/ stainless steel)
Fuel feed pumps (stainless steel)
Oil preheater (stainless steel)
Pipe and valves (stainless steel)
Electrical and instrumentation
Modified oil burner
Estimated Delivered Costs: K28,200

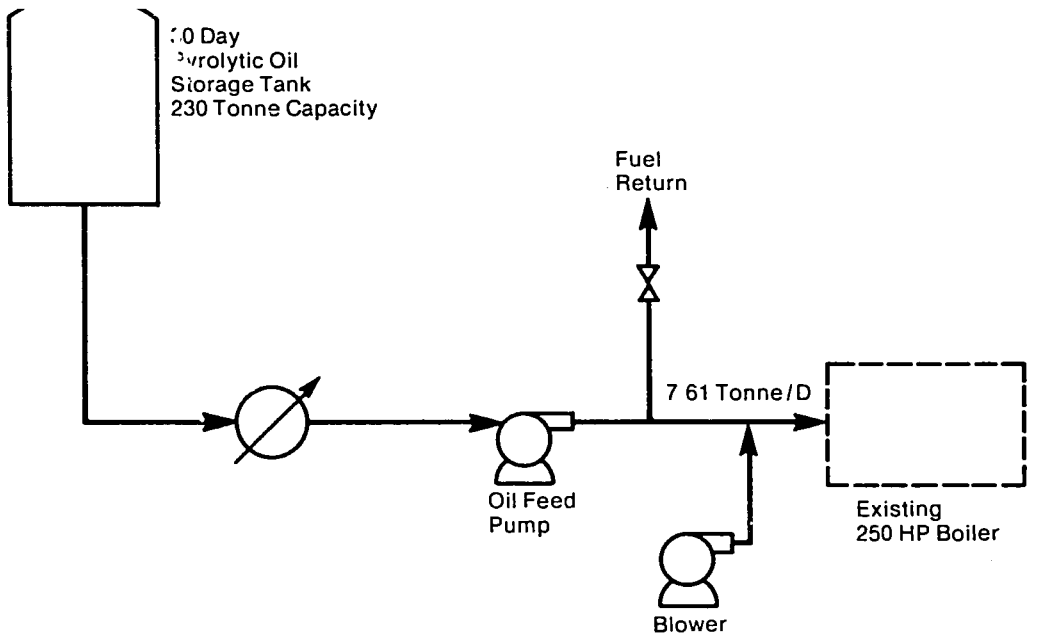
Labor Requirements:

Supervisory	0.33 M/hr
General	1.00 M/hr

Utilities:
Electricity: 8.0kw
H.V. of Fuel: 30.2 MM Btu/tonne 70/30

Boiler Efficiency: 0.80

FIGURE 4-2
OPTION 1: RETROFIT 70/30 PYROLYTIC OIL—
RESIDUAL OIL MIXTURE FUEL SYSTEM—250 HP BOILER



Fuel System Equipment:

Fuel storage tank (resin coated)
Fuel feed pumps (stainless steel)
Oil preheater (stainless steel)
Pipe and valves (stainless steel)
Electrical and instrumentation
Modified oil burner
Estimated Delivered Costs K24,800

Labor Requirements:

Supervisory	0.33 M/hr
General	1.0 M/hr

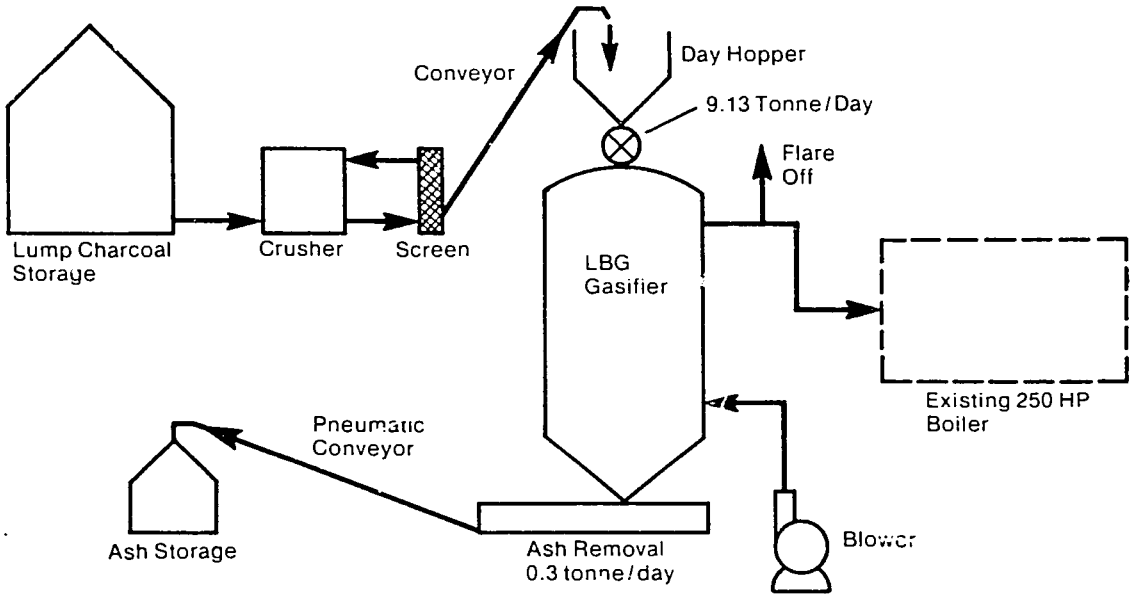
Utilities:

Electricity	7.0kw

H.V. of Fuel: 26.4MM Btu/tonne pyrolytic oil

Boiler Efficiency: 0.80

FIGURE 4-3
OPTION 2: RETROFIT 100% PYROLYTIC OIL SYSTEM—
250 HP BOILER



Fuel System Equipment:
- Charcoal Storage—300 tonne
- Crushers—two 1 tonne/hr
- Screens—two 1 tonne/hr
- Conveyors—two 1 tonne/hr
- Day hopper—20 tonne
- LBG gasifier/reactor*—10 tonne/day
- Ash removal—0.3 tonne/day
- Ash storage—9 tonne
- Gas burner—15 MM Btu/hr

*Including all electrical, instrumentation, pipe and valves
Estimated Delivered Costs K120.00

Labor Requirements:

Supervisory	0.5M/hr
General	2.0M/hr

Utilities:

Electricity	35kw

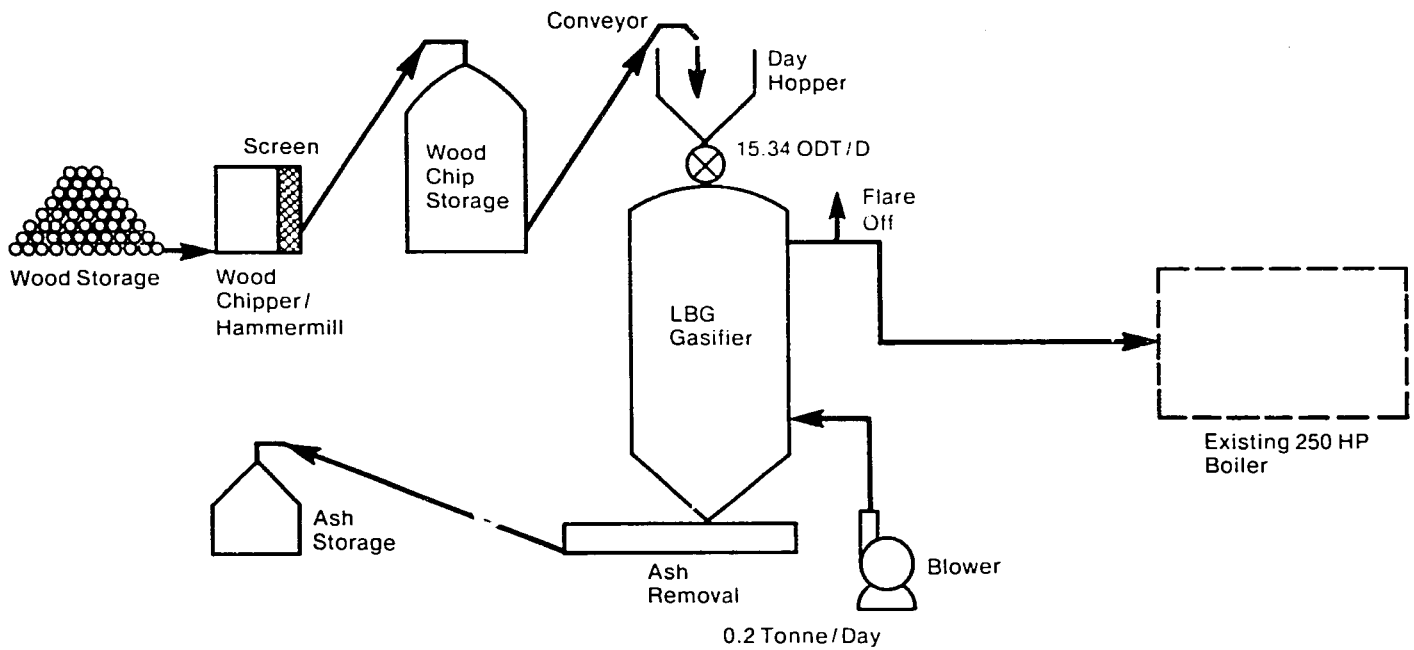
H.V. of Fuel: 27.5MM Btu/tonne charcoal

Boiler Efficiency: 0.80

Gasifier Efficiency: 0.80

Additional land required:
0.2 hectares

FIGURE 4-4
OPTION 3: RETROFIT LBG CHARCOAL GASIFIER—
250 HP BOILER



Fuel System Equipment:
- Wood storage shed—600 tonne
- Wood chipper/hammermill—two 2 tonne/hr
- Screens—two 2 tonne/hr
- Wood chip storage and air drying—200 tonne
- Conveyors—two 2 tonne/hr
- Day hopper—25 tonne
- LBG gasifier/reactor*—16 ODT/day
- Ash removal—0.2 tonne/day
- Ash storage—5 tonne
- Gas burner—15MM Btu/hr

*Including all electrical, instrumentation, pipe, and valves

Estimated Delivered Costs K203,000

Labor Requirements:

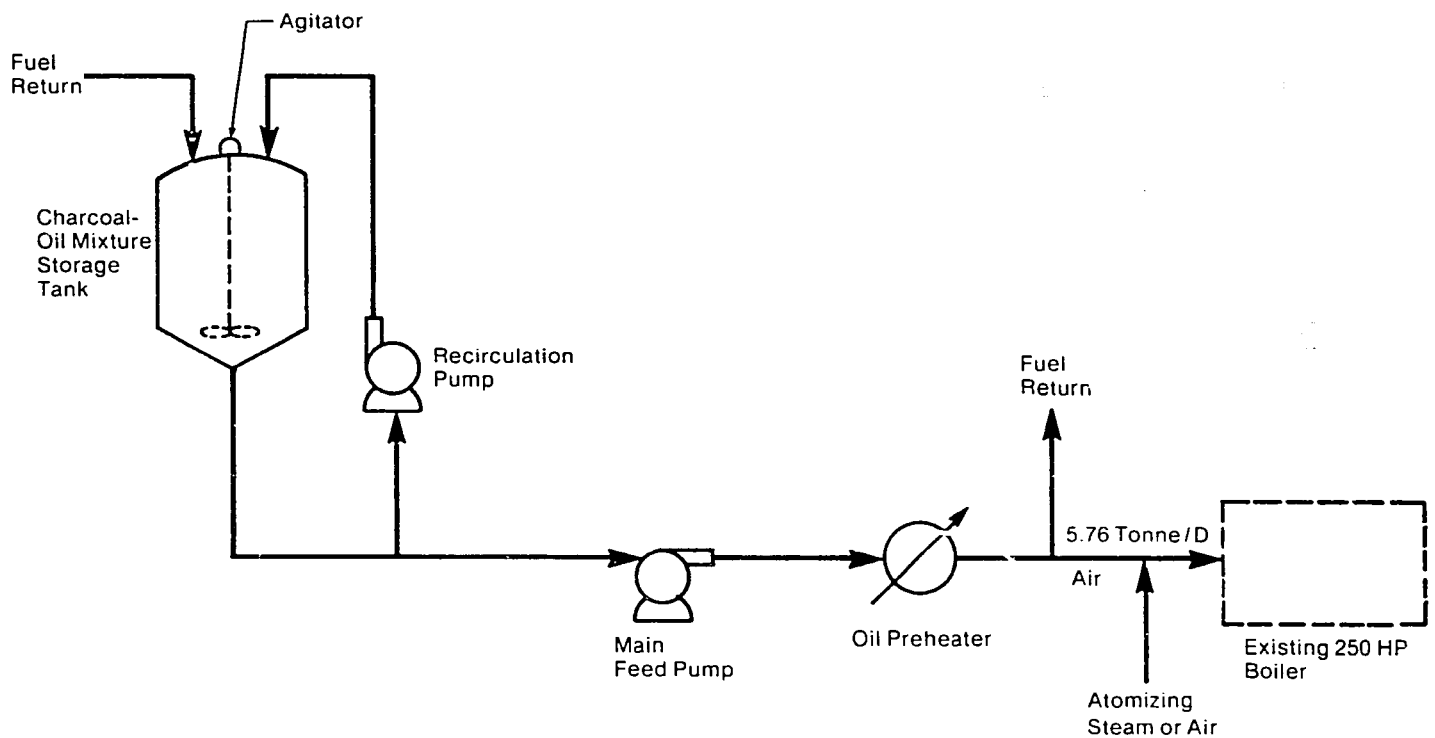
Supervisory	0.5 M/hr
General	3.0M/hr

Utilities:

Electricity	60kw

H.V. of Fuel 18.7 MM Btu/ODT Wood
Moisture Content of Fuel: 43% on dry basis
Boiler Efficiency: 0.80
Gasifier Efficiency: 0.70
Additional Land Required: 0.4 hectares

FIGURE 4-5
OPTION 4: RETROFIT LBG WOOD GASIFIER—250 HP BOILER



Fuel System Equipment:
- Storage tank w/agitator—175 tonne
- Abrasive slurry pumps
- Oil preheater
- Corrosive resistant pipes and valves
- Electrical and instrumentation
- Modified (COM) burner

Estimated Delivered Cost K36,400

Labor Requirements:

Supervisory	0.33 M/hr
General	1.0M/hr

Utilities:

Electricity	17kw

H.V. of Fuel: 34.9 MM Btu/tonne COM

Boiler Efficiency: 0.80

FIGURE 4-6
OPTION 5: RETROFIT 50/50 CHARCOAL-OIL MIXTURE FUEL SYSTEM—250 HP BOILER

TABLE 4-IV

CASE A: INITIAL COST AND OPERATING PARAMETER ESTIMATES

OPTIONS / COSTS IN KINA	#6 OIL	#2 OIL	70/30 MIX	100% PYROLYTIC	LBG-CHARCOAL	LBG-WOOD	50/50 COM
CAPITAL INVESTMENT	26,930	26,930	44,670	39,280	191,840	325,070	57,660
WORKING CAPITAL	28,060	47,580	24,860	22,700	28,770	23,590	25,670
TOTAL INITIAL CAPITAL INVESTMENT	54,990	74,510	69,530	61,980	220,610	248,660	83,330
INITIAL ANNUAL COSTS:							
PRIMARY FUEL	256,440	451,690	218,360	197,950	209,520	117,360	221,200
OPERATING LABOR	18,250	18,250	20,580	20,580	36,500	47,740	20,580
UTILITIES	1,840	1,840	2,940	2,570	12,850	22,030	6,240
MAINTENANCE	4,040	4,040	6,700	5,890	28,780	48,760	8,650
TOTAL INITIAL ANNUAL OPERATING EXPENDITURES	280,570	475,810	248,580	226,990	287,660	235,890	256,670
EQUIPMENT COSTS	17,000	17,000	28,200	24,800	120,000	203,000	36,400
ADDITIONAL LAND COSTS	N/A	N/A	0	0	4,000	8,000	0
OPERATING PARAMETERS:							
FIH (10^{-3} tonne/hr)	198.4	198.4	277.1	317.1	380.4	639.2	240.0
SUVPL (m/hr)	0.25	0.25	0.33	0.33	0.50	0.50	0.33
GENL (m/hr)	1.0	1.0	1.0	1.0	2.0	3.0	1.0
ELI (KW)	5.0	5.0	8.0	7.0	35.0	50.0	17.0
PCOIL	1.0	1.0	0.245	0.0	0.0	0.0	0.50
HRIND (hr)	24	24	24	24	24	24	24
ALOAD	0.85	0.85	0.85	0.85	0.85	0.85	0.85

TABLE 4-V

CASE A: SENSITIVITY ANALYSIS OF NPV (x 10^3 KINA); i* = 0.11

SENSITIVITY PARAMETER \ OPTIONS / BASE FUEL	70/30		100% PYROLYTIC		LBG-CHARCOAL		LBG WOOD		50/50 COMB.	
	#6 OIL	#2 OIL	#6 OIL	#2 OIL	#6 OIL	#2 OIL	#6 OIL	#2 OIL	#6 OIL	#2 OIL
BASELINE	240	1740	409	1909	-111	1389	236	1736	175	1675
EQUIP + 25%	220	1720	391	1891	-195	1305	95	1595	149	1649
% Δ	(-8)	(-1)	(-4)	(-1)	(-76)	(-6)	(-60)	(-8)	(-15)	(-2)
EQUIP - 25%	260	1760	426	1926	-28	1472	377	1877	200	1700
FUELC + 25%	-10	1490	27	1527	-514	986	11	1511	47	1547
% Δ	(-104)	(-14)	(-93)	(-20)	(-363)	(-29)	(-95)	(-13)	(-73)	(-8)
FUELC - 25%	491	1991	789	2289	291	1791	461	1961	302	1802
HRIND = 16 HR	150	1150	265	1265	-170	830	-17	984	98	1098
% Δ	(-38)	(-34)	(-35)	(-34)	(-53)	(-40)	(-107)	(-43)	(-44)	(-34)
FIH + 25%	-180	1320	28	1528	-514	986	11	1511	-250	1250
% Δ	(-175)	(-24)	(-93)	(-20)	(-363)	(-29)	(-95)	(-13)	(-243)	(-25)
FIH - 25%	660	2160	789	2289	291	1791	401	1961	600	2100
INSTAL = ENGIN = 0.10 (-50%)	245	1745	412	1912	-65	1435	319	1819	183	1683
% Δ	(+2)	(+ .2)	(+ .7)	(+ .2)	(+41)	(+3)	(+35)	(+5)	(+5)	(+ .5)
INSTAL = ENGIN = 0.30 (+50%)	235	1735	405	1905	-161	1339	146	1646	165	1665
MAINT = 0.10 (-33%)	246	1746	412	1912	-60	1440	329	1829	184	1684
% Δ	(+3)	(+ .3)	(+ .7)	(+ .2)	(+46)	(+4)	(+39)	(+5)	(+5)	(+ .5)
MAINT = 0.20 (+33%)	234	1734	405	1905	-163	1337	143	1643	165	1665
WAGES (+ 100%)	225	1725	394	1894	-226	1274	51	1551	160	1660
% Δ	(-6)	(- .9)	(-4)	(- .8)	(-104)	(-8)	(-78)	(-11)	(-9)	(- .9)
CONTIN = 0.20 (+100%)	237	1737	407	1907	-138	1362	188	1688	170	1670
% Δ	(-1)	(- .2)	(- .5)	(- .1)	(-24)	(-2)	(-20)	(-3)	(-3)	(- .3)
$FO = FW = F_{OL} = F_{ut} = F_{ma} = 0.0$	131	1018	233	1121	-166	722	-38	849	84	971
% Δ	(-45)	(-41)	(-43)	(-41)	(-50)	(-48)	(-116)	(-51)	(-52)	(-42)
N = 10	164	1227	285	1348	-135	927	66	1129	113	1175
% Δ	(-32)	(-29)	(-30)	(-29)	(-22)	(-33)	(-72)	(-35)	(-35)	(-30)

% Δ = percent change in value from the baseline value.

TABLE 4-VI

CASE A: SENSITIVITY ANALYSIS OF NPV (x 10^3 KINA); $i^* = 0.20$

SENSITIVITY PARAMETER \ OPTIONS / BASE FUEL	70/30		100% Pyrolytic		LBG-CHARCOAL		LBG WOOD		50/50 COMB.	
	#6 OIL	#2 OIL	#6 OIL	#2 OIL	#6 OIL	#2 OIL	#6 OIL	#2 OIL	#6 OIL	#2 OIL
BASELINE	134	1018	235	1120	-138	745	7	892	89	974
EQUIP + 25%	117	1002	221	1106	-208	677	-109	775	68	953
%Δ	(-13)	(-2)	(-6)	(-1)	(-51)	(-9)	(-1.7x10^3)	(-13)	(-24)	(-2)
EQUIP - 25%	150	1035	250	1134	-70	815	124	1009	110	995
FUELC + 25%	-14	871	11	895	-376	509	-126	759	14	899
%Δ	(-110)	(-14)	(-95)	(-20)	(-172)	(-32)	(-1.9x10^3)	(-15)	(-84)	(-8)
FUELC - 25%	282	1166	460	1344	99	983	140	1025	164	1049
HRIND = 16 HR	81	670	151	741	-172	418	-139	451	45	634
%Δ	(-40)	(-34)	(-36)	(-34)	(-25)	(-44)	(-2.1x10^3)	(-49)	(-49)	(-35)
FIH + 25%	-114	771	11	896	-376	509	-126	759	-161	723
%Δ	(-185)	(-24)	(-95)	(-20)	(-172)	(-32)	(-1.9x10^3)	(-15)	(-280)	(-26)
FIH - 25%	381	1266	460	1345	99	983	140	1025	340	1225
INSTAL = ENGIN = 0.10 (-50%)	1378	1023	2382	1123	-1008	785	7604	961	9635	981
%Δ	(+928)	(+.5)	(+914)	(+.3)	(-630)	(+5)	(+108.5x10^3)	(+8)	(+10.7x10^3)	(+.7)
INSTAL = ENGIN = 0.30 (+50%)	129	1014	232	1117	-180	705	-67	817	81	966
MAINT = 0.10 (-33%)	137	1022	238	1123	-107	778	65	949	95	980
%Δ	(+2)	(+.3)	(+1)	(+.3)	(+22)	(+4)	(+829)	(+6)	(+7)	(+.6)
MAINT = 0.20 (+33%)	130	1015	233	1118	-171	714	-50	835	83	968
WAGES (+ 100%)	125	1010	226	1111	-209	676	-106	779	80	965
%Δ	(-7)	(-.8)	(-4)	(-.8)	(-5)	(-9)	(-1.6x10^3)	(-13)	(-10)	(-.9)
CONTIN = 0.20 (+100%)	131	1016	234	1119	-161	724	-32	353	85	970
%Δ	(-2)	(-.2)	(-.4)	(-.09)	(-17)	(-3)	(-557)	(-4)	(-4)	(-.4)
$FO = FW = F_{OL} = F_{ut} = F_{ma} = 0.0$	79	658	148	726	-165	413	-128	450	44	622
%Δ	(-41)	(-35)	(-37)	(-35)	(-20)	(-45)	(-1.9x10^3)	(-50)	(-51)	(-36)
N = 10	106	829	190	913	-147	576	-55	669	66	790
%Δ	(-21)	(-19)	(-19)	(-18)	(-7)	(-23)	(-886)	(-25)	(-26)	(-19)

%Δ = percent change in value from the baseline value

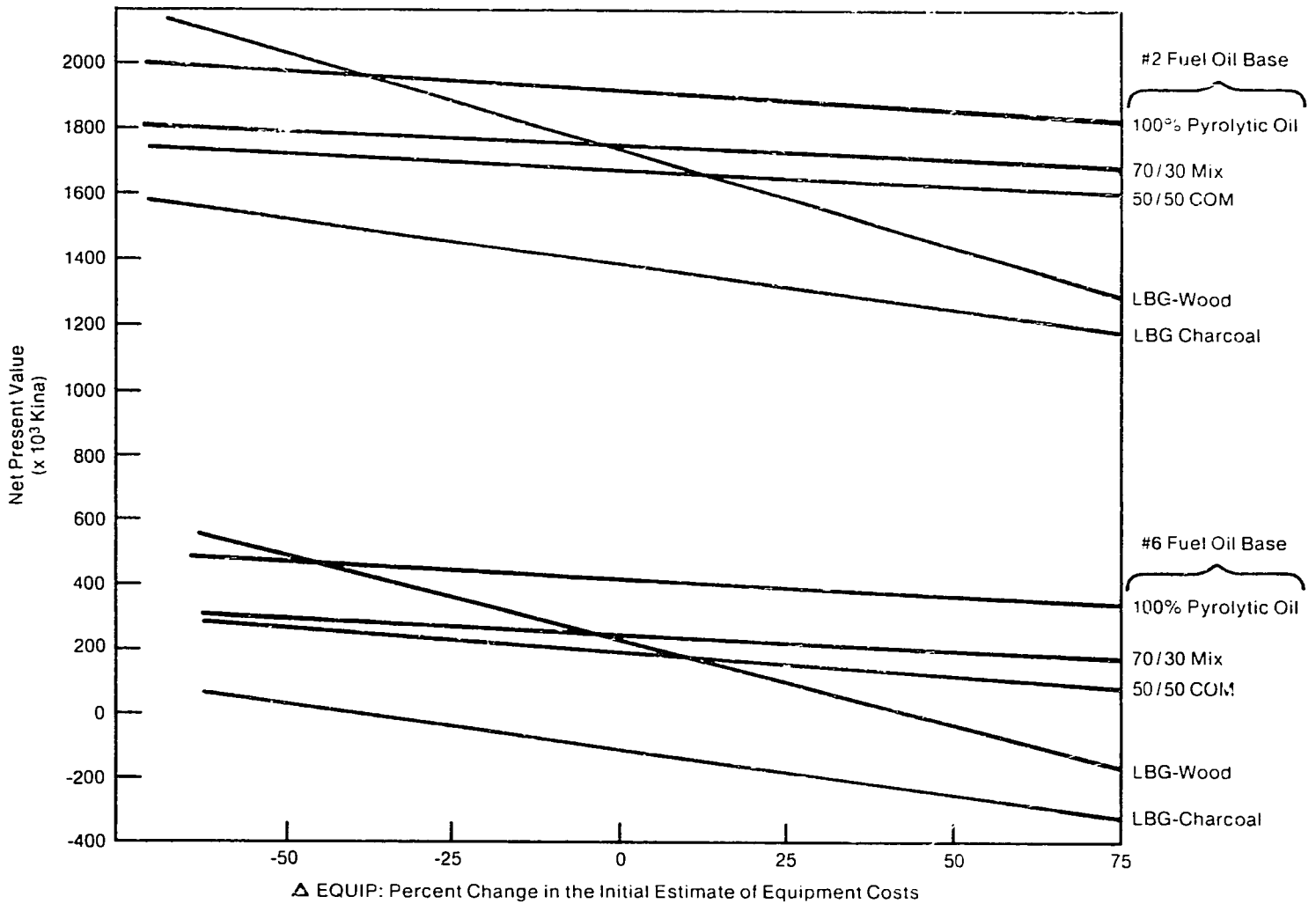


FIGURE 4-7
NPV (i* = 0.11) VS. CHANGE IN INITIAL ESTIMATES OF EQUIPMENT COST FOR 250 HP RETROFIT FUEL FEED SYSTEMS

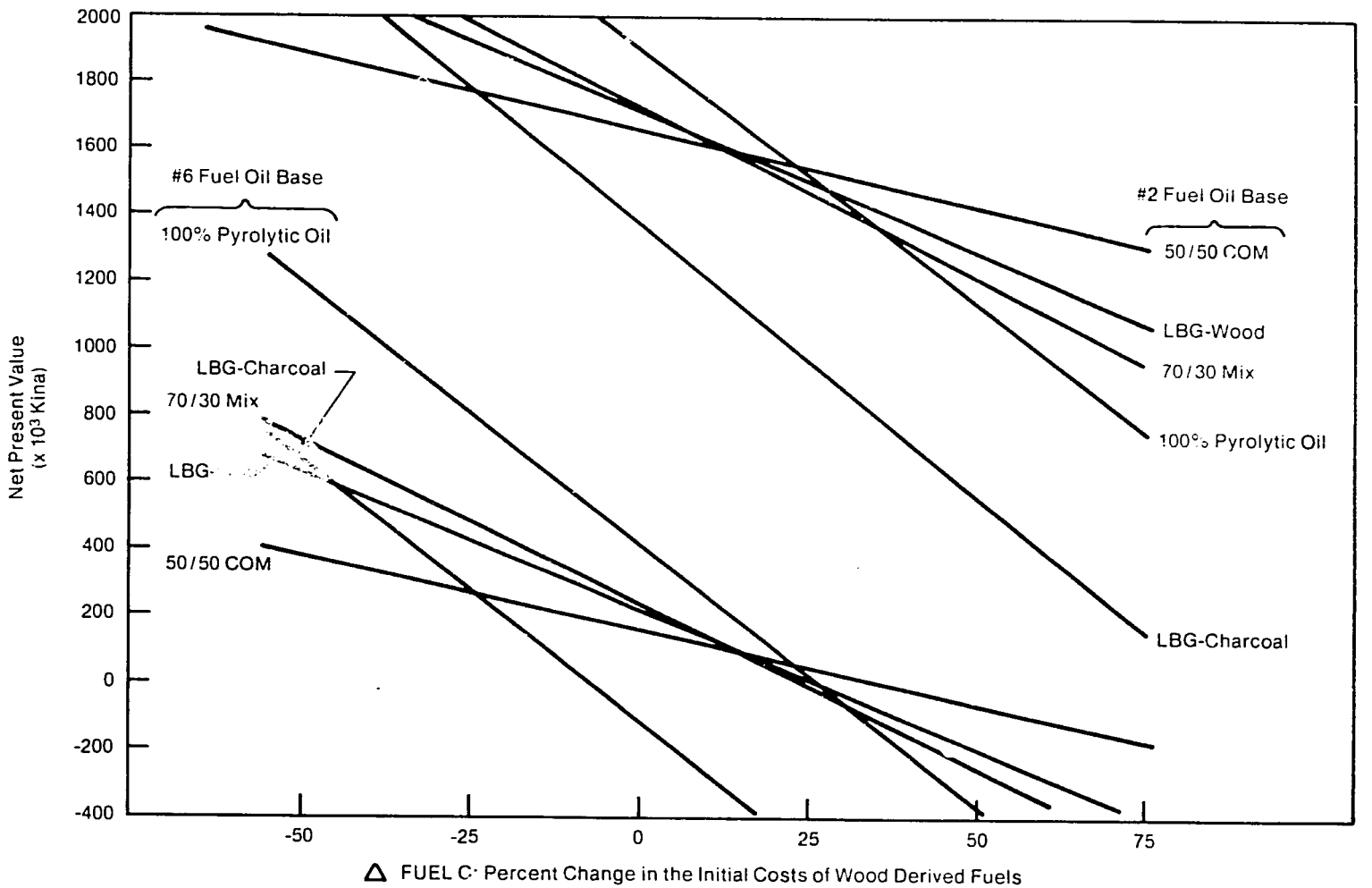


FIGURE 4-8
NPV (i* = 0.11) VS. CHANGE IN INITIAL COSTS OF WOOD-DERIVED FUELS FOR 250HP RETROFIT FUEL FEED SYSTEMS

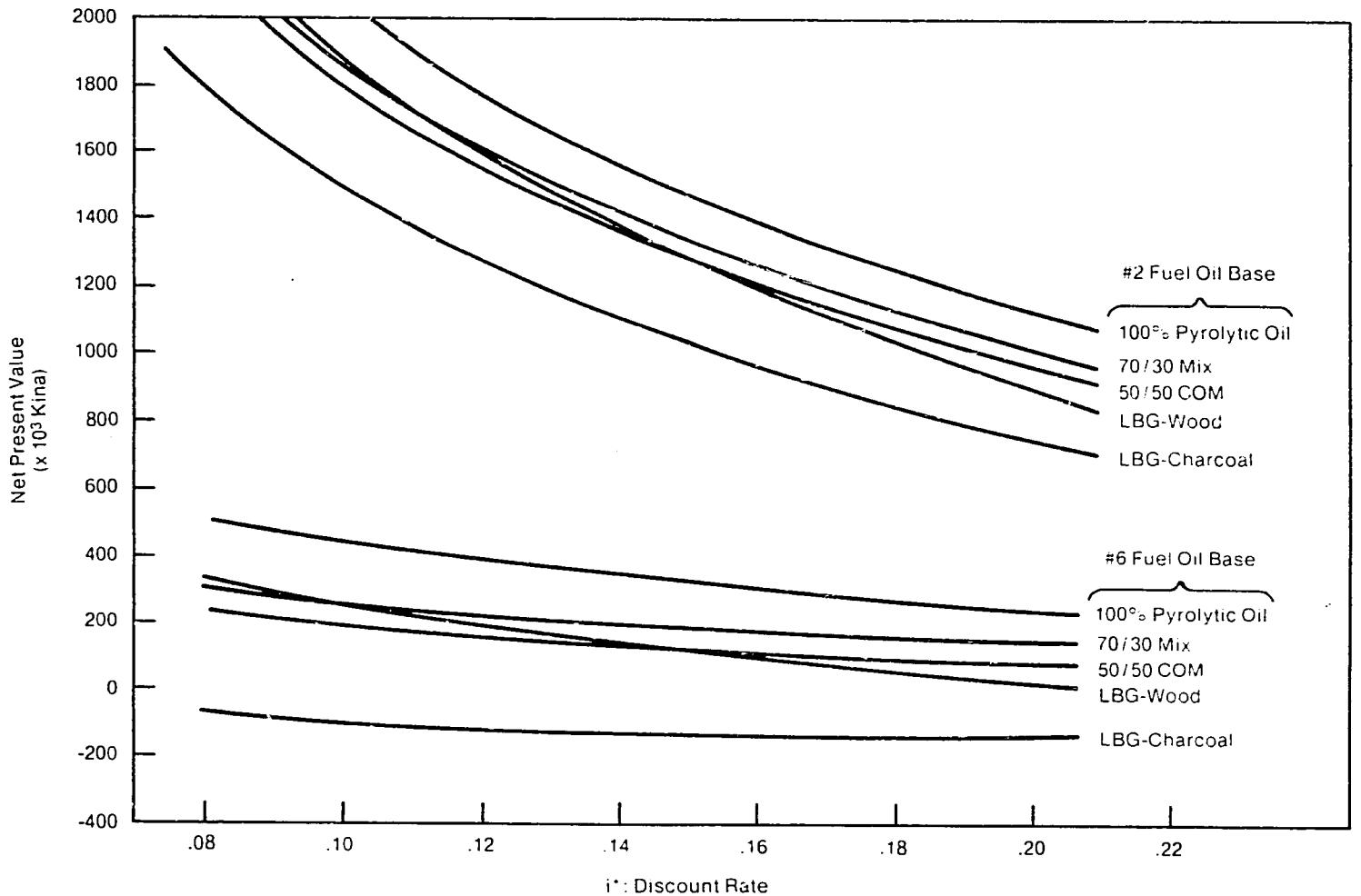


FIGURE 4-9
NPV VS. DISCOUNT RATE FOR 250 HP RETROFIT FUEL FEED SYSTEMS

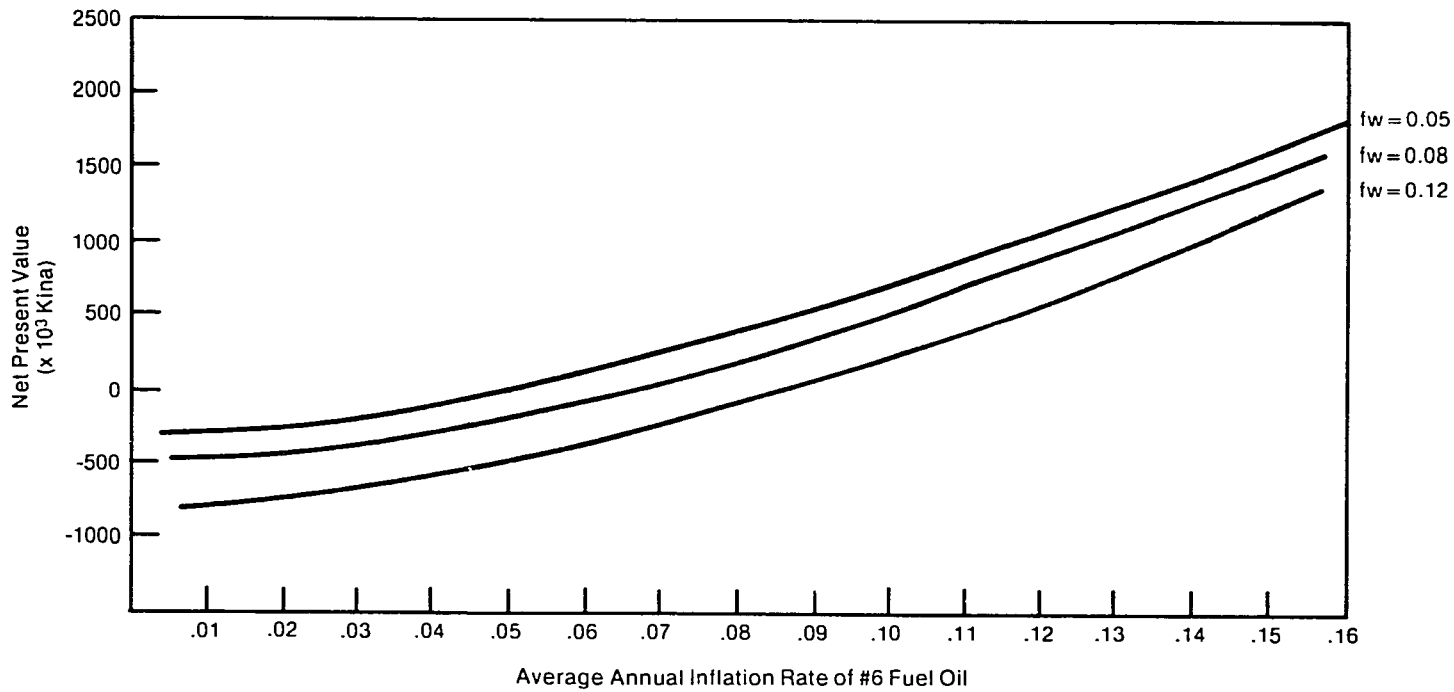


FIGURE 4-10
NPV (i* = 0.11) VS. AVERAGE ANNUAL INFLATION RATE OF #6 FUEL OIL: 250 HP RETROFIT LBG WOOD GASIFIER

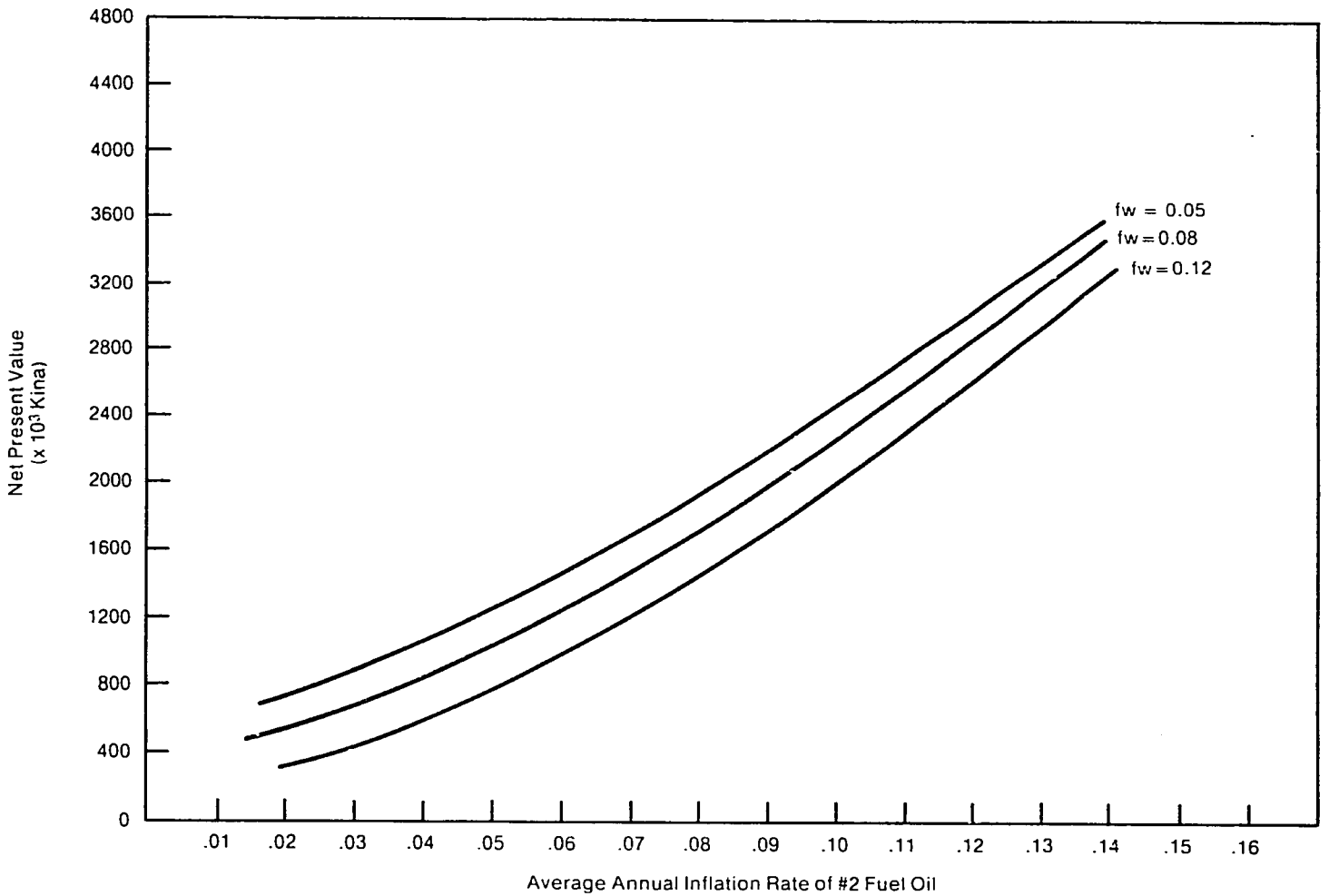


FIGURE 4-11
NPV (i* = 0.11) VS. AVERAGE ANNUAL INFLATION RATE OF #2 FUEL OIL: 250 HP RETROFIT LBG WOOD GASIFIER

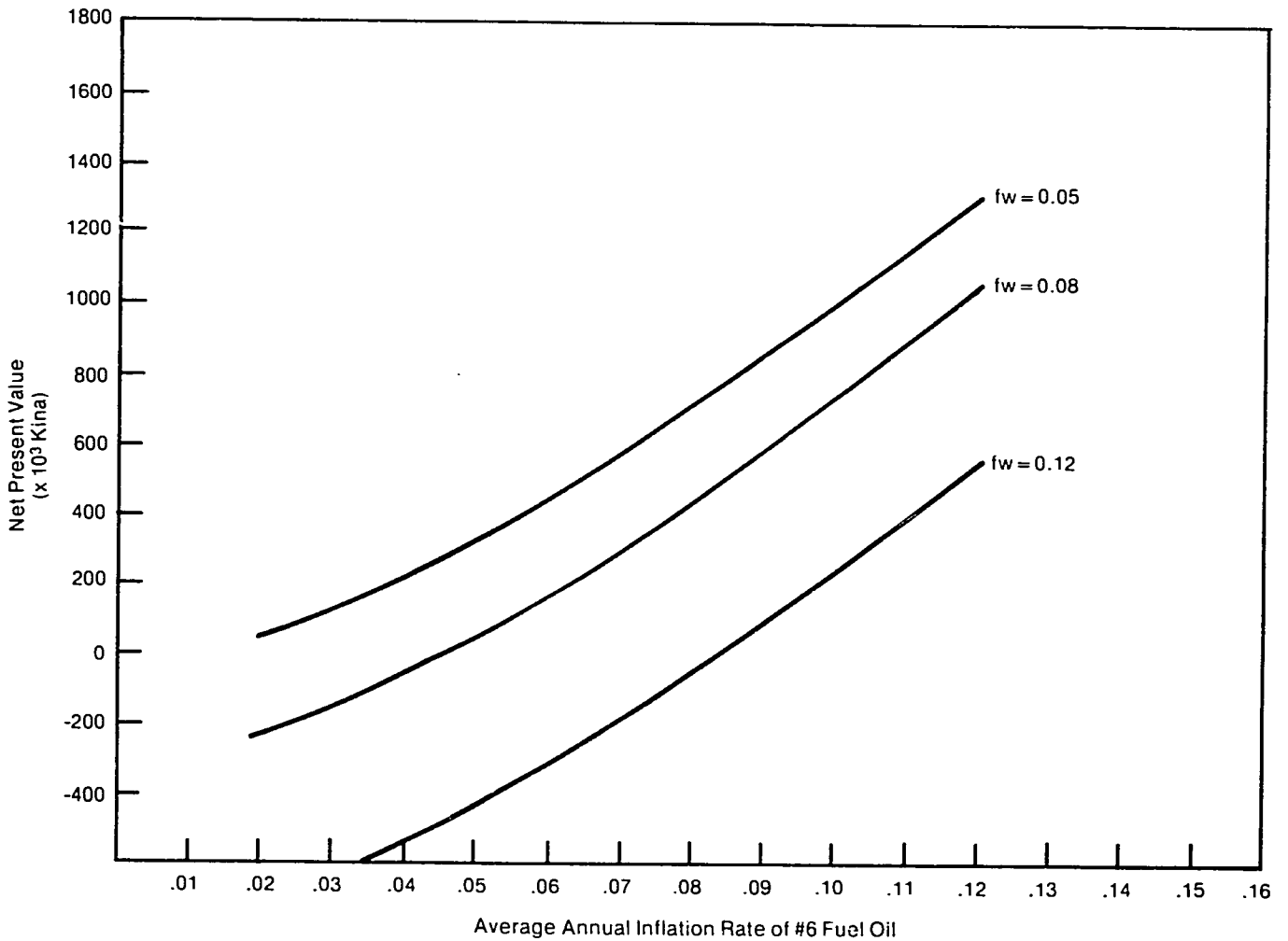


FIGURE 4-12
NPV(i* = 0.11) VS. AVERAGE ANNUAL INFLATION RATE OF #6 FUEL OIL: 250 HP RETROFIT 100% PYROLYTIC OIL SYSTEM

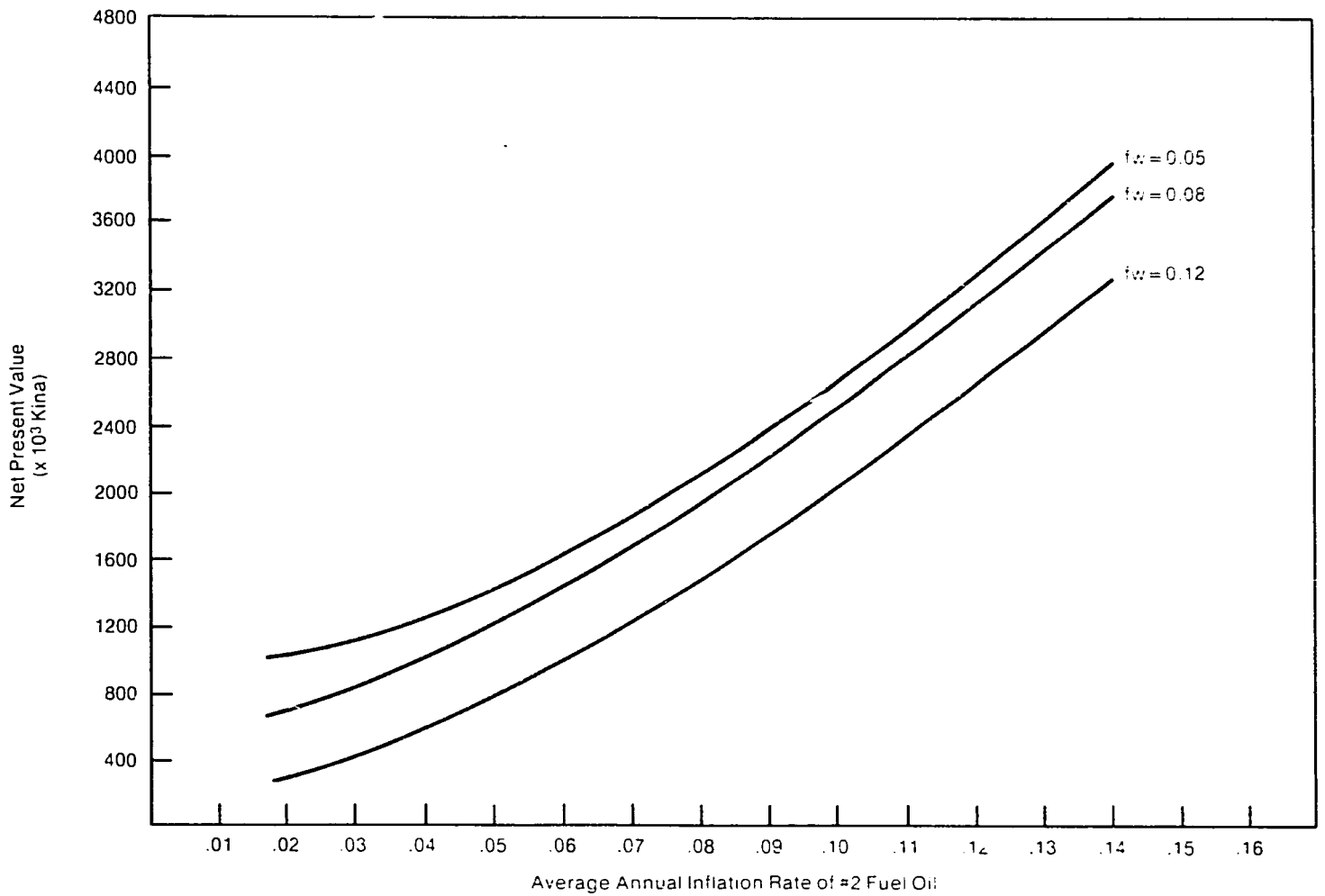


FIGURE 4-13
NPV(i* = 0.11) VS. AVERAGE ANNUAL INFLATION RATE OF #2 FUEL OIL: 250 HP RETROFIT 100% PYROLYTIC OIL SYSTEM

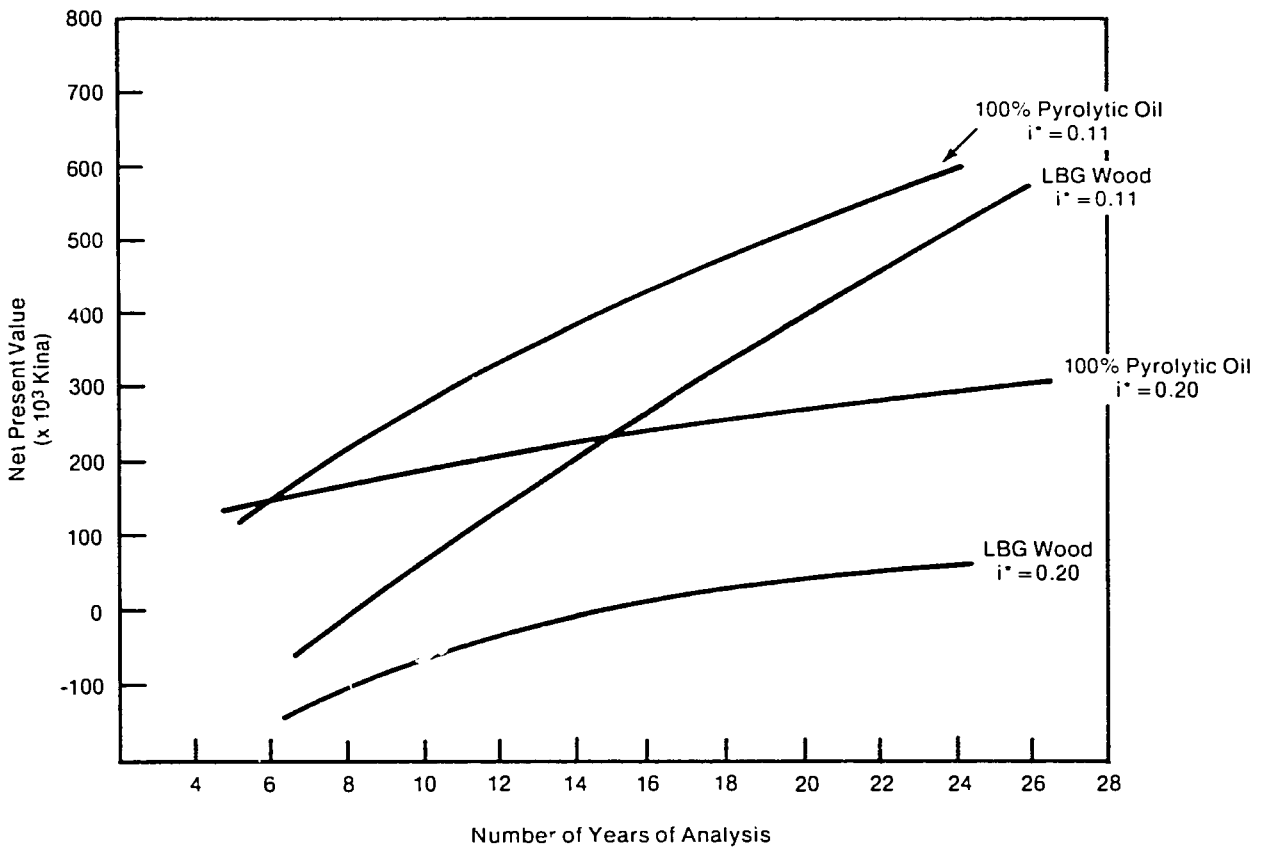


FIGURE 4-14
NPV VS. NUMBER OF YEARS OF THE ANALYSIS PERIOD:
250 HP RETROFIT FUEL FEED SYSTEMS COMPARED TO #6 OIL BASE CASE

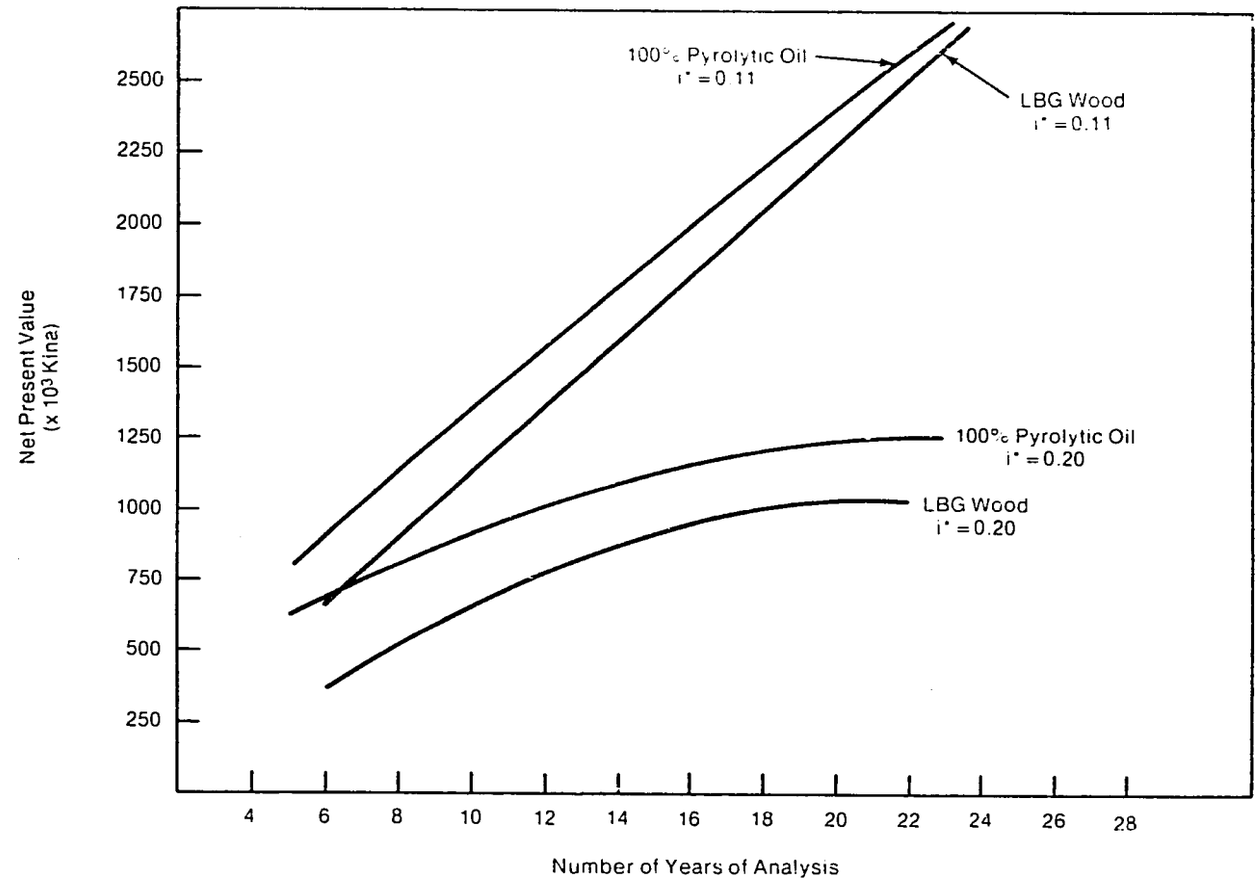


FIGURE 4-15
NPV VS. NUMBER OF YEARS OF THE ANALYSIS PERIOD:
250 HP RETROFIT FUEL FEED SYSTEMS COMPARED TO #2 OIL BASE CASE

Case B. New package boiler system (250, 500 and 1000 HP).

- System Description

The boiler is base loaded at 80 percent of its capacity, operates 24 hours per day and has an annual utility of 85 percent. Four options were analyzed including two base case petroleum fuel options.

Option 0-a: A residual fuel oil package boiler (see Figure 4-16).

Option 0-b: A distillate fuel oil package boiler (similar to Figure 4-16).

Option 1: An automatic stoker wood-fired package boiler (see Figure 4-17).

Option 3: An automatic stoker charcoal-fired package boiler (see Figure 4-18).

Three boiler sizes were analyzed to illustrate the economics of scale. Initial costs and operating parameters were estimated for each option in each size range. These data are presented in Table 4-VII. Only the additional land costs (over that needed for the oil system) were estimated for the wood-fired and charcoal-fired boiler systems.

- Results

The analysis of new boiler systems shows that both the wood-fired and charcoal-fired boilers are more economically attractive than either the residual oil-fired or distillate oil-fired boilers. Given the baseline assumptions, the NPV of the charcoal-fired boilers is generally higher than that for the wood-fired boilers. The

wood-fired boilers have a higher NPV at a low discount rate (e.g., $i^* = 0.11$) and large boiler size (e.g., greater than 600 HP). Figures 4-19 and 4-20 show the NPV of both the wood-fired and charcoal-fired boilers as a function of boiler size range. Figures 4-21 through 4-23 show the NPV as a function of the discount rate.

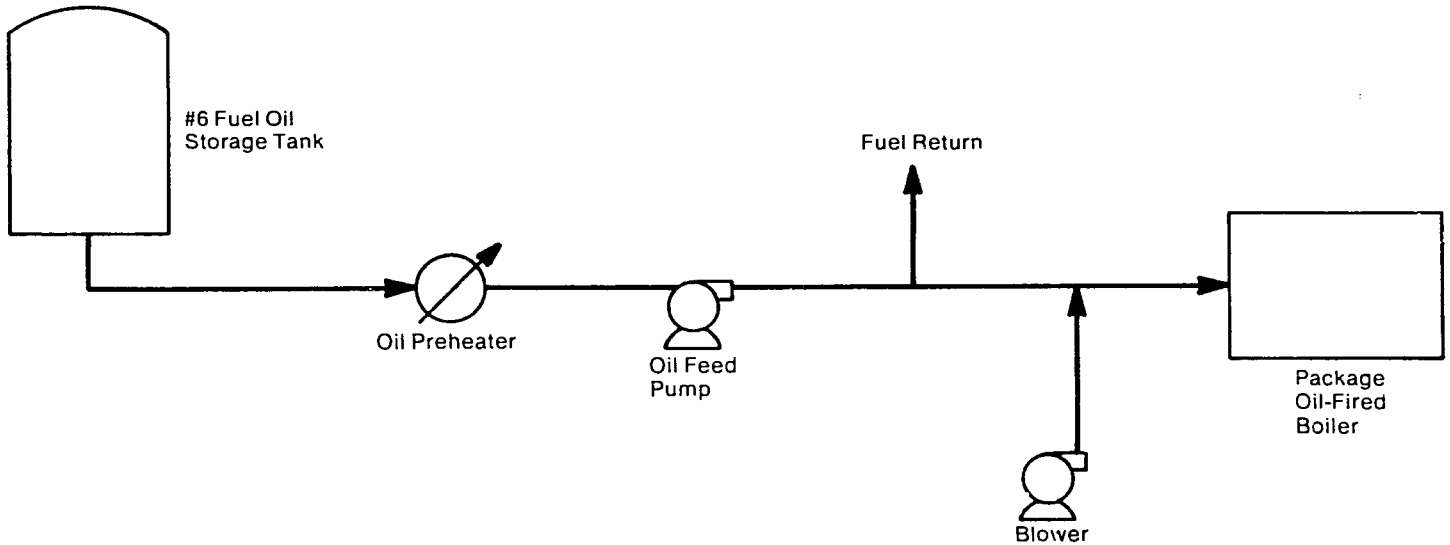
A change in the initial estimate of equipment costs as it impacts the NPV of the boiler systems is illustrated in Figures 4-24 through 4-29. These data indicate that an underestimate of the equipment costs would bias the analysis in favor of wood systems. The slopes of these graphs show that the NPV of the wood-fired boilers is more sensitive to equipment costs than that for the charcoal-fired boilers.

Figures 4-30 through 4-35 illustrate the sensitivity of NPV estimates for the wood- and charcoal-fired boilers as a function of changes in the estimated baseline price of wood fuel and charcoal. The fuel price differentials that yield equivalent NPVs for either boiler system can be determined from these plots. For example, the baseline NPV for a 250 HP wood-fired boiler compared to a residual oil-fired boiler at a discount rate of 11 percent is K289,000 (see Figure 4-30). The NPV for a 250 HP charcoal-fired boiler under similar assumptions is K382,000. The baseline fuel prices are K25/ODT for wood and K75/tonne for charcoal. Given the baseline NPV for the wood-fired boiler (K289,000), an equivalent NPV for the charcoal-fired boiler will result when the price of charcoal is 7 percent

higher than the K75/tonne charcoal baseline price. This is equivalent to a price differential of K5/tonne charcoal. The graphical method for determining this price differential is shown in Figure 4-30. These price differentials may be used to determine margins for fuel transportation or other costs over those assumed in the baseline analysis.[1]

Table 4-VIII summarizes the NPV analysis for Case B. The data for hours of daily operation (HRIND) indicates that the NPV of each fuel option drops rapidly as its average utilization declines. This suggests that wood- and charcoal-fired boilers should not be employed where average daily use is low (i.e., less than 10 hours per day).

[1]A maximum distance of 30 kilometers is assumed in the baseline prices of wood and charcoal.



Package Oil-Fired Boiler System:
- Fuel storage tank
- Fuel feed pumps
- Oil preheater
- Pipes and valves
- Electrical and instrumentation
- Oil burner
- Boiler

Estimated Delivered Costs:	250HP	K58,500
	500HP	K88,700
	1000HP	K134,000

Labor Requirements:
(See Table 4-VII)

Utilities: (See Table 4-VII)

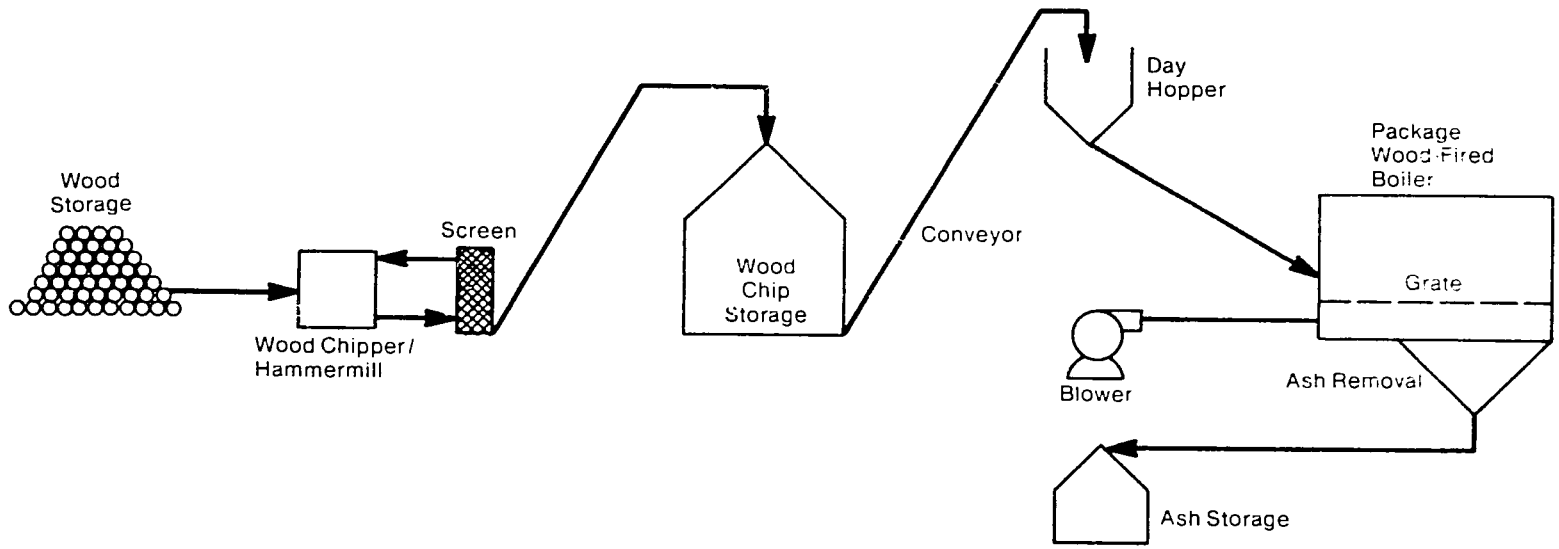
Daily Fuel Input:

250 HP	4.76 tonne/day
500 HP	9.52 tonne/day
1000 HP	19.04 tonne/day

H.V. of Fuel: 42.2 MM Btu/tonne #6 fuel oil

Boiler Efficiency: 0.80

FIGURE 4-16
OPTION 0: RESIDUAL FUEL OIL PACKAGE BOILER



Package Wood Fired Boiler Systems:

- Wood storage shed
- Wood chipper/hammermill and screens
- Conveyors
- Wood chip storage
- Day hopper
- Stoker
- Air cooled grate
- Ash removal and storage
- Boiler
- Electrical and instrumentation

Estimated Delivered Costs:		
	250 HP	K245,000
	500 HP	K399,000
	1000 HP	K549,000

Labor Requirements:

(See Table 4-VII)

Utilities: (See Table 4-VII)

Daily Fuel Input:

250 HP	13.2 ODT/day
500 HP	25.4 ODT/day
1000 HP	52.8 ODT/day

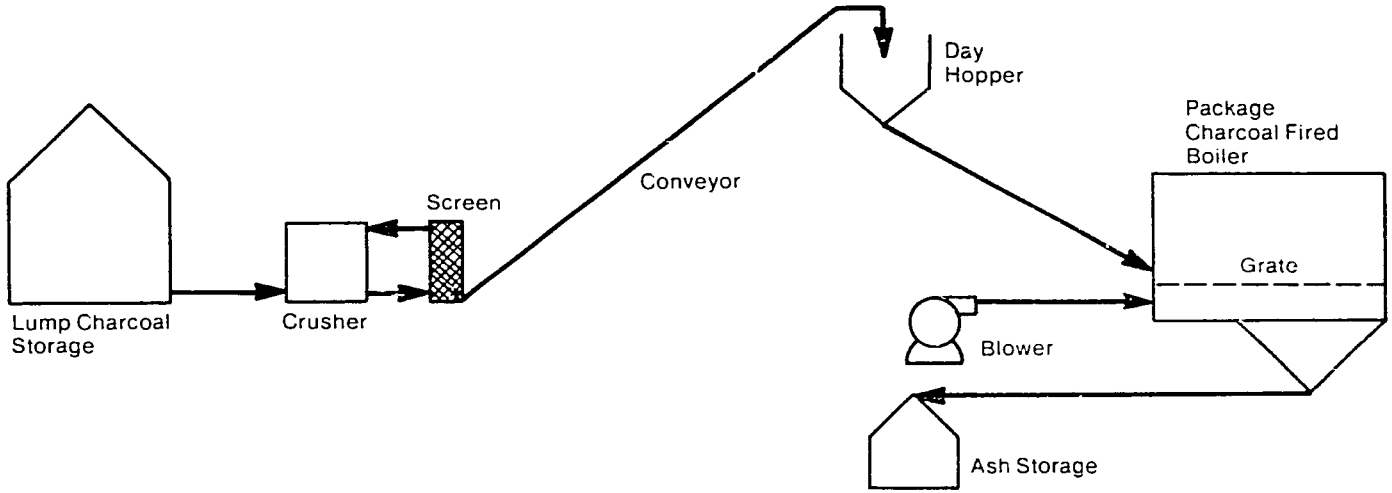
H.V. of Fuel: 18.7MM Btu/ODT wood

Moisture Content of Fuel: 43% on a dry basis

Boiler Efficiency: 0.65

Additional Land Required: 250 HP—0.35 hectares

FIGURE 4-17
OPTION 1: WOOD-FIRED PACKAGE BOILER



Package Charcoal-Fired Boiler System:

Lump charcoal storage
Crusher and screens
Conveyor
Day hopper
Stoker
Water cooled grate
Ash removal and storage
Boiler
Electrical and instrumentation

Estimated Delivered Costs:	250 HP	K106,250
	500 HP	K153,000
	1000 HP	K248,500

Labor Requirements:

(See Table 4-VII)

Utilities: (See Table 4-VII)

Daily Fuel Input:

250 HP	7.3 tonne/day
500 HP	14.6 tonne/day
1000 HP	29.2 tonne/day

H.V. of Fuel: 27.5 MM Btu/tonne charcoal

Boiler Efficiency: 0.80

Additional Land Required: 250 HP - 0.18 hectares

FIGURE 4-18
OPTION 2: CHARCOAL-FIRED PACKAGE BOILER

TABLE 4-VII

CASE B: INITIAL COSTS AND OPERATING PARAMETER ESTIMATES

COSTS IN KINA / OPTIONS	250 HP #6 OIL	250 HP #2 OIL	250 HP WOOD	250 HP CHARCOAL	500 HP #6 OIL	500 HP #2 OIL	500 HP WOOD	500 HP CHARCOAL	1000 HP #6 OIL	1000 HP #2 OIL	1000 HP WOOD	1000 HP CHARCOAL
CAPITAL INVESTMENT	92,660	92,660	391,160	169,840	140,500	140,500	638,180	245,430	212,260	212,260	1,040,340	399,780
WORKING CAPITAL	29,040	48,570	24,080	23,960	56,380	95,430	43,760	45,250	110,140	188,240	79,190	86,030
TOTAL INITIAL CAPITAL INVESTMENT	121,700	141,230	415,240	193,800	196,880	235,930	681,940	290,680	322,400	400,500	1,119,530	485,810
INITIAL ANNUAL COSTS:												
PRIMARY FUEL	256,440	451,690	101,130	167,610	512,880	903,370	202,330	335,220	1,025,760	1,806,740	404,470	670,320
OPERATING LABOR	18,250	18,250	58,970		26,200	26,200	95,470	54,760	36,500	36,500	143,210	78,620
UTILITIES	1,840	1,840	22,030	12,850	3,670	3,670	44,060	25,700	7,340	7,340	88,130	51,410
MAINTENANCE	13,900	13,900	58,670	25,480	21,080	21,080	95,730	36,810	31,840	31,840	156,050	59,970
TOTAL INITIAL ANNUAL OPERATING EXPENDITURES	290,430	485,680	240,800	239,640	563,830	954,320	437,590	452,490	1,101,440	1,882,420	791,860	860,320
EQUIPMENT COSTS	58,500	58,500	245,000	106,250	88,700	88,700	399,000	153,000	134,000	134,000	649,000	248,509
ADDITIONAL LAND COSTS	N/A	N/A	7,000	3,500	N/A	N/A	14,000	7,000	N/A	N/A	28,000	14,000
OPERATING PARAMETERS:												
FLR (10^{-3} tonne/hr)	198.4	198.4	550.8	304.3	396.8	396.8	1,101.6	608.6	793.6	793.6	2,203.2	1,217.3
SUVPL (m/hr)	0.25	0.25	0.5	0.4	0.33	0.33	1.0	0.75	0.5	0.5	1.5	1.0
GENL (m/hr)	1.0	1.0	4.0	2.0	1.50	1.5	6.0	3.0	2.0	2.0	9.0	4.5
ELI (KW)	5.0	5.0	60.0	35.0	10.0	10.0	120.0	70.0	20.0	20.0	240.0	140.0
PCOIL	1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0
HRIND (hr)	24	24	24	24	24	24	24	24	24	24	24	24
ALOAD	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85

TABLE 4-VIII

CASE B: SENSITIVITY ANALYSIS OF NPV (x 10^3 KINA)

OPTIONS / SENSITIVITY ANALYSIS	250HP WOOD		250HP CHARCOAL		500HP WOOD		500HP CHARCOAL		1000HP WOOD		1000HP CHARCOAL	
	#6 OIL	#2 OIL	#6 OIL	#2 OIL	#6 OIL	#2 OIL	#6 OIL	#2 OIL	#6 OIL	#2 OIL	#6 OIL	#2 OIL
$i^* = 0.11$												
BASELINE	289	1789	382	1882	829	3829	865	3866	2152	8152	1865	7865
EQUIP + 25%	119	1619	308	1808	552	3552	759	3759	1701	7701	1692	7692
EQUIP - 25%	460	1960	456	1956	1106	4106	972	3971	2603	8603	2037	8037
FUELC + 25%	95	1595	60	1560	440	3440	221	3222	1375	7375	577	6577
FUELC + 25%	484	1984	704	2204	1217	4217	1509	4509	2929	8929	3152	9152
HRIND = 16HR	19	1019	210	1210	262	2262	516	2516	952	4952	1135	5135
HRIND = 10HR	-184	441	81	706	-162	1088	254	1504	52	2553	587	3087
$i^* = 0.20$												
BASELINE	37	922	189	1074	265	2034	459	2229	896	4435	1009	4548
EQUIP + 25%	-104	781	128	1013	35	1805	371	2141	522	4061	866	4405
EQUIP - 25%	178	1063	250	1135	494	2264	547	2317	1269	4807	1151	4691
FUELC + 25%	-77	807	-1	884	36	1805	79	1849	437	3977	249	3788
FUELC - 25%	152	1037	379	1264	494	2264	839	2608	1354	4893	1768	5307
HRIND = 16HR	-119	470	89	679	-64	1116	255	1435	197	2556	582	2941
HRIND = 10HR	-237	132	14	382	-310	427	103	840	-327	1148	262	1737

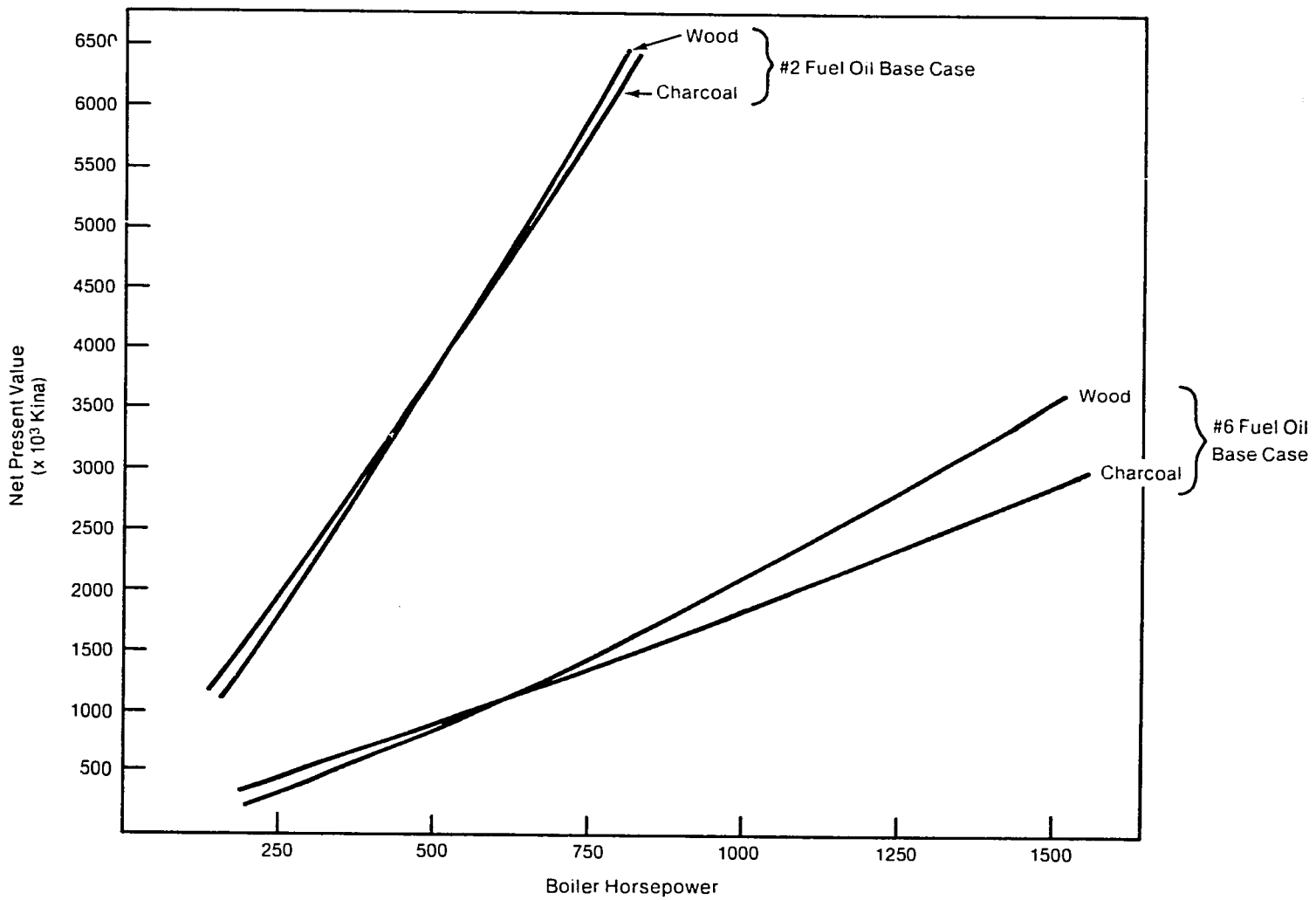


FIGURE 4-19
NPV (i* = 0.11) VS. BOILER SIZE: WOOD AND CHARCOAL BOILERS

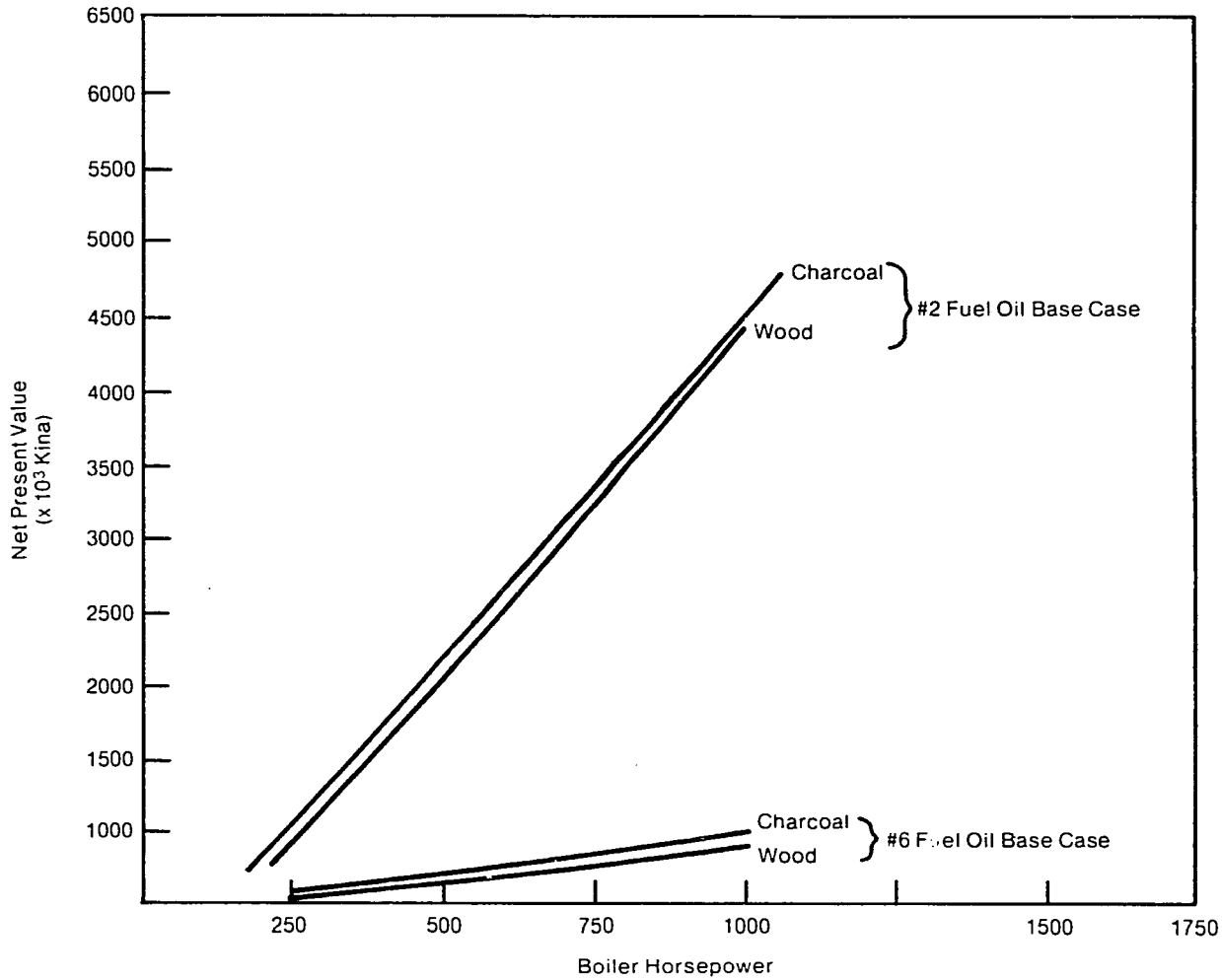


FIGURE 4-20
NPV (i* = 0.20) VS. BOILER SIZE:
WOOD AND CHARCOAL BOILERS

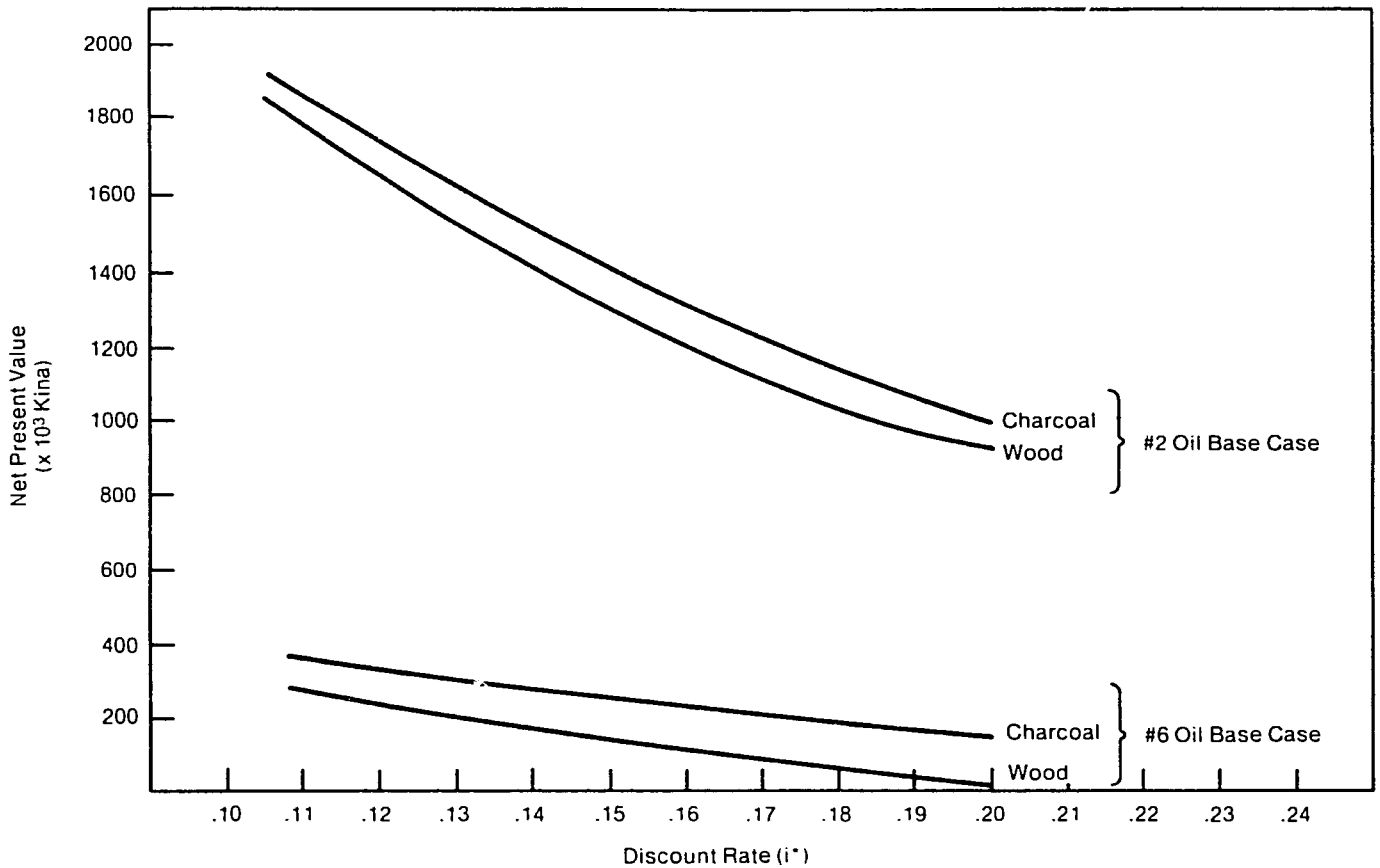


FIGURE 4-21
NET PRESENT VALUE VS. DISCOUNT RATE:
250 HP WOOD AND CHARCOAL BOILERS

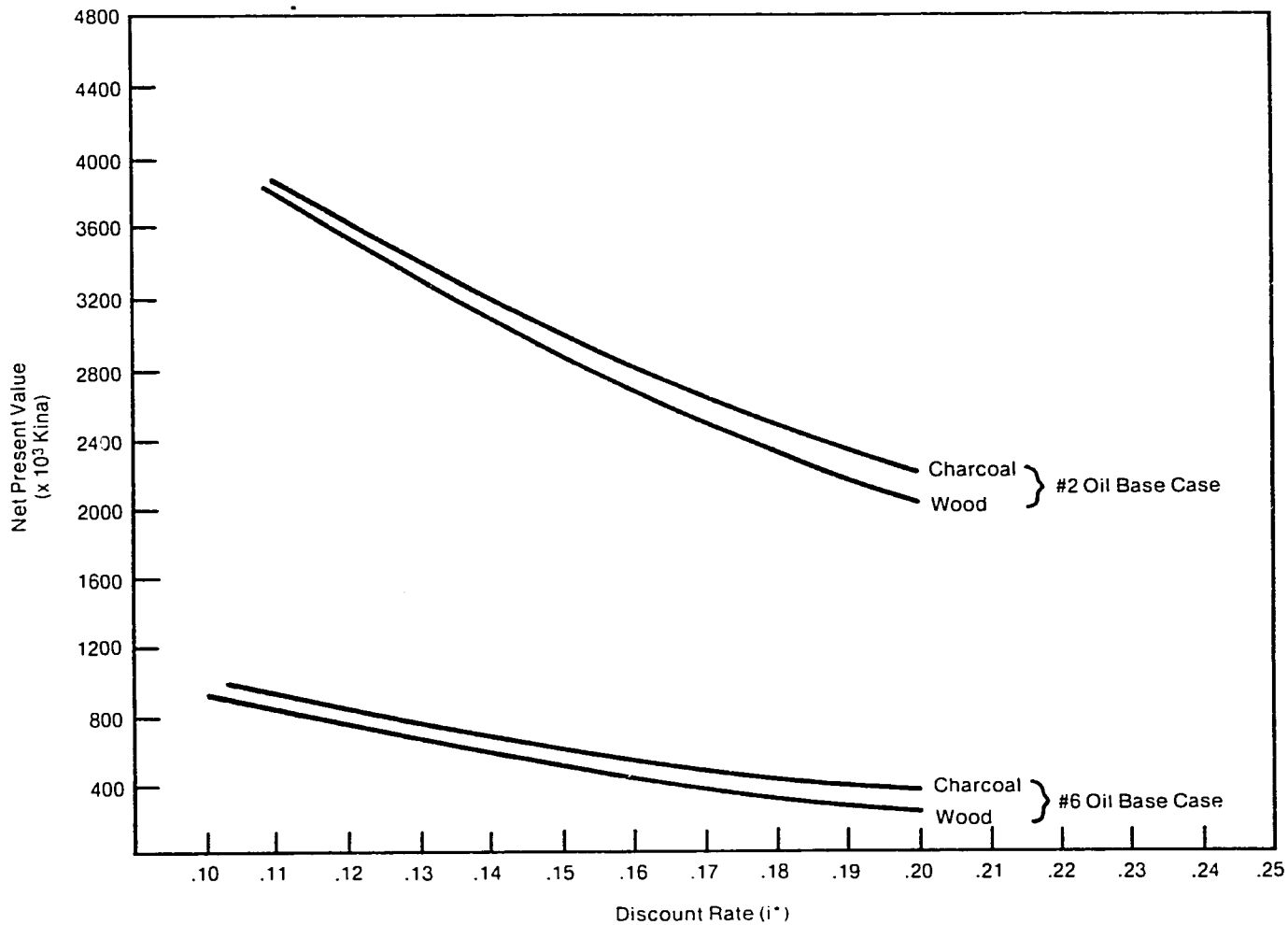


FIGURE 4-22
NET PRESENT VALUE VS. DISCOUNT RATE:
500 HP WOOD AND CHARCOAL BOILERS

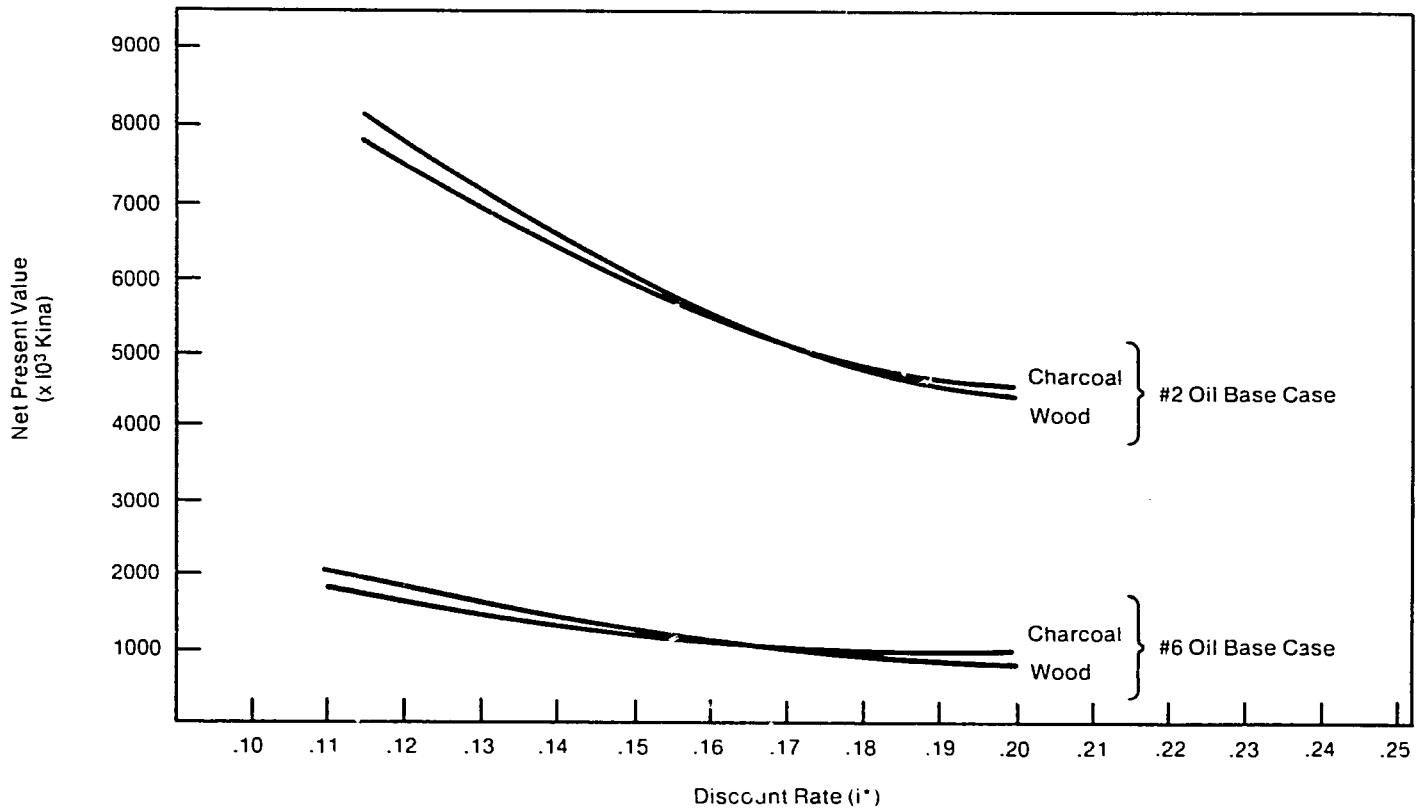


FIGURE 4-23
NET PRESENT VALUE VS. DISCOUNT RATE:
1000 HP WOOD AND CHARCOAL BOILERS

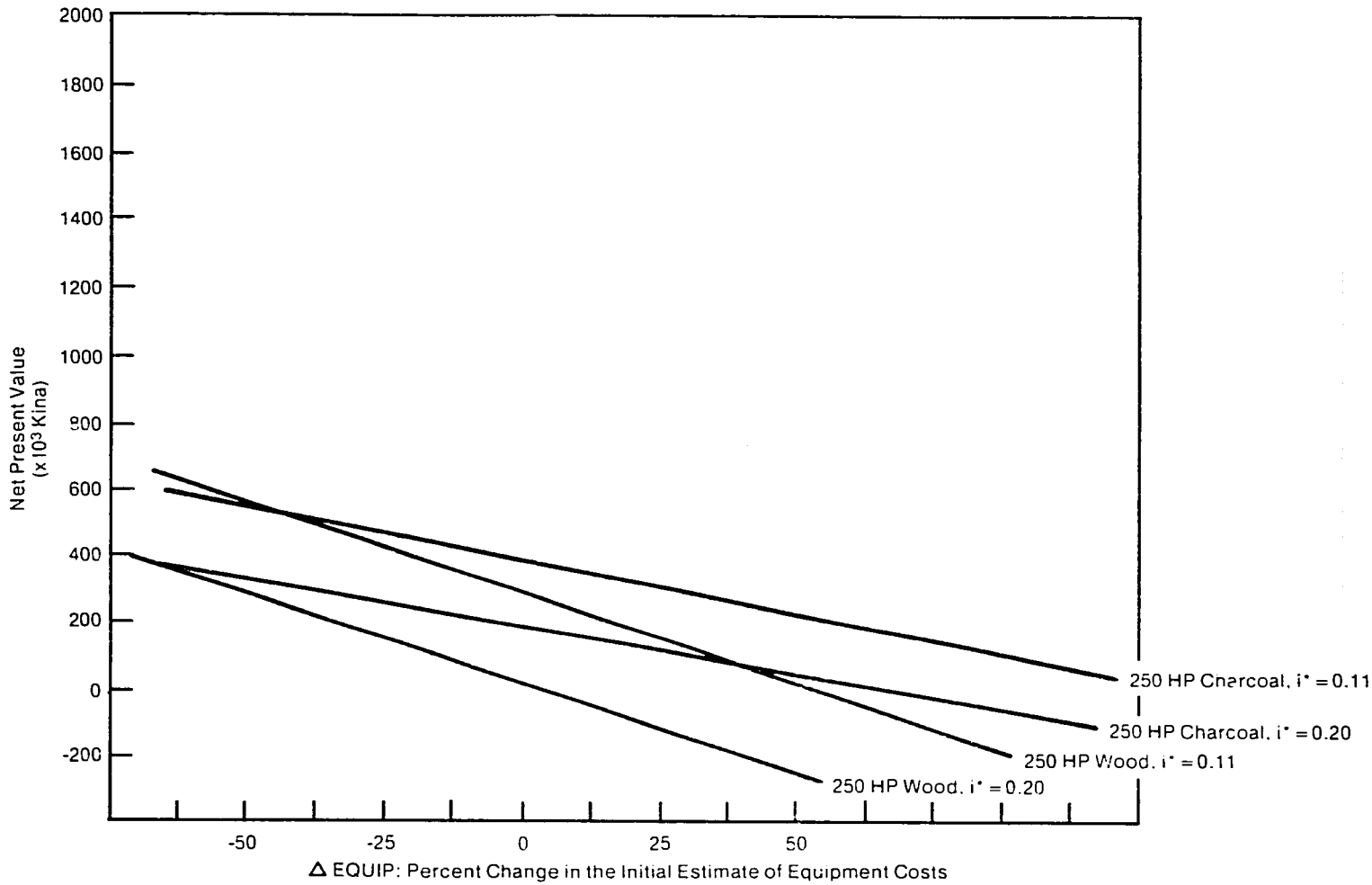


FIGURE 4-24
NPV VS. CHANGE IN INITIAL ESTIMATE OF EQUIPMENT COSTS: 250 HP WOOD AND CHARCOAL BOILERS COMPARED TO #6 OIL BASE CASE

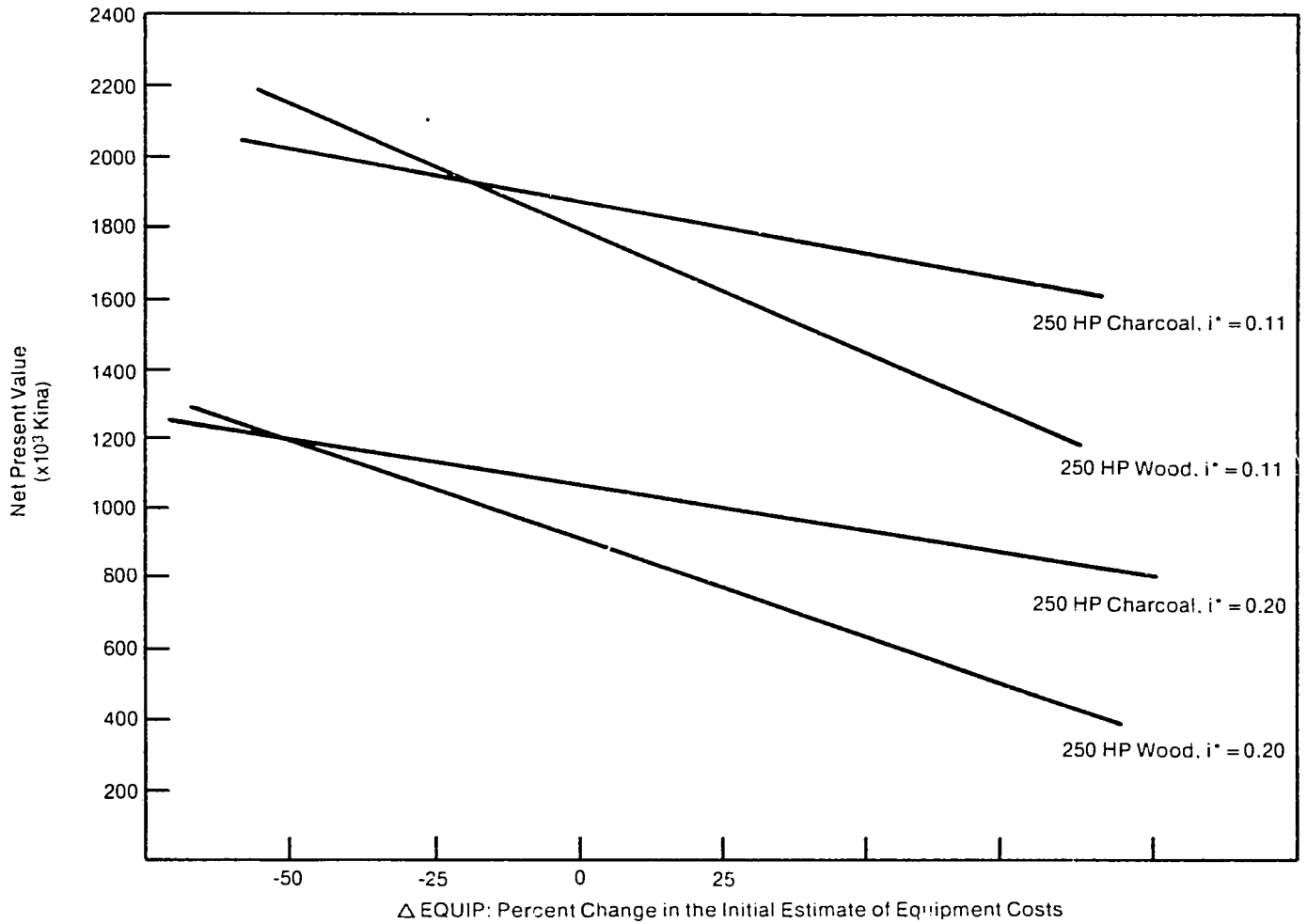


FIGURE 4-25
NPV VS. CHANGE IN THE INITIAL ESTIMATE OF EQUIPMENT COSTS: 250 HP WOOD AND CHARCOAL BOILERS COMPARED TO #2 OIL BASE CASE

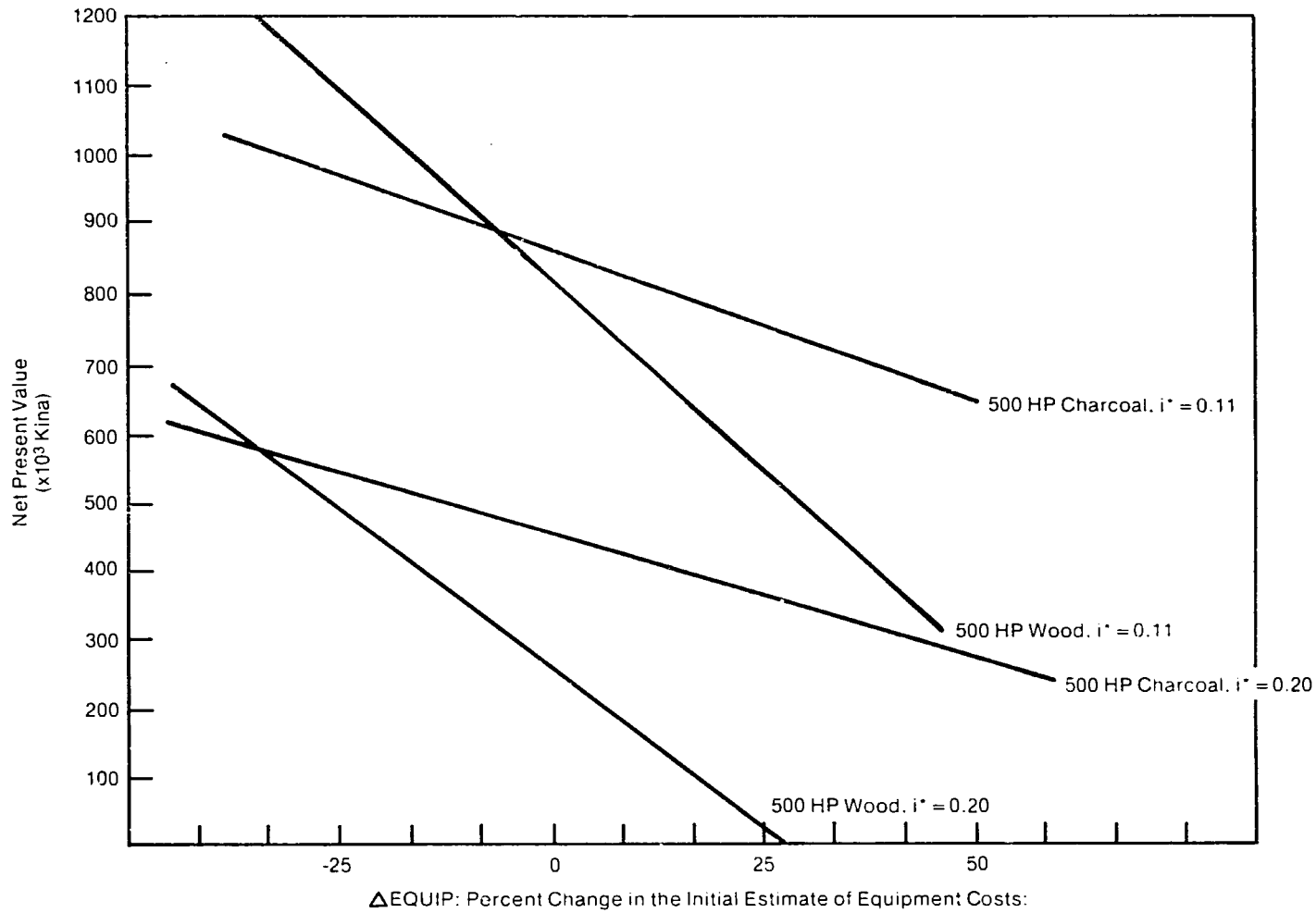


FIGURE 4-26
NPV VS. CHANGE IN INITIAL ESTIMATE OF EQUIPMENT COSTS: 500 HP WOOD AND CHARCOAL BOILERS COMPARED TO #6 OIL BASE CASE

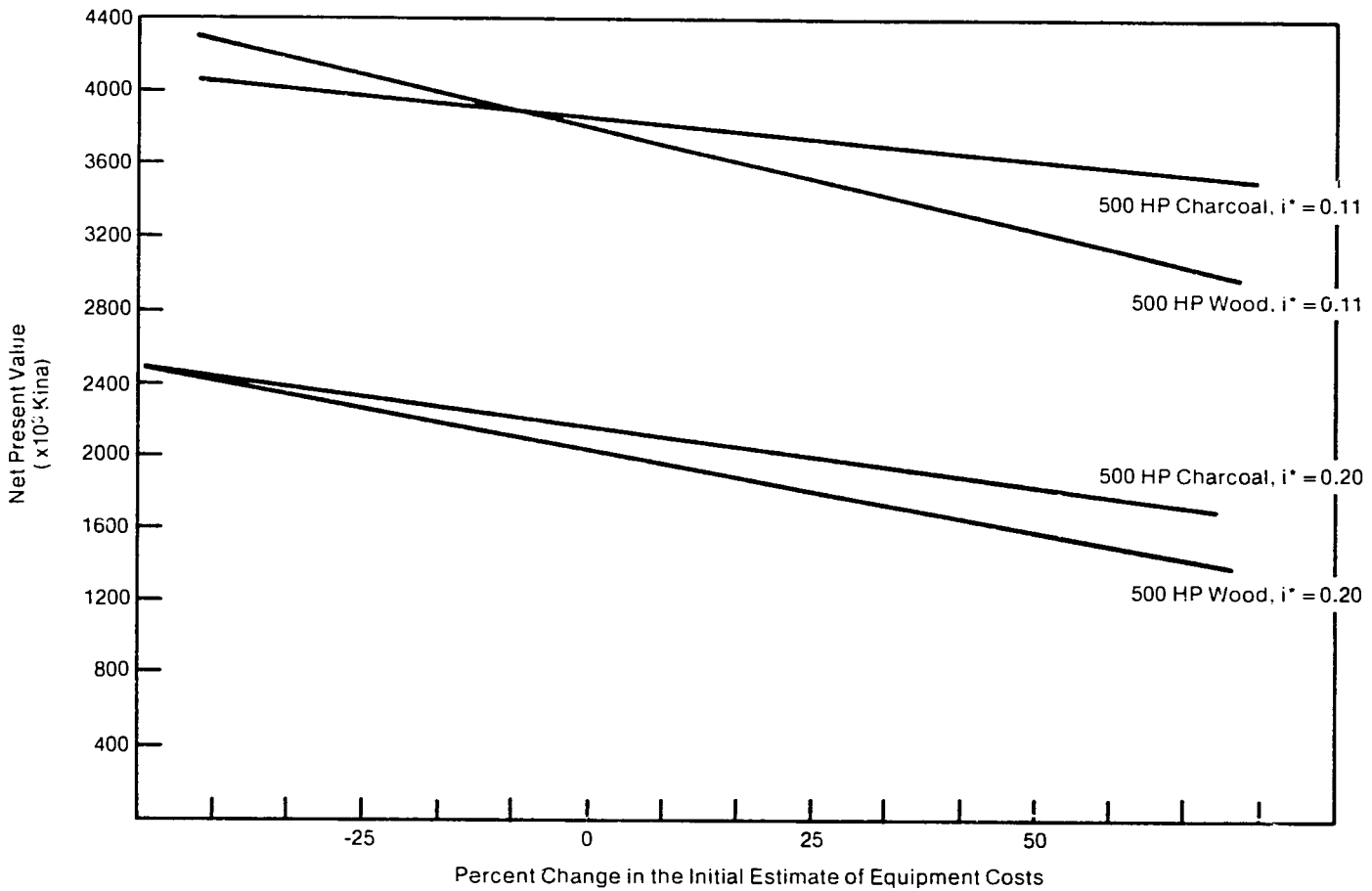


FIGURE 4-27
NPV VS. CHANGE IN THE INITIAL ESTIMATE OF EQUIPMENT COSTS:
500 HP WOOD AND CHARCOAL BOILERS COMPARED TO #2 OIL BASE CASE

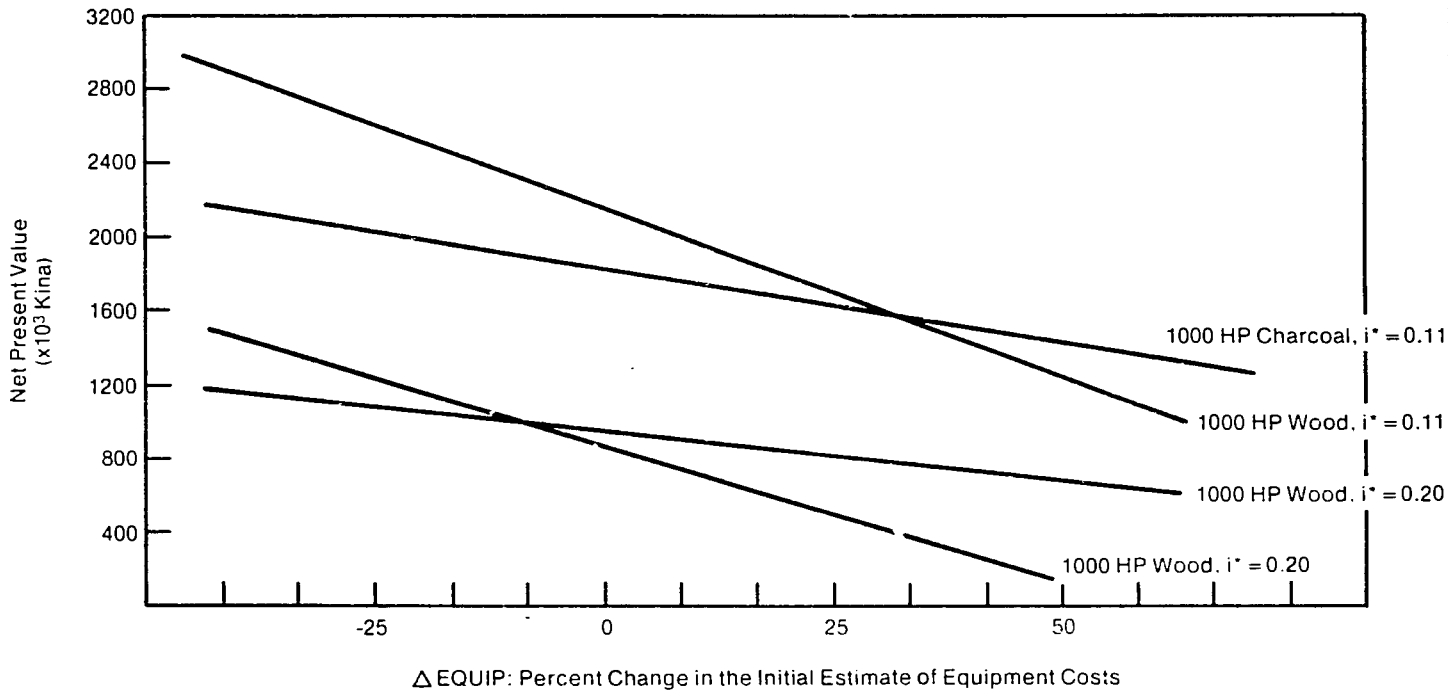


FIGURE 4-28
NPV VS. CHANGE IN THE INITIAL ESTIMATE OF EQUIPMENT COSTS:
1000 HP WOOD AND CHARCOAL BOILERS
COMPARED TO #6 OIL BASE CASE

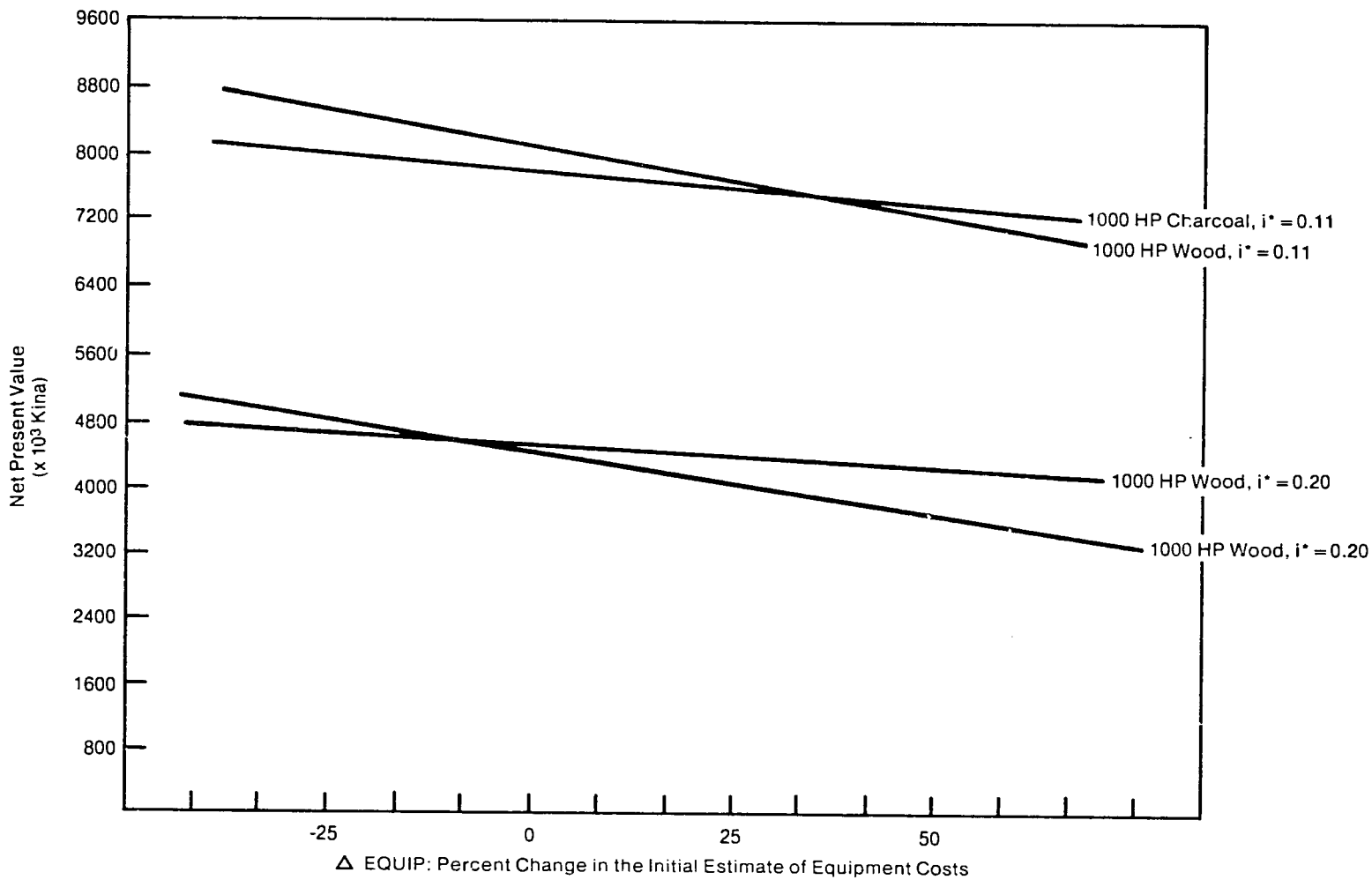


FIGURE 4-29
NPV VS. CHANGE IN THE INITIAL ESTIMATES OF EQUIPMENT COSTS:
1000 HP WOOD AND CHARCOAL BOILERS COMPARED TO #2 OIL BASE CASE

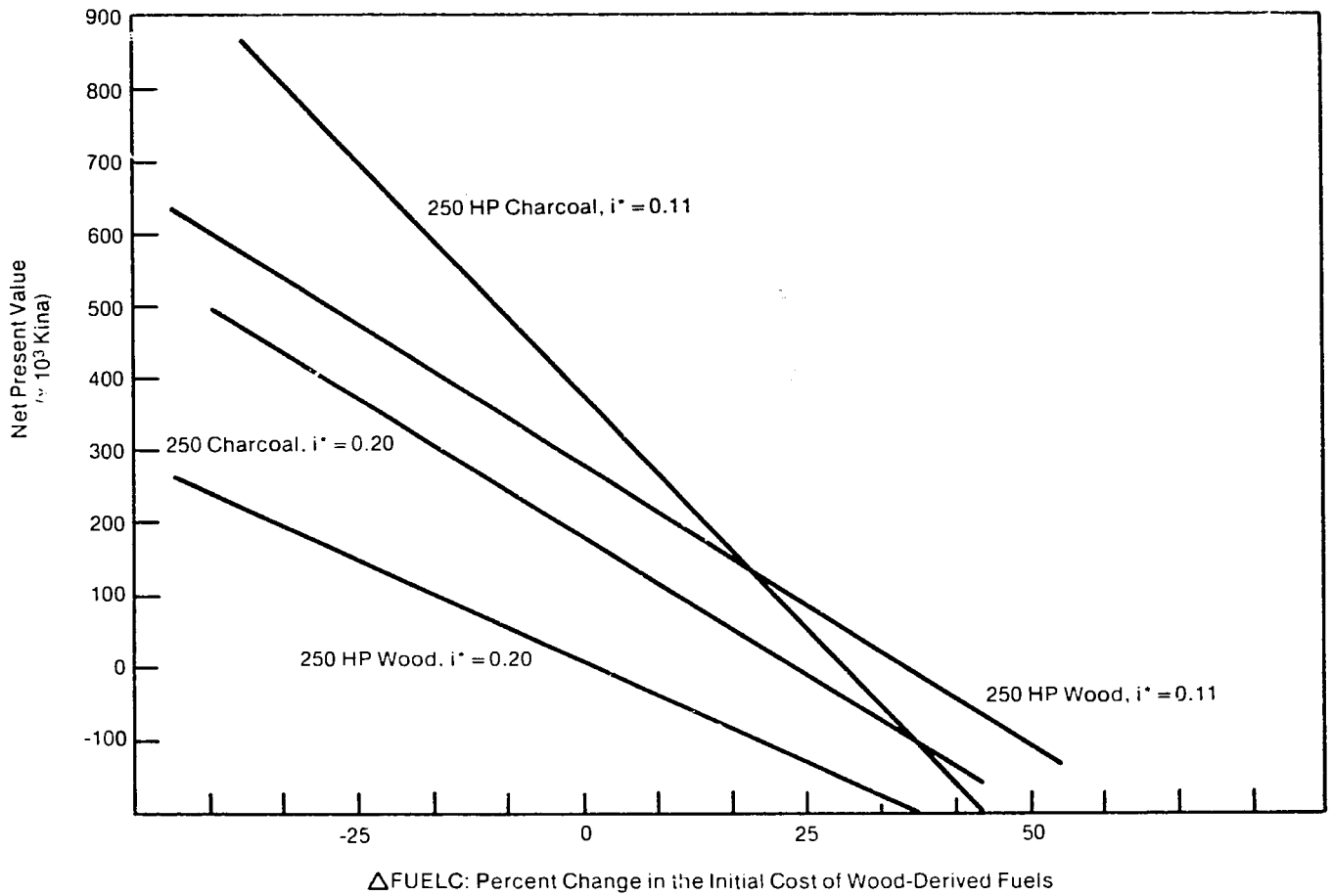


FIGURE 4-30
NPV VS. CHANGE IN THE INITIAL COST OF WOOD-DERIVED FUELS: 250 HP WOOD AND CHARCOAL BOILERS COMPARED TO #6 OIL BASE CASE

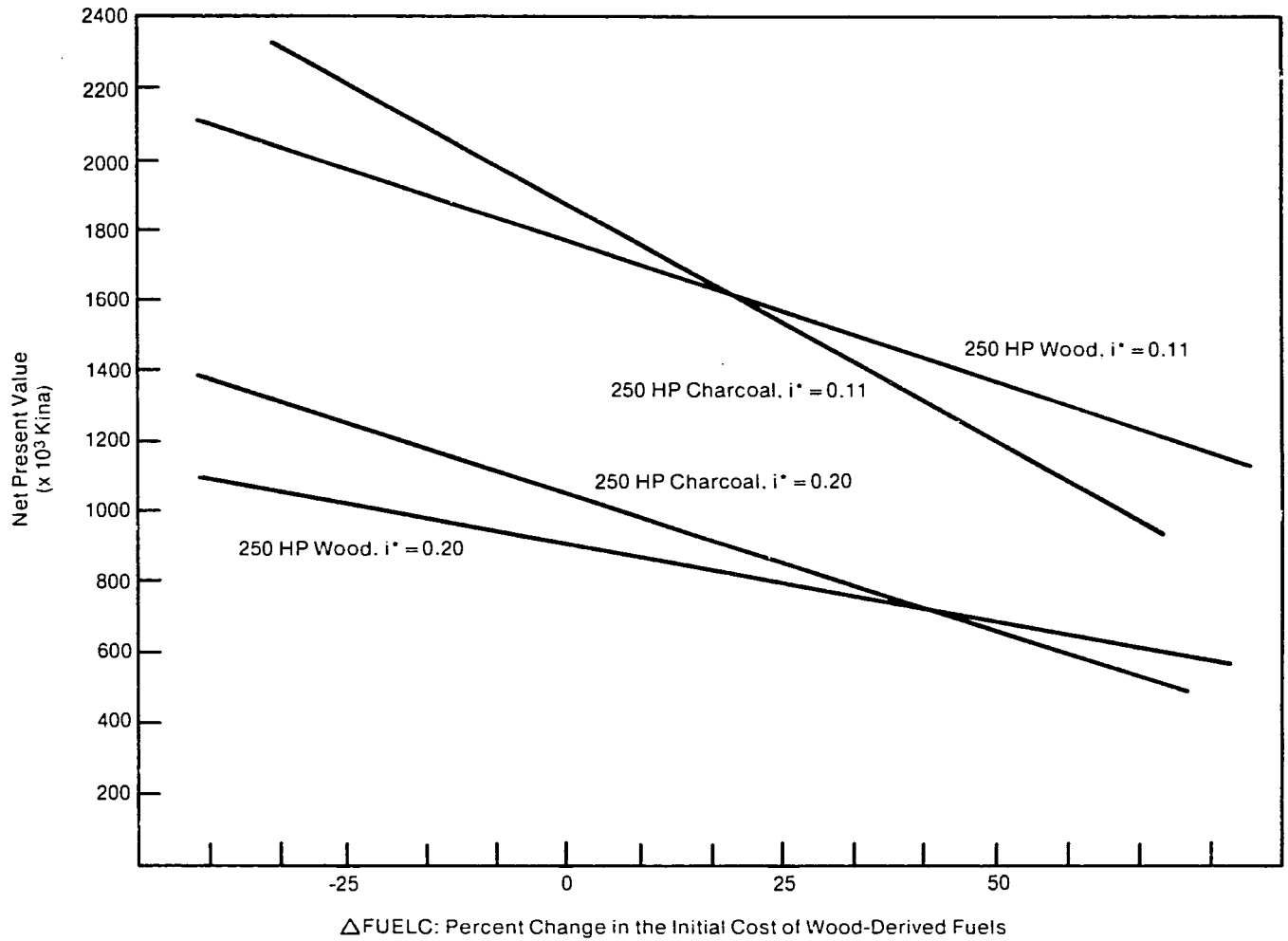


FIGURE 4-31
NPV VS. CHANGE IN THE INITIAL COST OF WOOD-DERIVED FUELS: 250 HP WOOD AND CHARCOAL BOILERS COMPARED TO #2 OIL BASE CASE

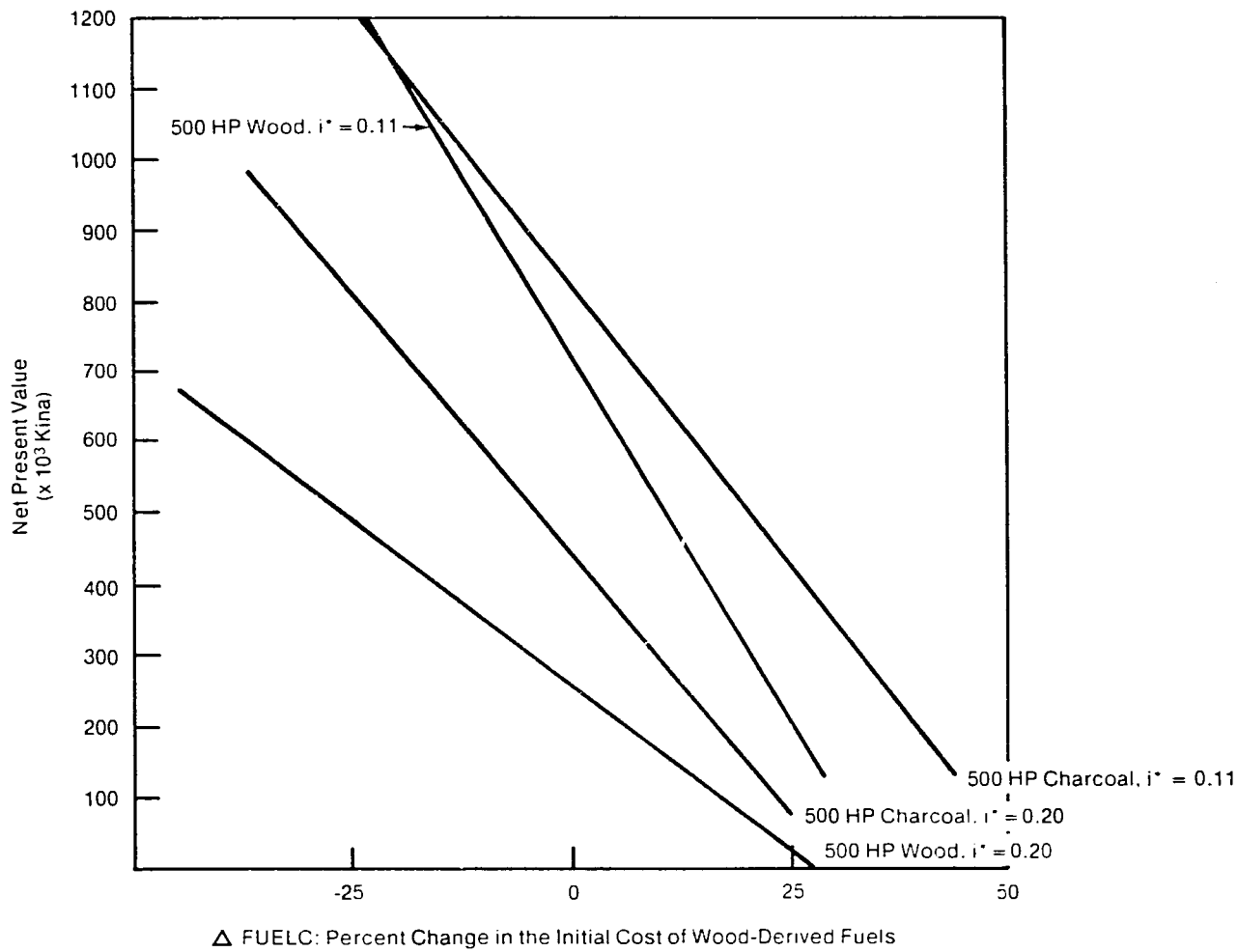


FIGURE 4-32
NPV VS. CHANGE IN THE INITIAL COST OF WOOD-DERIVED FUELS: 500 HP WOOD AND CHARCOAL BOILERS COMPARED TO #6 OIL BASE CASE

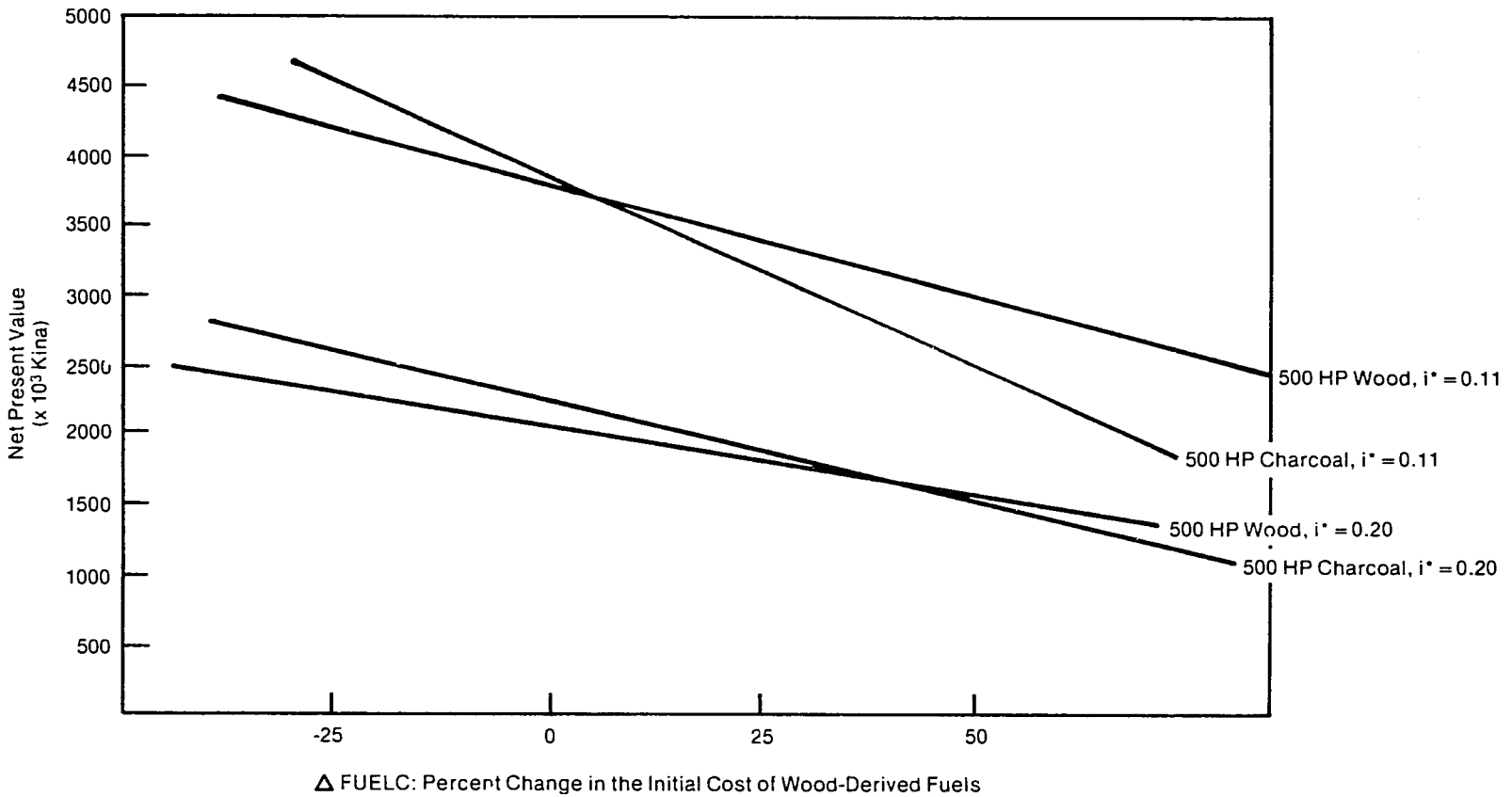


FIGURE 4-33
NPV VS. CHANGE IN THE INITIAL COST OF WOOD-DERIVED FUELS: 500 HP WOOD AND CHARCOAL BOILERS COMPARED TO #2 OIL BASE CASE

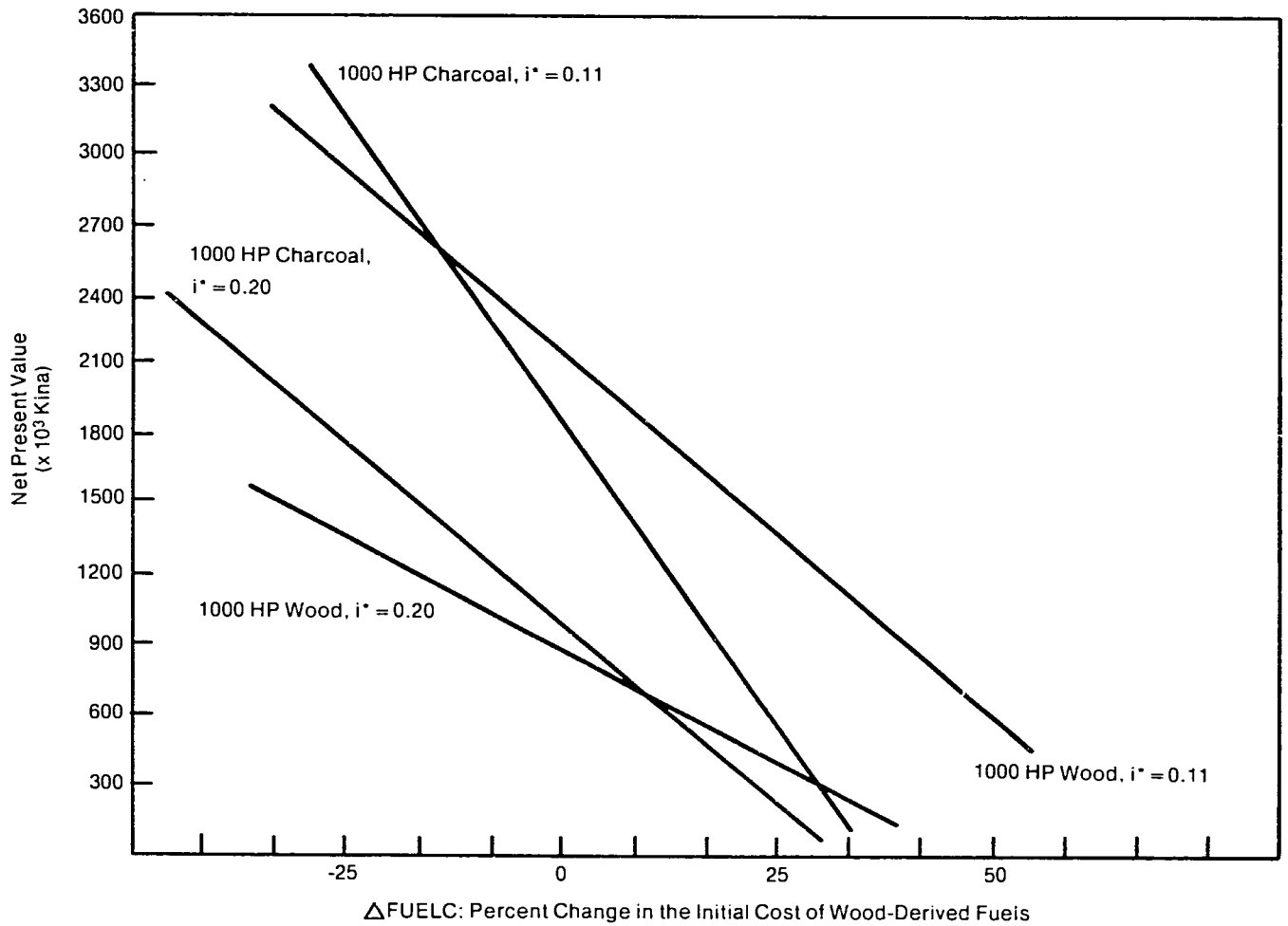


FIGURE 4-34
NPV VS. CHANGE IN THE INITIAL COST OF WOOD-DERIVED FUELS: 1000 HP WOOD AND CHARCOAL BOILERS COMPARED TO #6 OIL BASE CASE

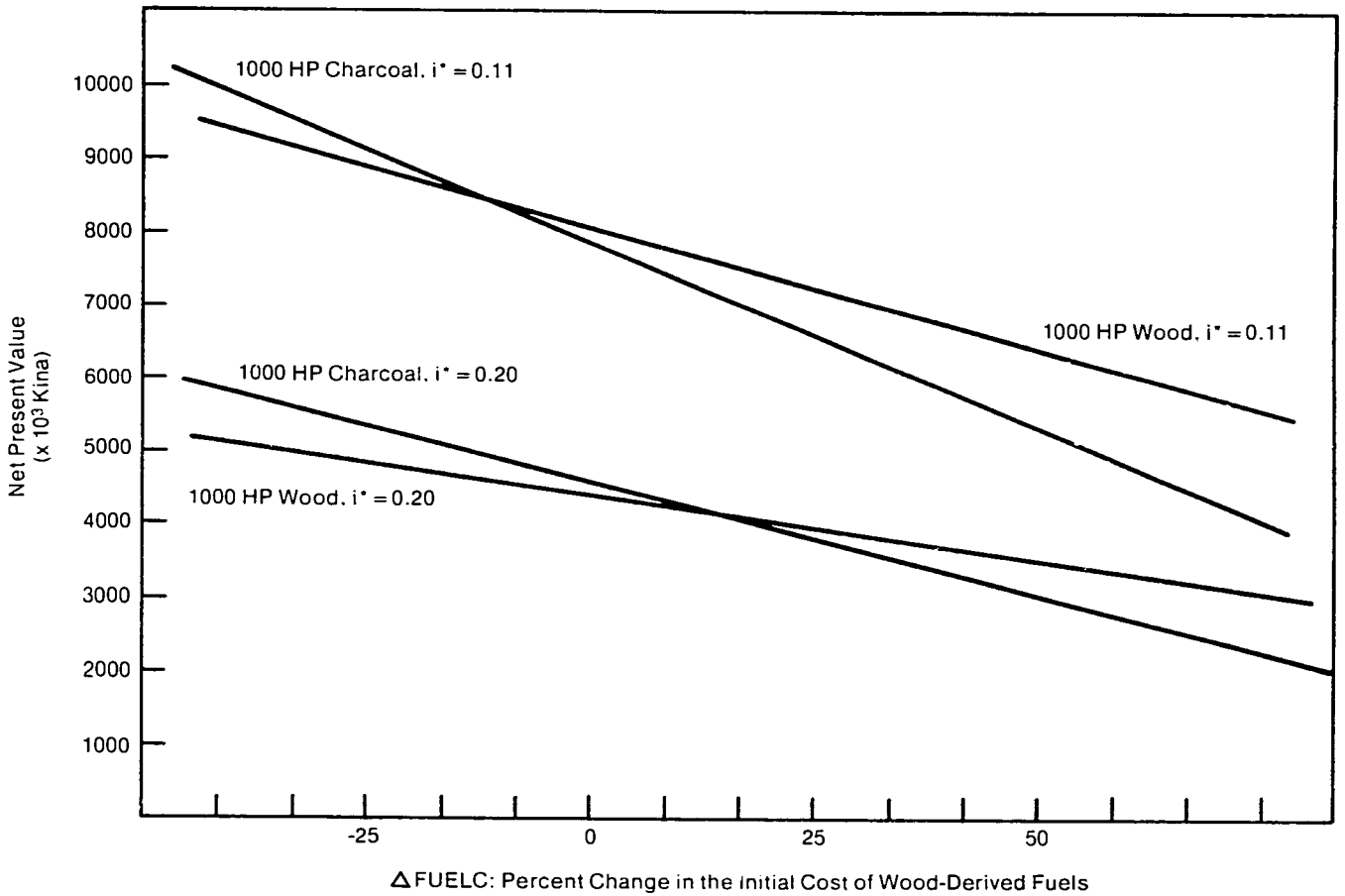


FIGURE 4-35
NPV VS. CHANGE IN THE INITIAL COST OF WOOD-DERIVED FUELS: 1000 HP WOOD AND CHARCOAL BOILERS COMPARED TO #2 OIL BASE CASE

Case C. Retrofit fuel feed system for existing oil-fired hot air furnaces (two 2.0 MMBtu/hr units).

- System Description

The existing system consists of two 2.0 MMBtu/hr distillate oil-fired hot air furnaces. The furnaces are operated, on average, at 75 percent of capacity for 16 hours/day and have an annual utility of 85 percent. Five fuel feed systems were analyzed, including a base case distillate fuel system.

Option 0: An existing #2 distillate fuel feed system (see Figure 4-36).

Option 1: Retrofit a 70/30 pyrolytic-distillate oil system (see Figure 4-37).

Option 2: Retrofit a 70/30 pyrolytic-residual oil system (similar to Figure 4-37)

Option 3: Retrofit a pyrolytic fuel oil system (see Figure 4-38).

Option 4: Retrofit one LBG charcoal gasifier coupled to both furnaces (see Figure 4-39).

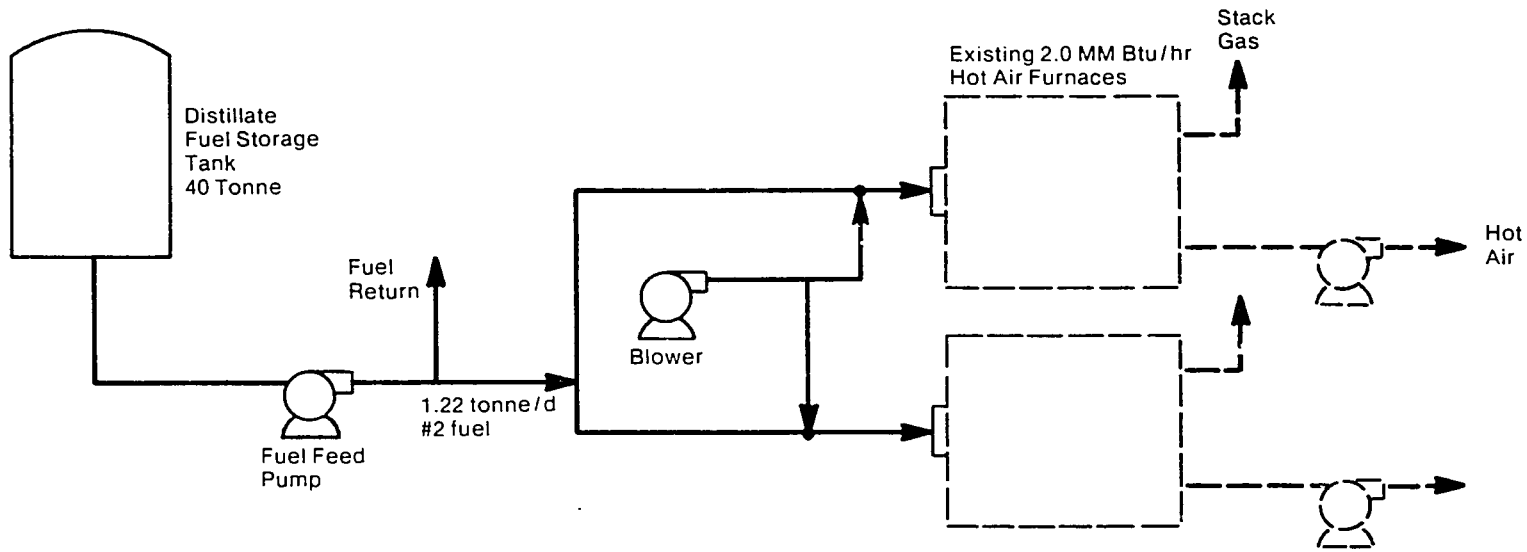
Option 5: Retrofit one LBG wood gasifier coupled to both furnaces (see Figure 4-40).

The analysis is based on the fuel systems only and did not account for the hot air heat exchanger and other furnace components. The costs of each retrofit option include modifications to the existing furnace. Replacement of the entire fuel feed and heat exchanger system is addressed in Case E. Initial costs and operating parameters were estimated for each of the options. These data are presented in Table 4-IX.

- Results

Substituting pyrolytic oil for distillate oil results in the highest NPV of savings in expenditures. Positive savings in expenditures are realized in all five retrofit options. However, the pyrolytic oil option maintains a higher NPV than the other fuel options for a wide range of discount rates, equipment cost and fuel cost estimates (see Figures 4-41 through 4-45). The NPV of savings over a 15-year period amounts to K494,000 at a discount rate of 11 percent, and K287,000 at a discount rate of 20 percent. Another advantage of the pyrolytic oil option, in this particular case, is the ease of startup of oil systems when compared to gasifiers.

Table 4-X summarizes the NPV analysis for the five fuel options. The NPV of all the retrofit options falls within the range of K494,000 to K287,000 for a discount rate of 11 percent and K287,000 to K115,000 for a discount rate of 20 percent. The charcoal gasifier has the lowest NPV at 11 percent while the wood gasifier has the lowest NPV at 20 percent. The sensitivity of the NPV of each of the options to changes in equipment costs and fuel price estimates are shown in Figures 4-42 through 4-45. The NPV of the wood and charcoal gasifiers is the most sensitive to equipment cost estimates. However, the NPV of the wood gasifier is the least sensitive of the five options to changes in fuel price.



Fuel System Equipment:
- Fuel storage tank—40 tonne
- Fuel feed pumps
- Pipe and valves
- Electrical and instrumentation
- Oil burner

Estimated Delivered Costs—K14,300

Labor Requirements:

Supervisory	0.25M/hr
General	1.0M/hr

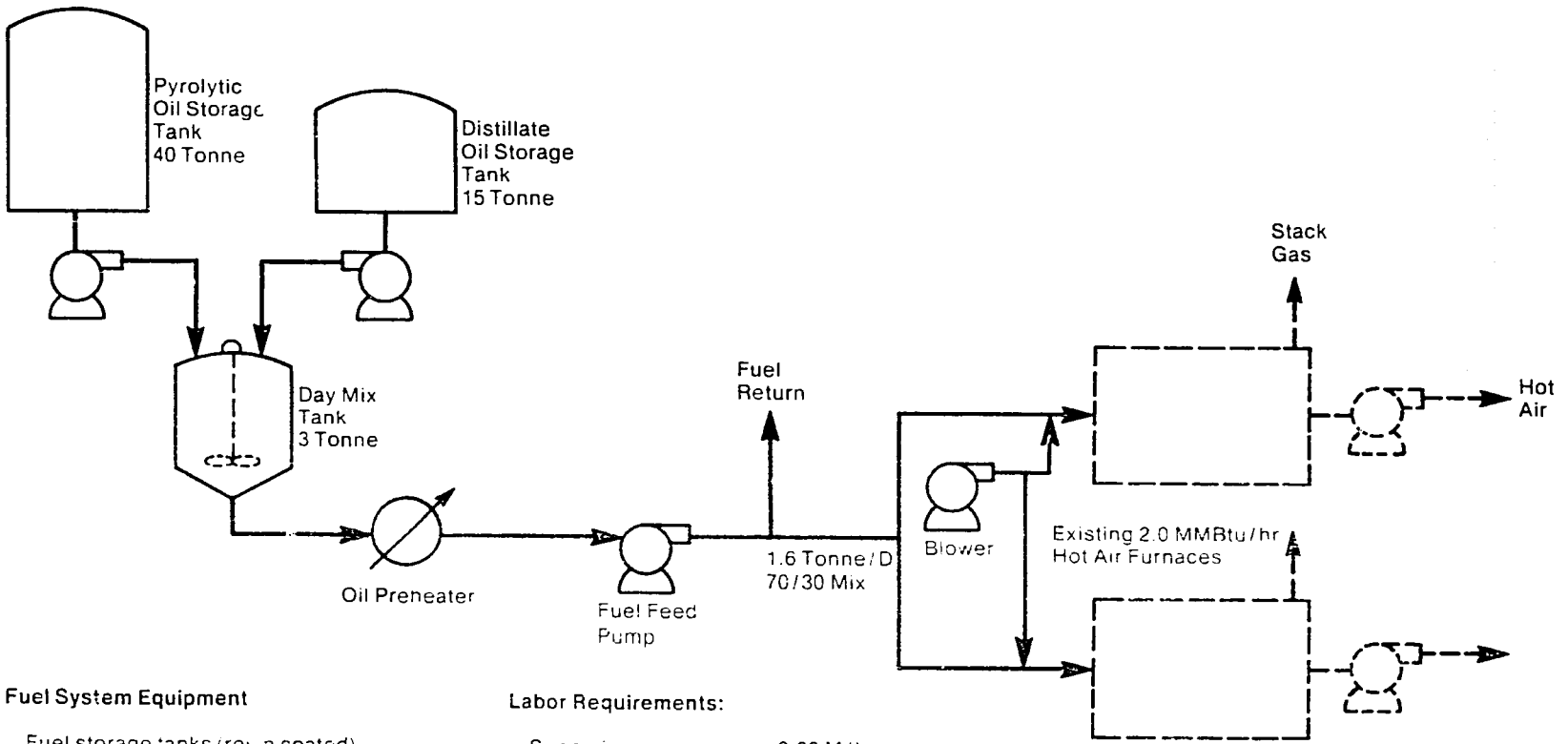
Utilities

Electricity	3.0kw

H.V. of Fuel: 39.7 MMBtu/tonne #2 fuel oil

Furnace Efficiency: 0.85

FIGURE 4-36
OPTION 0: EXISTING DISTILLATE FUEL FEED SYSTEM—
2.0 MM BTU/HR FURNACE



Fuel System Equipment

Fuel storage tanks (resin coated)
Day mix tank w/agitator (resin coated/ stainless steel)
Fuel feed pumps (stainless steel)
Oil preheater (stainless steel)
Pipe and valves (stainless steel)
Electrical and instrumentation
Modified oil burner
Estimated Delivered Costs-K23,500

Labor Requirements:

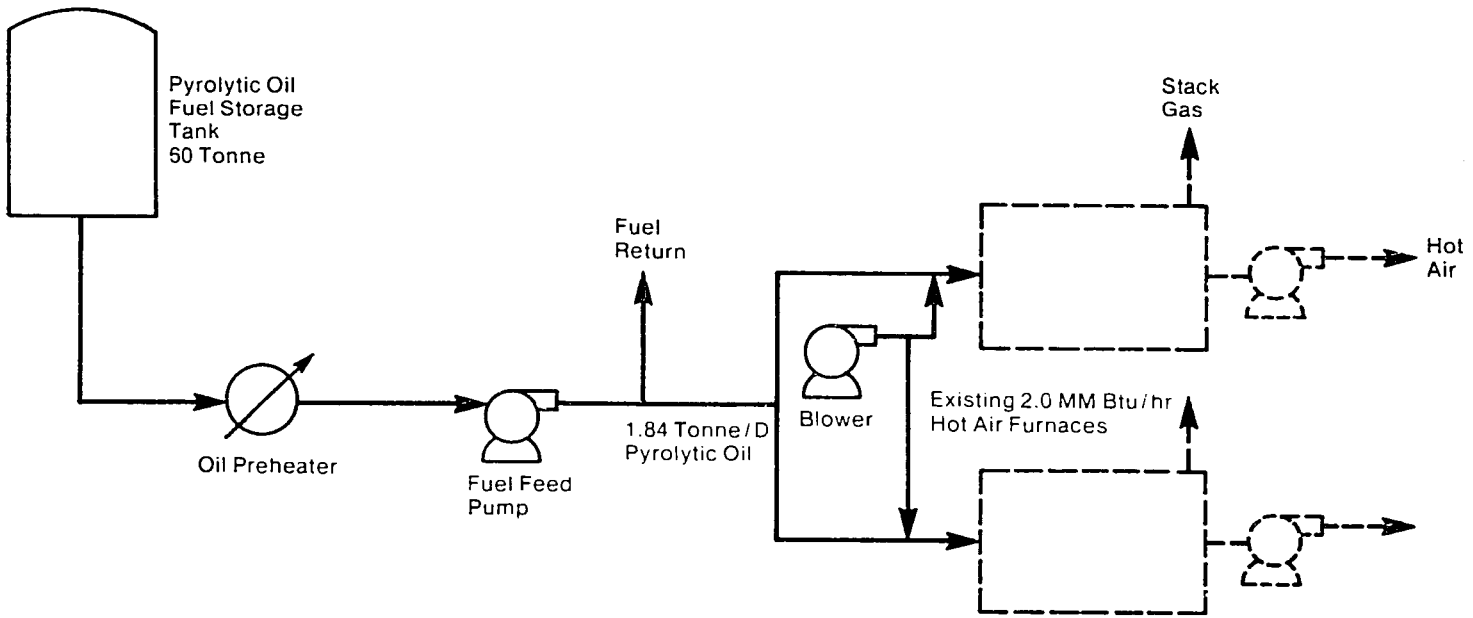
Supervisory	0.33 M/hr
General	1.00 M/hr

Utilities
Electricity 5.0kw

H.V. of Fuel: 30.0 MM/Btu/tonne, 70/30 pyrolytic oil-distillate oil

Furnace Efficiency: 0.85

FIGURE 4-37
OPTION 1: RETROFIT 70/30 PYROLYTIC OIL—DISTILLATE OIL FUEL SYSTEM—2.0 MM BTU/HR FURNACE



Fuel System Equipment

Fuel storage tank (resin coated)
Fuel feed pumps (stainless steel)
Oil preheater (stainless steel)
Pipe and valves (stainless steel)
Electrical and instrumentation
Modified oil burner
Estimated Delivered Costs K24,800

Labor Requirements:

Supervisory	0.33 M/hr
General	1.0 M/hr

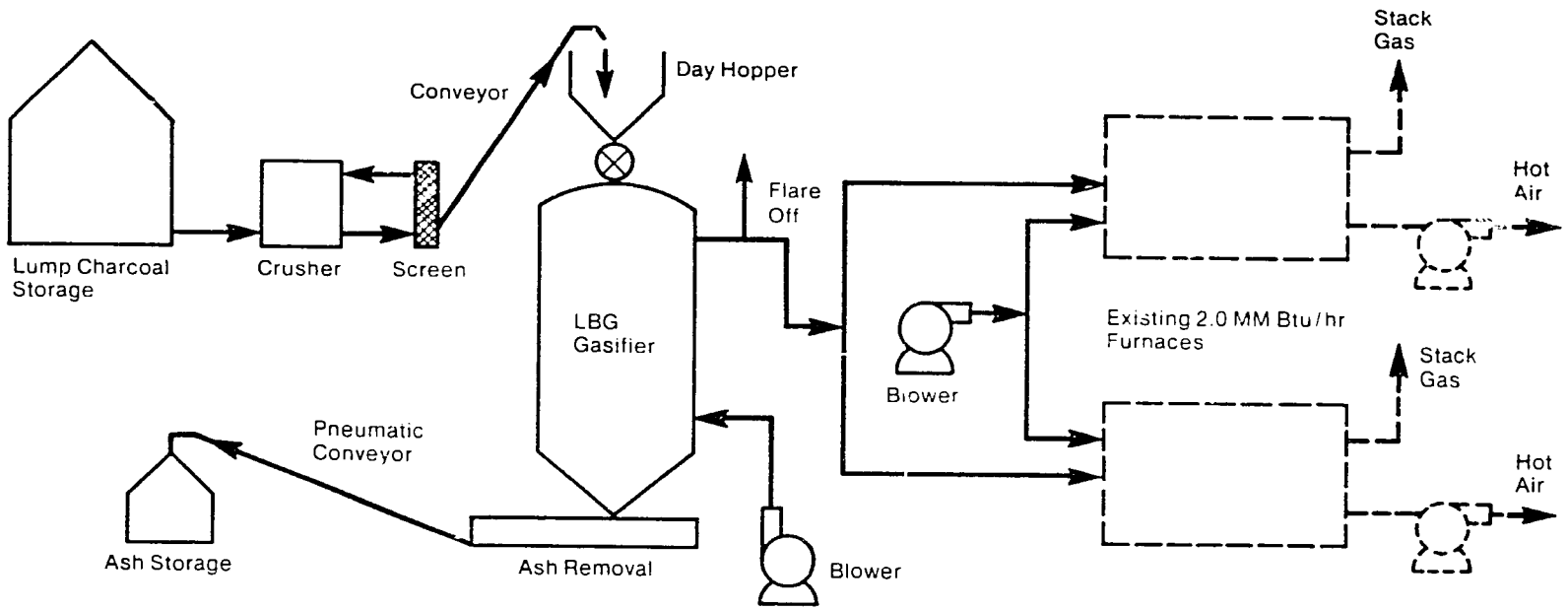
Utilities:

Electricity	4.0 kw

H.V. of Fuel: 26.4 MM Btu/tonne pyrolytic oil

Furnace Efficiency: 0.85

FIGURE 4-38
OPTION 2: RETROFIT 100% PYROLYTIC OIL FUEL SYSTEM—2.0 MM BTU/HR FURNACE



Fuel System Equipment

Charcoal storage—100 tonne
Crushers—two 1/2 tonne/hr
Screens—two 1/2 tonne/hr
Conveyors—two 1/2 tonne/hr
Day hopper—25 tonne
LBG gasifier/reactor*—4 tonne/day
Ash removal—0.1 tonne/day
Ash Storage—3 tonne
Gas burner—two 2.0 MM Btu/hr
*Including all electrical, instrumentation, pipe and valves
Estimated Delivered Costs—K65,000

Labor Requirements:

Supervisory	0.5M/hr
General	1.5 M/hr

Utilities:

Electricity	15 kw

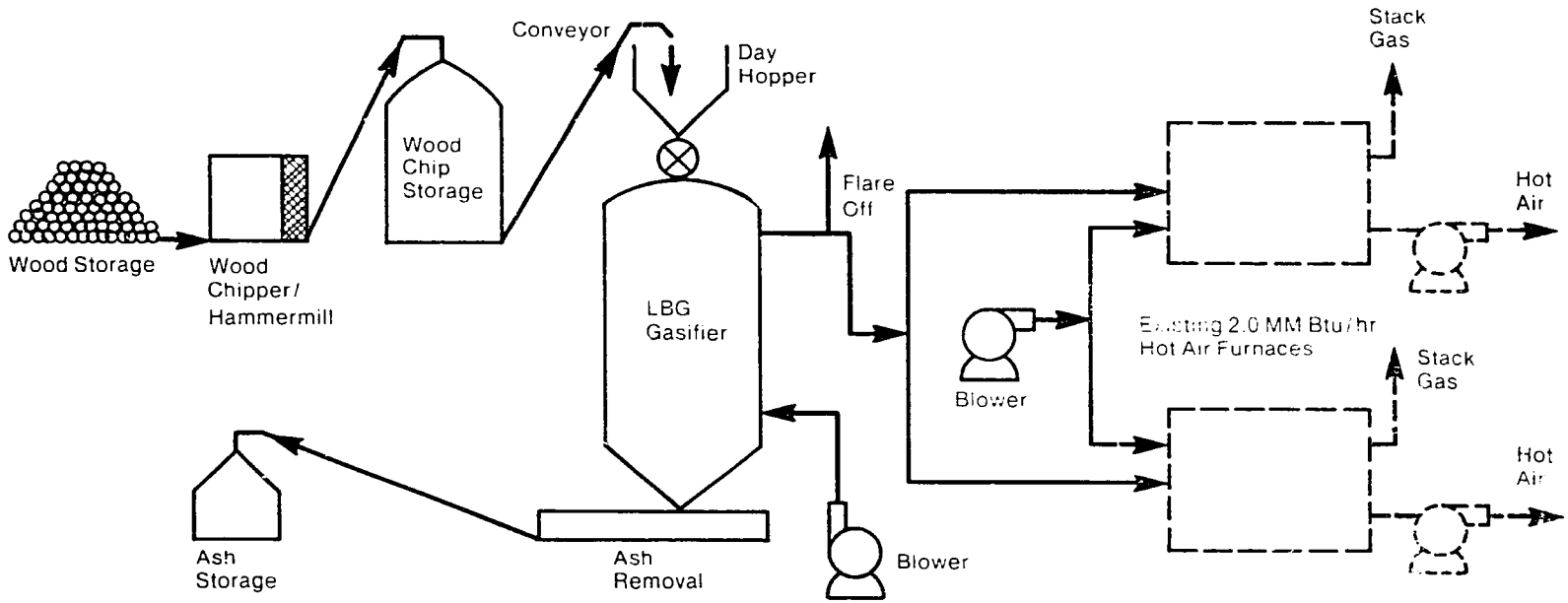
H.V. of Fuel: 27.5 MM Btu/tonne charcoal

Furnace Efficiency: 0.85

Gasifier Efficiency: 0.80

Additional Land Required: 0.05 hectares

FIGURE 4-39
OPTION 3: RETROFIT LBG CHARCOAL GASIFIER—
2.00 MM BTU/HR FURNACE



Fuel System Equipment:

Wood storage shed—200 tonne
Wood chipper/hammermill—two 1/2 tonne/hr
Screws—two 1/2 tonne/hr
Wood chip storage and air drying—60 tonne
Conveyors—two 1/2 tonne/hr
Day hopper—7 tonne
LBG gasifier/reactor*—6 ODT/day
Ash removal—0.1 tonne/day
Ash storage—2 tonne
Gas burners—Two 2 MM Btu/hr
*Including all electrical, instrumentation, pipe and valves
Estimated Delivered Costs—K106,500

Labor Requirements:

Supervisory	0.5 M/hr
General	2.0 M/hr

Utilities:
Electricity 25 kw

H.V. of Fuel: 18.7 MM Btu/ODT wood

Moisture Content of Fuel: 43% on a dry basis

Furnace Efficiency: 0.85

Gasifier Efficiency: 0.70

Additional Land Required: 0.1 hectare

FIGURE 4-40
OPTION 4: RETROFIT LBG WOOD GASIFIER—
2.0 MM BTU/HR FURNACE

TABLE 4-IX

CASE C: INITIAL COSTS AND OPERATING PARAMETER ESTIMATES

OPTIONS / COSTS IN KINA	#2 OIL	70/30 MIX		100% PYROLYTIC	LBG-CHARCOAL	LBG-WOOD
		#2 OIL	#6 OIL			
CAPITAL INVESTMENT	22,650	37,220	37,220	31,840	103,400	169,580
WORKING CAPITAL	13,200	8,870	7,270	6,730	8,840	8,420
TOTAL INITIAL CAPITAL INVESTMENT	35,850	46,090	44,490	38,570	112,240	178,000
INITIAL ANNUAL COSTS:						
PRIMARY FUEL	115,650	68,220	52,170	47,780	50,600	28,350
OPERATING LABOR	12,170	13,720	13,720	13,720	20,590	24,340
UTILITIES	730	1,220	1,220	980	3,670	6,120
MAINTENANCE	3,400	5,580	5,580	4,780	15,500	25,440
TOTAL INITIAL ANNUAL OPERATING EXPENDITURES	131,950	88,740	72,690	67,260	90,360	84,250
EQUIPMENT COSTS	14,300	23,500	23,500	20,100	65,000	106,500
ADDITIONAL LAND COSTS	N/A	0	0	0	1,000	2,000
OPERATING PARAMETERS:						
FIH (10^{-3} tonne/hr)	76.2	100.0	100.0	114.8	137.5	231.6
SUVFL (m/hr)	0.25	0.33	0.33	0.33	0.5	0.5
GENL (m/hr)	1.0	1.0	1.0	1.0	1.5	2.0
ELI (KW)	3.0	5.0	5.0	4.0	15.0	25.0
FCOIL	1.0	0.23	0.25	0.0	0.0	0.0
NRIND (hr)	16	16	16	16	16	16
ALOAD	0.85	0.85	0.85	0.85	0.85	0.85

TABLE 4-X

CASE C: SENSITIVITY ANALYSIS OF NPV ($x10^3$ KINA)

SENSITIVITY ANALYSIS \ OPTIONS	70/30 MIX		100% PYROLYTIC	LBG-CHARCOAL	LBG-WOOD
	#2 OIL	#6 OIL			
$i^* = 0.11$					
BASELINE	326	449	494	287	303
EQUIP + 25%	310	433	480	242	229
EQUIP - 25%	342	466	508	332	377
FUELC + 25%	195	349	402	190	249
FUEL - 25%	457	550	586	384	358
$i^* = 0.20$					
BASELINE	186	259	287	134	115
EQUIP + 25%	172	245	276	97	539
EQUIP - 25%	199	272	299	171	176
FUELC + 25%	109	200	233	77	83
FUELC - 25%	263	318	341	191	147

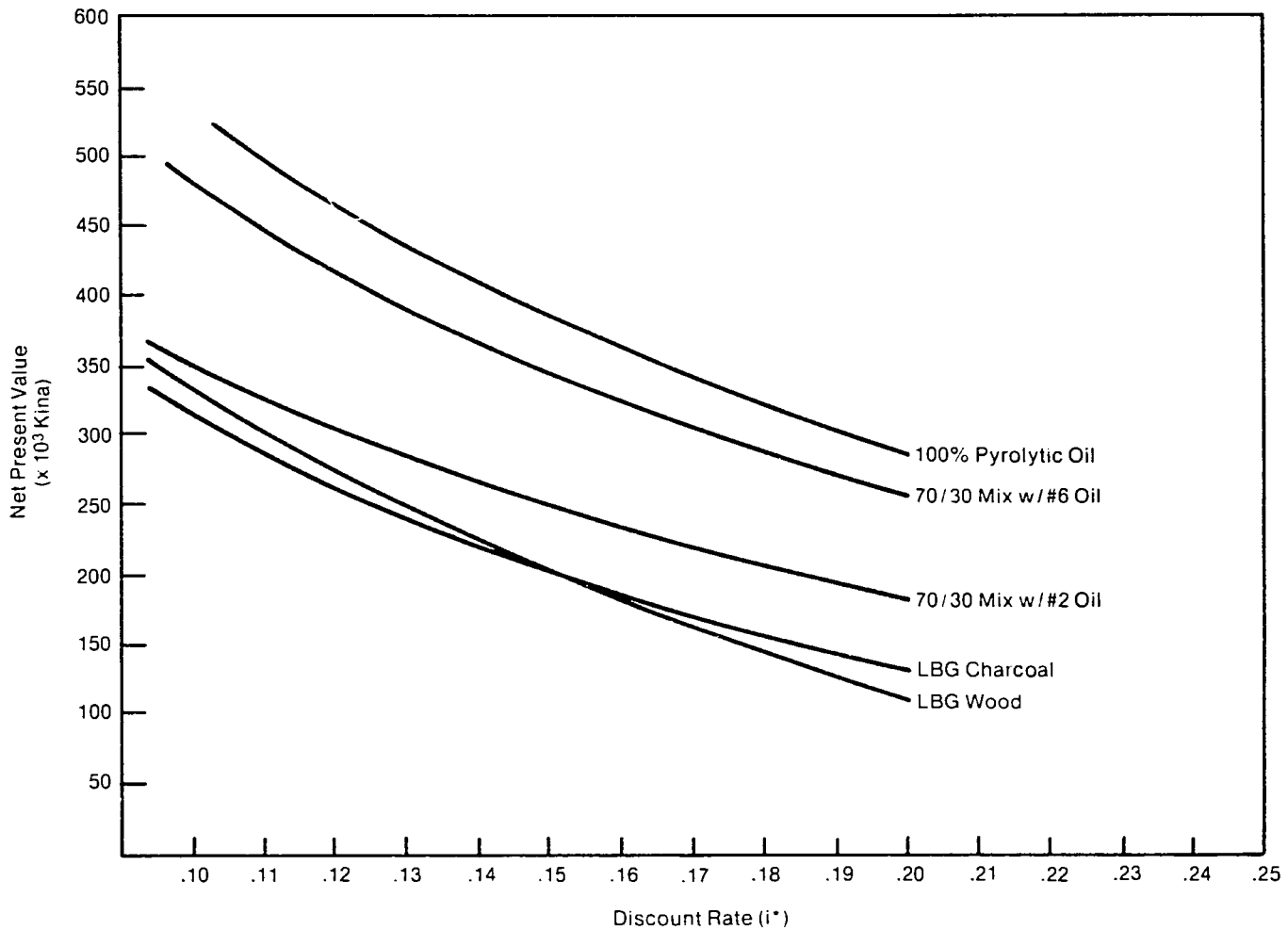


FIGURE 4-41
NPV VS. DISCOUNT RATE: TWO 2.0 MMBTU/HR
HOT AIR FURNACE RETROFIT FUEL FEED SYSTEMS

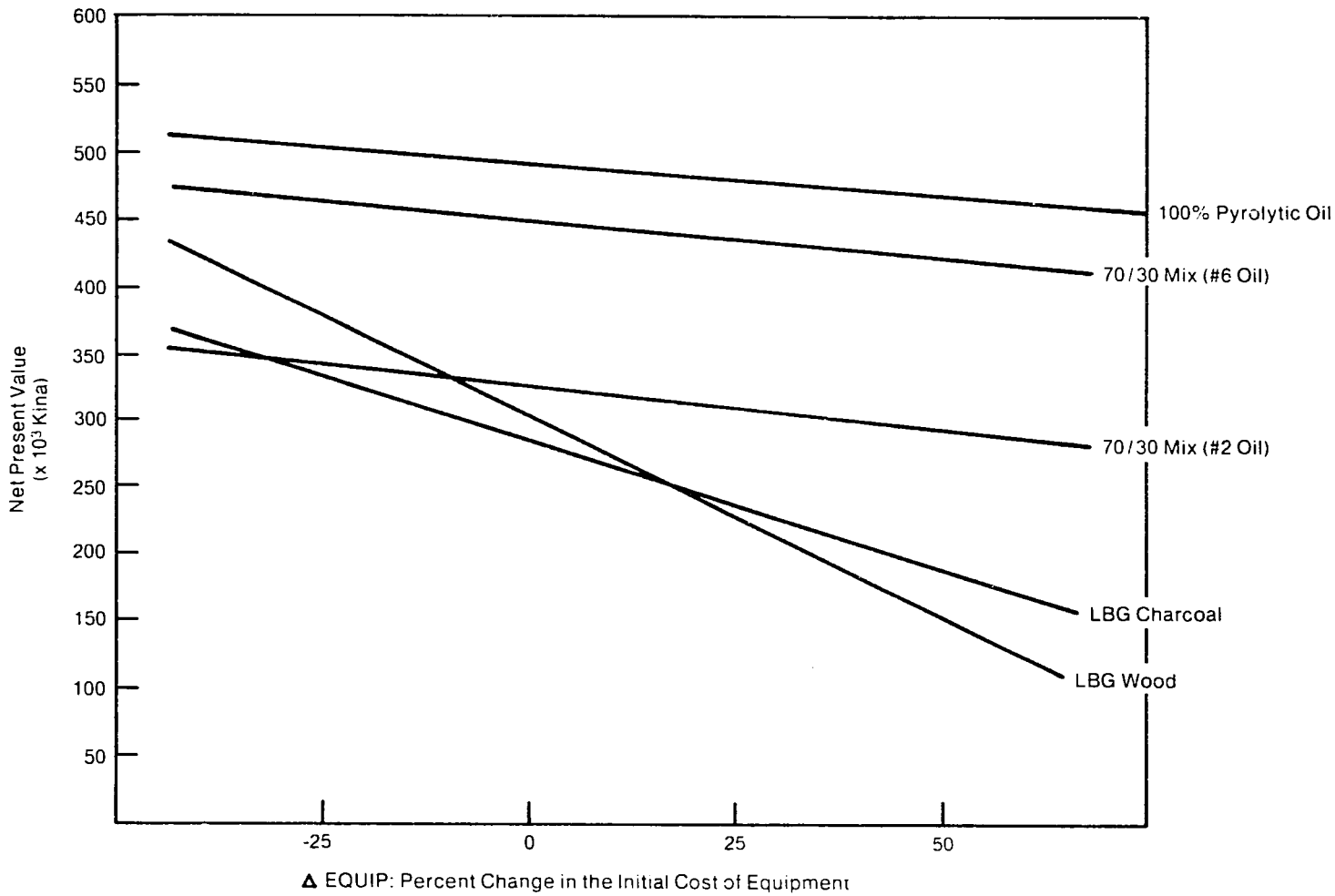


FIGURE 4-42
NPV VS. CHANGE IN THE INITIAL COST OF EQUIPMENT: TWO 2.0 MMBTU/HR HOT AIR FURNACE RETROFIT FUEL FEED SYSTEMS, i* = 0.11

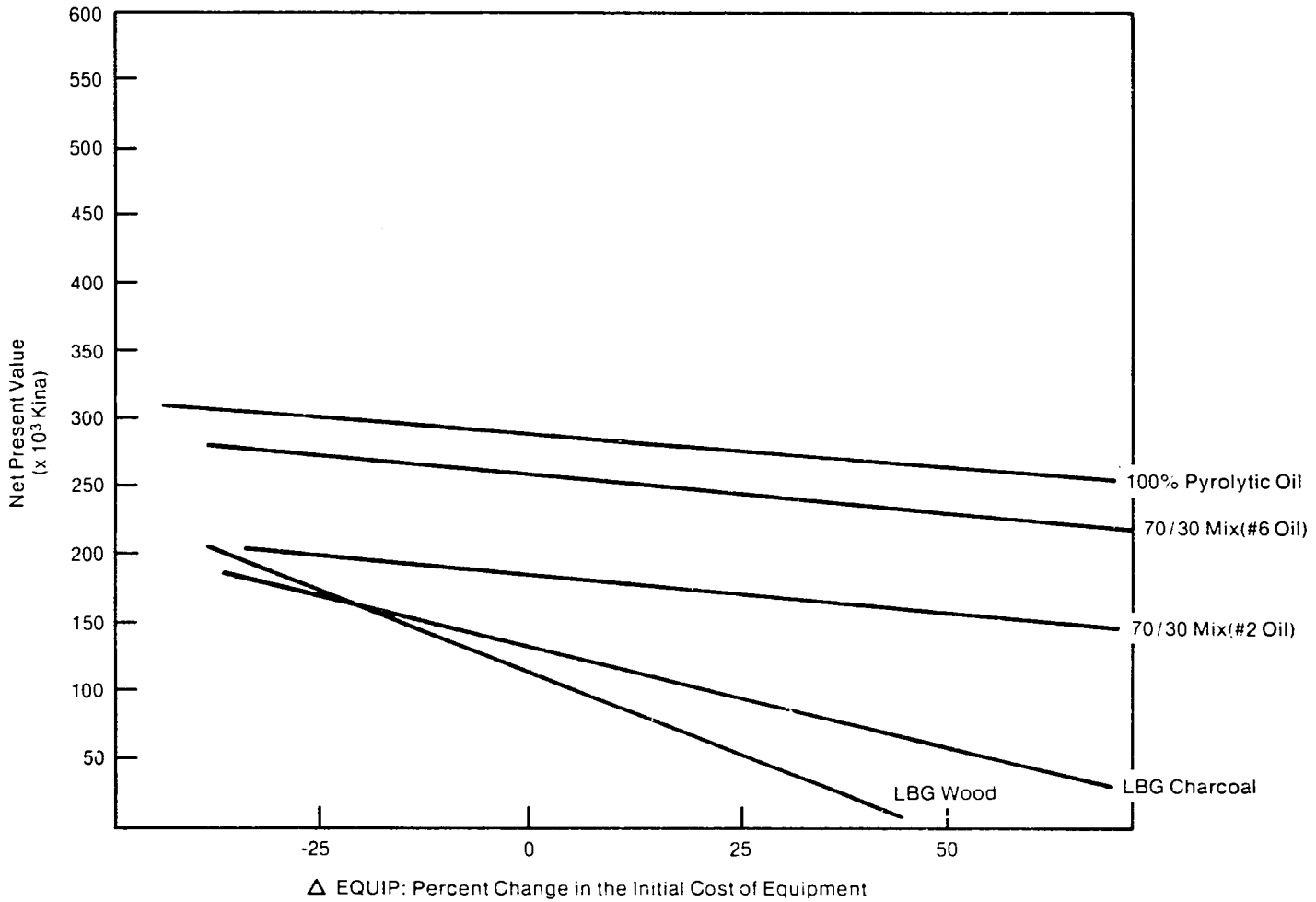


FIGURE 4-43
NPV VS. CHANGE IN THE INTITIAL COST OF EQUIPMENT: TWO 2.0 MMBTU/HR HOT AIR FURNACE RETROFIT FUEL FEED SYSTEMS, i* = 0.20

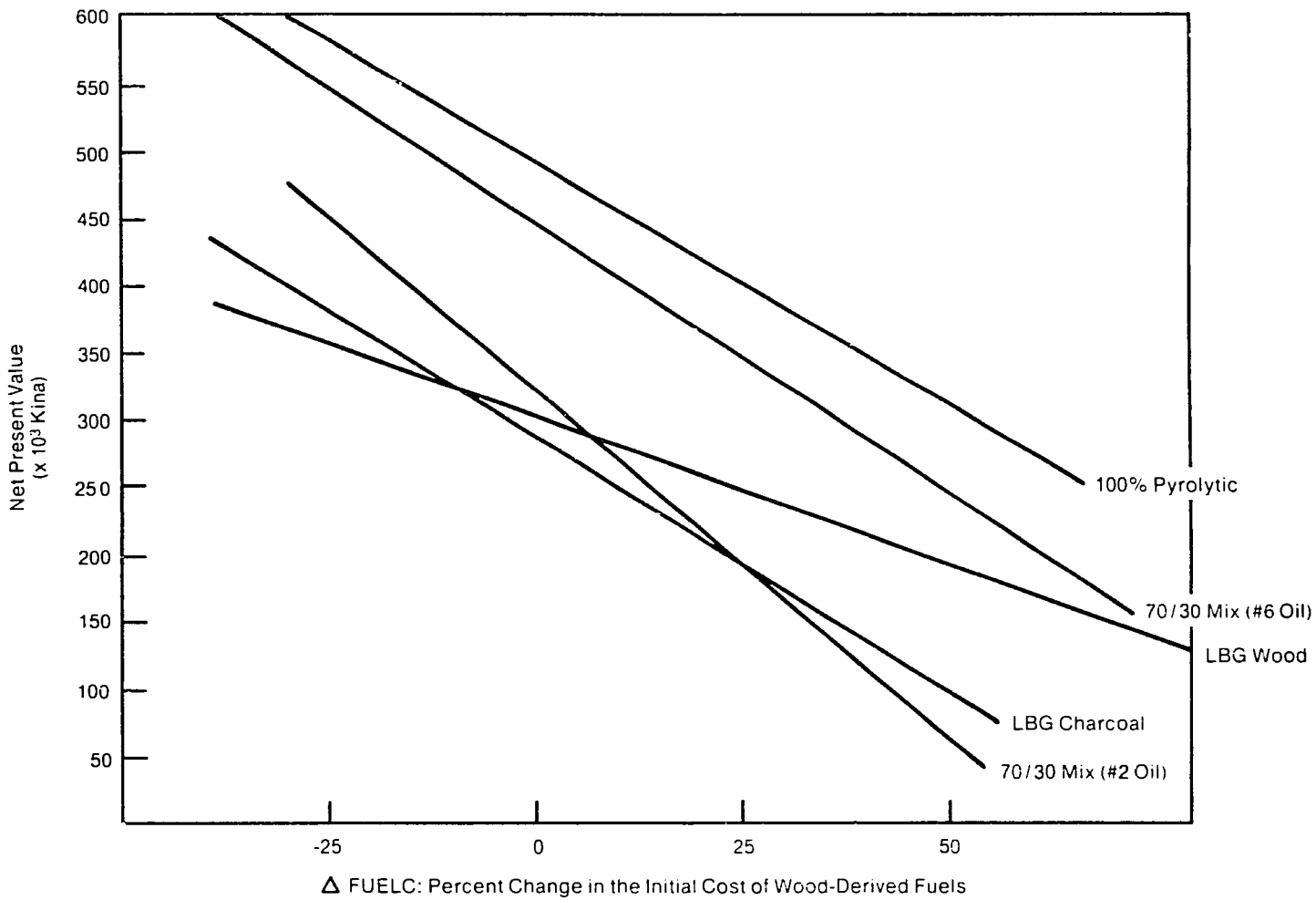


FIGURE 4-44
NPV VS. CHANGE IN THE INITIAL COST OF WOOD-DERIVED FUELS: TWO 2.0 MMBTU/HR HOT AIR FURNACE RETROFIT FUEL FEED SYSTEMS, $i^* = 0.11$

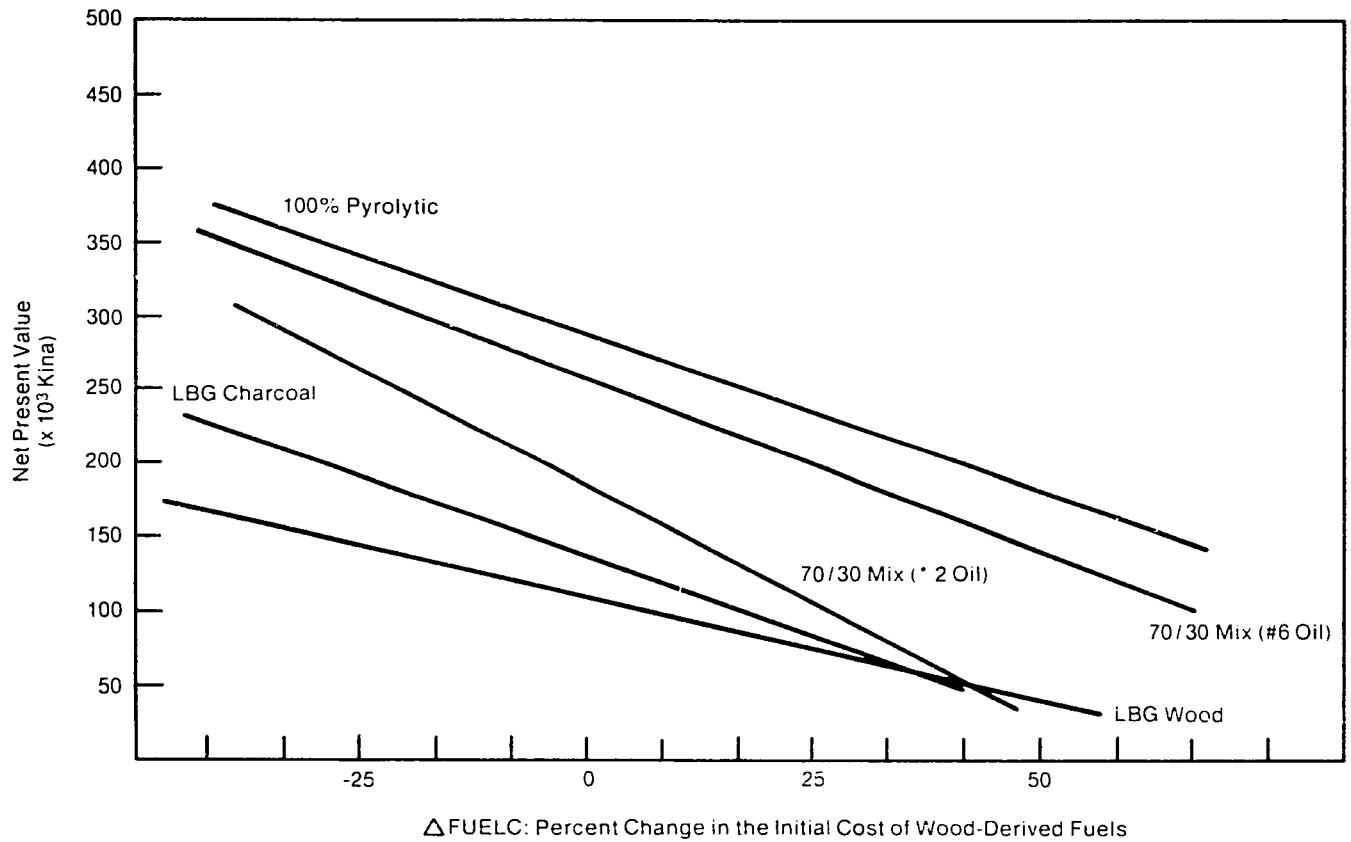


FIGURE 4-45
NPV VS. CHANGE IN THE INITIAL COST OF WOOD-DERIVED FUELS: TWO 2.0 MMBTU/HR HOT AIR FURNACE RETROFIT FUEL FEED SYSTEMS, i* = 0.20

Case D. Retrofit fuel systems for existing manually stoked, wood-fired hot air furnaces (three 2.5-MMBtu/hr units).

- System Description

The existing system consists of three 2.5-MMBtu/hr wood-fired, manually stoked hot air furnaces. The furnaces are operated, on an average, at 85 percent of capacity for 16 hours/day with an annual utility factor of 85 percent. The system presently operates at a heat-conversion efficiency of approximately 50 percent. With some modifications to the system including proper draught control, waste heat recovery from the stack gases, proper stoking practices, and improved maintenance, efficiency can be improved to 60 percent.[1] The fuel requirements assumed for the existing case were based on the improved efficiency. The improved existing manual system and four retrofit options were analyzed.

Option 0: Improved existing manually stoked wood-fired system (see Figure 4-46).

Option 1: Retrofit automatic stoker charcoal-fired system (see Figure 4-47).

Option 2: Retrofit automatic stoker wood-fired system (see Figure 4-48).

Option 3: Retrofit one LBG charcoal gasifier coupled to the three furnaces (see Figure 4-49).

Option 4: Retrofit one LBG wood gasifier coupled to the three furnaces (see Figure 4-50).

The analysis was based on the fuel systems only, and did not account for the hot air heat exchanger and other furnace components.

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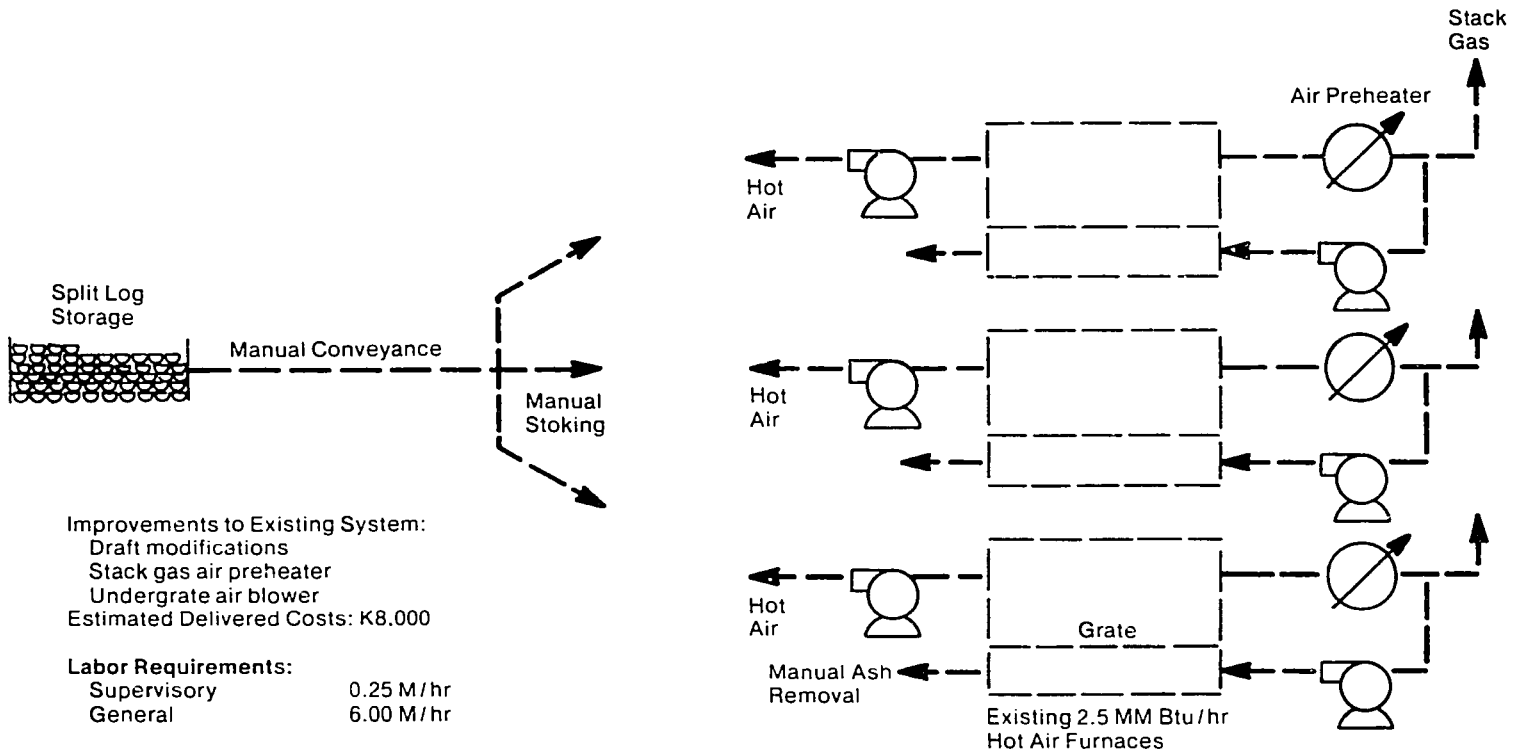
[1]Based on report by Ian Gilmour (Reference 12).

The costs of each retrofit option include the costs of required modifications to the existing furnace, the grate and the combustion chamber.

Initial costs and operating parameters were estimated for each of the options. These data are presented in Table 4-XI.

- Results

A summary of the results of the NPV analysis is presented in Table 4-XII and Figures 4-51 through 4-53. Given the baseline assumptions, all the retrofit fuel options result in negative NPVs. This implies that for the remaining service life of the existing system, a retrofit automatic stoker system or LBG gasifier is not economically justified. However, the non-quantifiable economic parameters, such as quality and reliability of manual labor, must also enter the decision process. These non-quantifiables must be weighed against the additional costs of the automated fuel systems. If the remaining service life of the existing furnaces is short, such that the NPV of fuel savings does not exceed the cost of improving the manual system, then a decision to replace the furnace and fuel system should be addressed. Given this alternative, the automatic stoker wood-fired option would be the most economical.



Improvements to Existing System:
- Draft modifications
- Stack gas air preheater
- Undergrate air blower

Estimated Delivered Costs: K8,000

Labor Requirements:

Supervisory	0.25 M/hr
General	6.00 M/hr

Utilities:

Electricity	2.0 kw

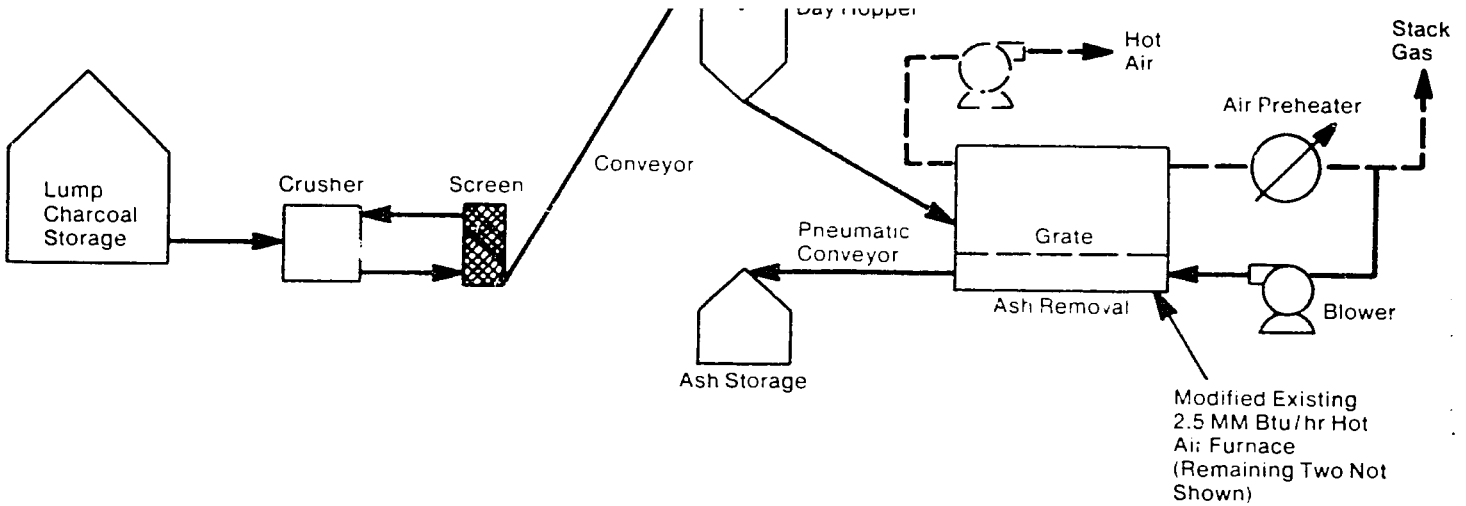
H.V. of Fuel: 18.7 MM Btu/ODT wood

Moisture Content of Fuel: 43% dry basis

Daily Fuel Input: 8.8 ODT wood

Furnace Efficiency: 0.60

FIGURE 4-46
OPTION 0: IMPROVED EXISTING MANUALLY STOKED 2.5 MM BTU/HR FURNACES



Automatic Charcoal System:
- Lump charcoal storage—175 tonne
- Charcoal crusher—two 1/4 tonne/hr
- Screens—two 1/4 tonne/hr
- Conveyor—two 1/4 tonne/hr
- Dry hopper—7 tonne
- Spreader stoker—three 1/8 tonne/hr
- Water cooled grate
- Ash removal and storage
- Stack gas air preheater
- Undergrate air blower
- Electric and instrumentation

Estimated Delivered Costs—K54,000

Labor Requirements:

Supervisory	0.33 M/hr
General	2.00 M/hr

Utilities:

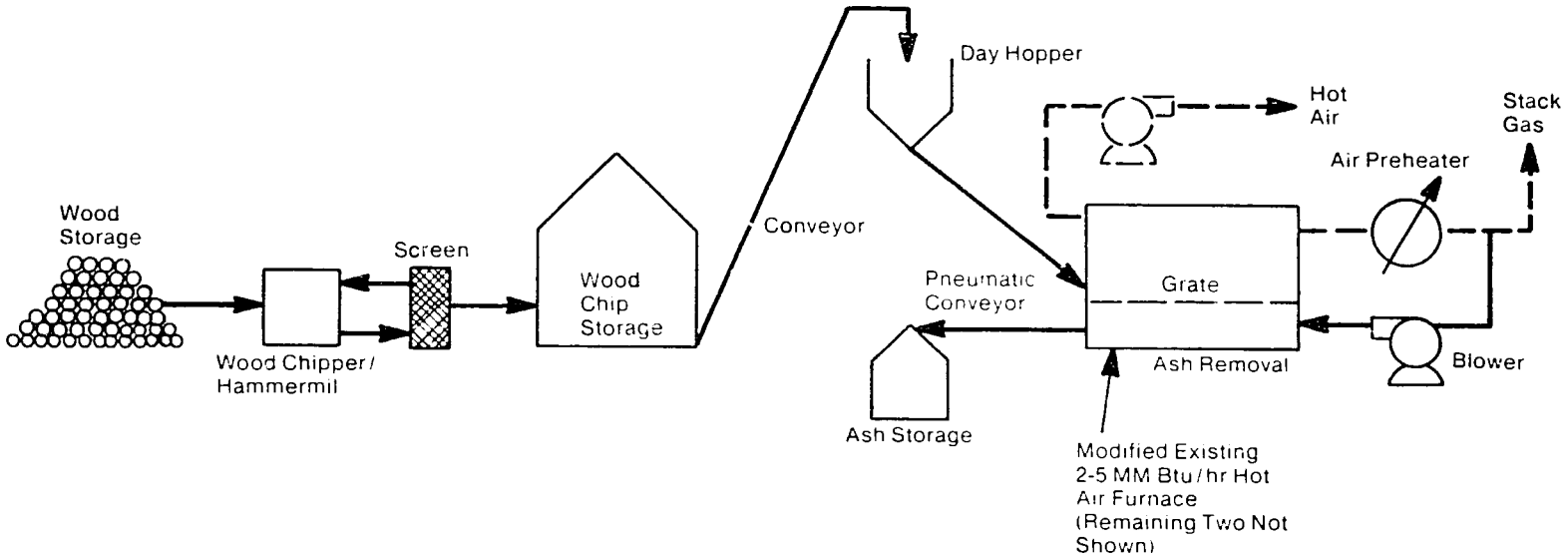
Electricity	30 kw

H.V. of Fuel: 27.5 MM Btu/tonne charcoal

Daily Fuel Input: 4.8 tonne charcoal

Furnace Efficiency: 0.75

FIGURE 4-47
OPTION 1: RETROFIT AUTOMATIC CHARCOAL STOKER SYSTEM—
2.5 MM BTU/HR FURNACES



Automatic Wood System:
- Wood chipper/hammermil—two 1/2 tonne/hr
- Screens—two 1/2 tonne/hr
- Conveyor—two 1/2 tonne/hr
- Wood chip storage—100 tonne/hr
- Day hopper—12 tonne
- Spreader stoker—three 1/4 tonne/hr
- Air cooled grate
- Ash removal and storage
- Stack gas air preheater
- Undergrate air blower
- Electrical and instrumentation

Estimated Delivered Costs—K69.000

Labor Requirements:

Supervisory	0.33 M/hr
General	2.5 M/hr

Utilities:

Electricity	50 kw

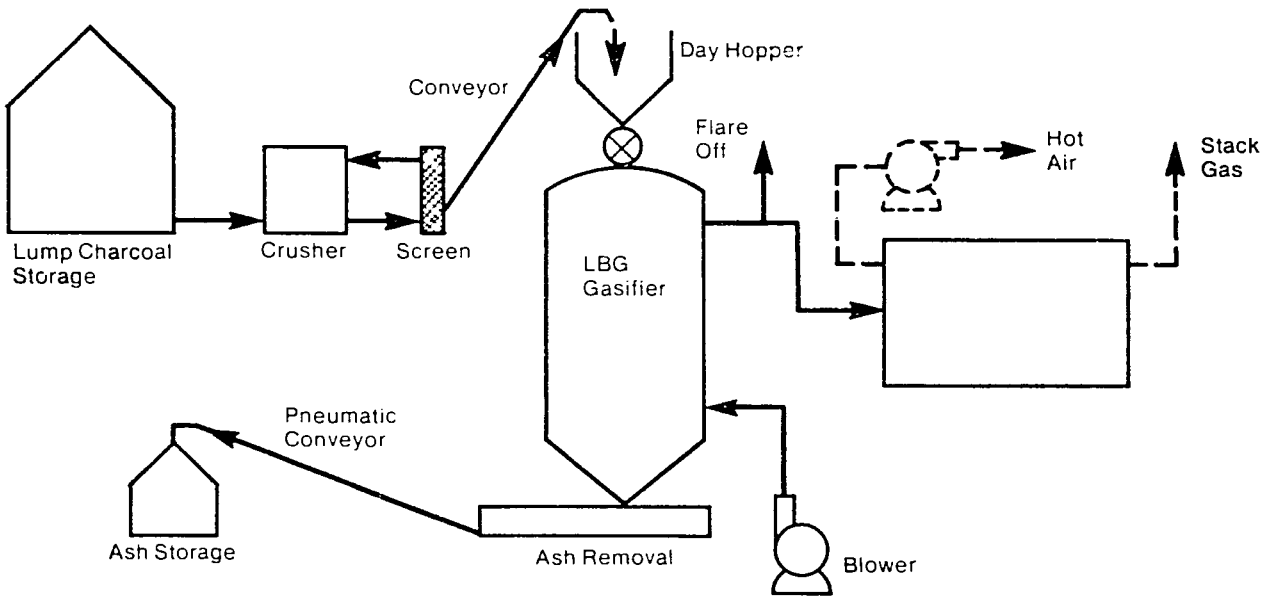
H.V. of Fuel: 18.7 MM Btu/ODT wood

Moisture Content of Fuel: 43% dry basis

Daily Fuel Input: 8.1 ODT wood

Furnace Efficiency: 0.65

FIGURE 4-48
OPTION 2: RETROFIT AUTOMATIC WOOD STOKER SYSTEM—
2.5 MM BTU/HR FURNACES



LBG Charcoal Gasifier System:
- Lump charcoal storage—190 tonne
- Charcoal crusher—two 1/4 tonne/hr
- Screen—two 1/4 tonne/hr
- Conveyor—two 1/4 tonne/hr
- Day hopper—8 tonne
- LBG gasifier/reactor—7 tonne/day
- Ash removal and storage
- Gas burner—three 2.5 MM Btu/hr
- Electrical and instrumentation
- Pipe and valves

Estimated Delivered Costs: K100,000

Labor Requirements:

Supervisory	0.5 M/hr
General	2.0 M/hr

Utilities:

Electricity	30 kw

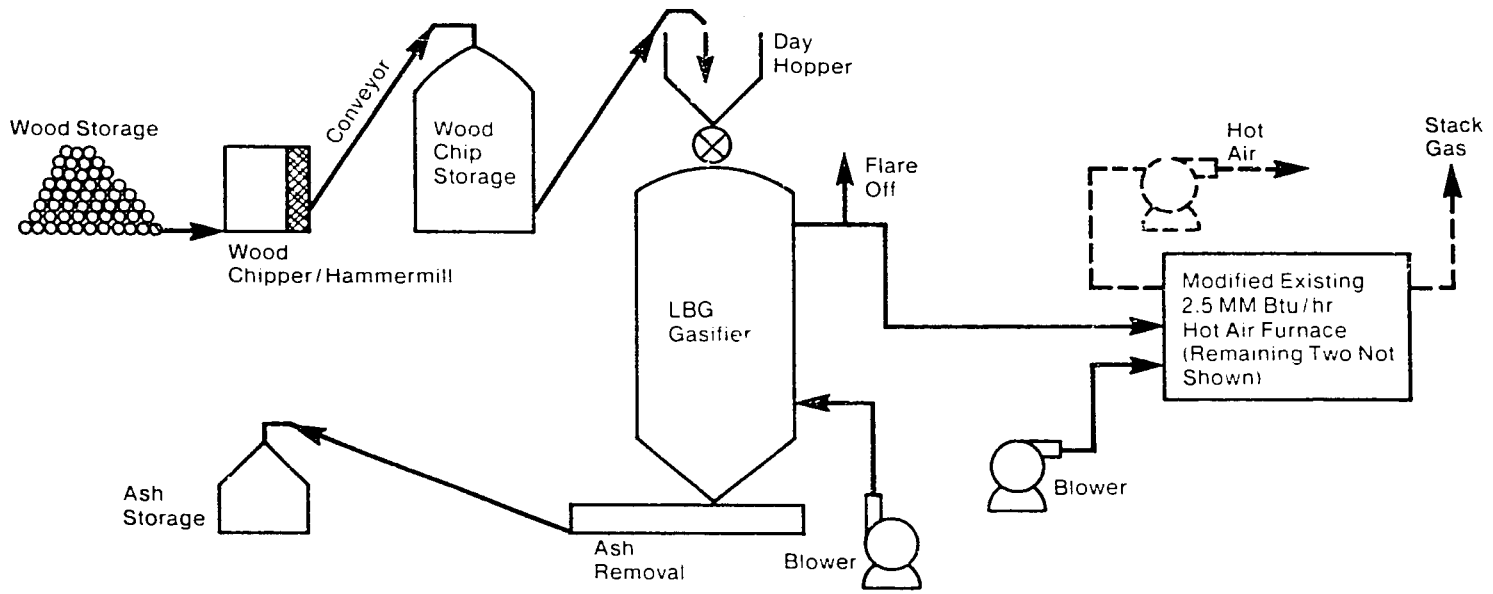
H.V. of Fuel: 27.5 MM Btu/tonne charcoal

Daily Fuel Input: 5.3 tonne charcoal

Furnace Efficiency: 0.85

Gasifier Efficiency: 0.80

FIGURE 4-49
OPTION 3: RETROFIT LBG CHARCOAL GASIFIER—
2.5 MM BTU/HR FURNACES



LBG Wood Gasifier System:
- Wood storage
- Wood chipper/hammermil—two 1/2 tonne/hr
- Screens—two 1/2 tonne/hr
- Conveyor—two 1/2 tonne/hr
- Wood chip storage—100 tonne
- Day hopper—13 tonne
- LBG gasifier/reactor—12 tonne
- Ash removal and storage
- Gas burner—three 2.5 MM Btu/hr
- Electrical and instrumentation
- Pipe and valves

Estimated Delivered Costs: K155.000

Labor Requirements:

Supervisory	0.5 M/hr
General	2.5 M/hr

Utilities:

Electrical	50 kw

H.V. of Fuel: 18.7 MM Btu/ODT wood

Daily Fuel Input: 8.8 ODT wood

Moisture Content of Fuel: 43% dry basis

Furnace Efficiency: 0.85

Gasifier Efficiency: 0.70

FIGURE 4-50
OPTION 4: RETROFIT LBG WOOD GASIFIER—
2.5 MM BTU/HR FURNACES

TABLE 4-XI

CASE D: INITIAL COSTS AND OPERATING PARAMETER ESTIMATES

COSTS IN KINA \ OPTIONS	MANUAL STOKER WOOD	AUTOMATIC STOKER CHARCOAL	AUTOMATIC STOKER WOOD	LBG - CHARCOAL	LBG - WOOD
CAPITAL INVESTMENT	12,670	85,540	108,820	158,500	245,520
WORKING CAPITAL	11,900	15,080	12,220	17,500	14,470
TOTAL INITIAL CAPITAL INVESTMENT	24,570	100,620	121,040	176,000	259,990
INITIAL ANNUAL COSTS:					
PRIMARY	67,010	109,390	61,860	120,630	67,580
OPERATING LABOR	49,600	21,210	31,820	24,340	28,080
UTILITIES	490	7,340	12,240	7,340	12,240
MAINTENANCE	1,900	12,830	16,320	23,760	36,830
TOTAL INITIAL ANNUAL OPERATING EXPENDITURES	119,000	150,770	122,240	176,070	144,730
EQUIPMENT COSTS	8,000[1]	54,000	69,000	100,000	155,000
ADDITIONAL LAND COSTS	N/A	0	0	0	0
OPERATING PARAMETERS:					
FIH (10^{-3} tonne/hr)	547.5	297.9	505.4	328.5	552.1
SUVPL (m/hr)	0.25	0.33	0.33	0.5	0.5
GENL (m/hr)	6.0	2.0	3.0	2.0	2.5
ELI (KW)	2.0	30.0	50.0	30.0	50.0
PCOIL	0.0	0.0	0.0	0.0	0.0
HRIND (hr)	16	16	16	16	16
ALOAD	0.85	0.85	0.85	0.85	0.85

[1] Estimated cost of improvements to existing system.

TABLE 4-XII

CASE D: SENSITIVITY ANALYSIS OF NPV ($\times 10^3$ KINA)

SENSITIVITY ANALYSIS \ OPTIONS	AUTOMATIC STOKER CHARCOAL	AUTOMATIC STOKER WOOD	LBG CHARCOAL	LBG WOOD
i* = 0.11				
BASELINE	-318	-91	-552	-352
EQUIP + 25%	-356	-139	-622	-459
EQUIP - 25%	-280	-43	-482	-245
FUELC + 25%	-529	-210	-784	-481
FUELC - 25%	-107	28	-320	-223
1* = 020				
BASELINE	-215	-93	-384	-303
EQUIP + 25%	-246	-133	-441	-392
EQUIP - 25%	-184	-53	-327	-214
FUELC + 25%	-339	-163	-520	-380
FUELC - 25%	-91	-23	-248	-226

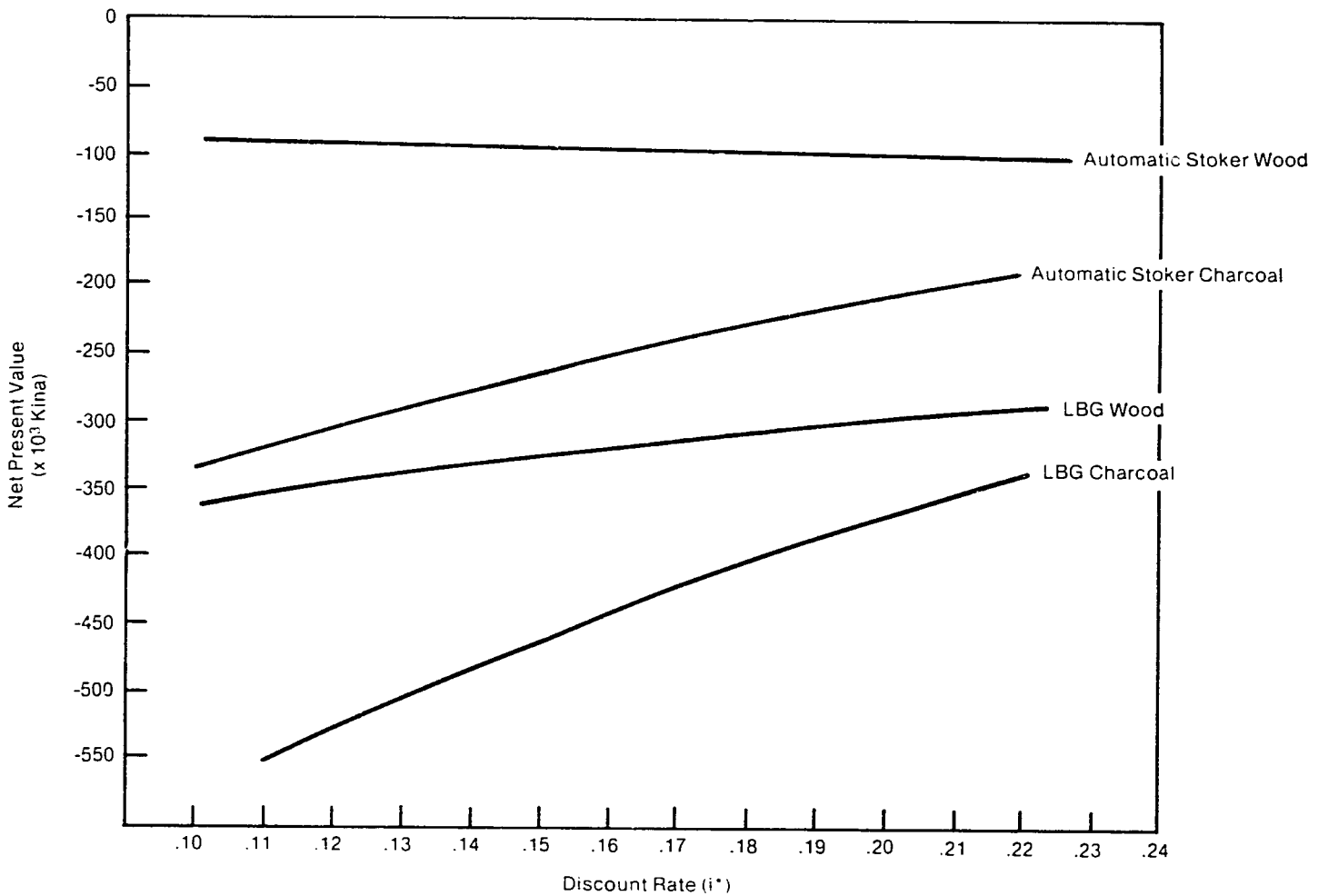


FIGURE 4-51
NPV VS. DISCOUNT RATE: RETROFIT MANUAL STOKED WOOD FURNACES

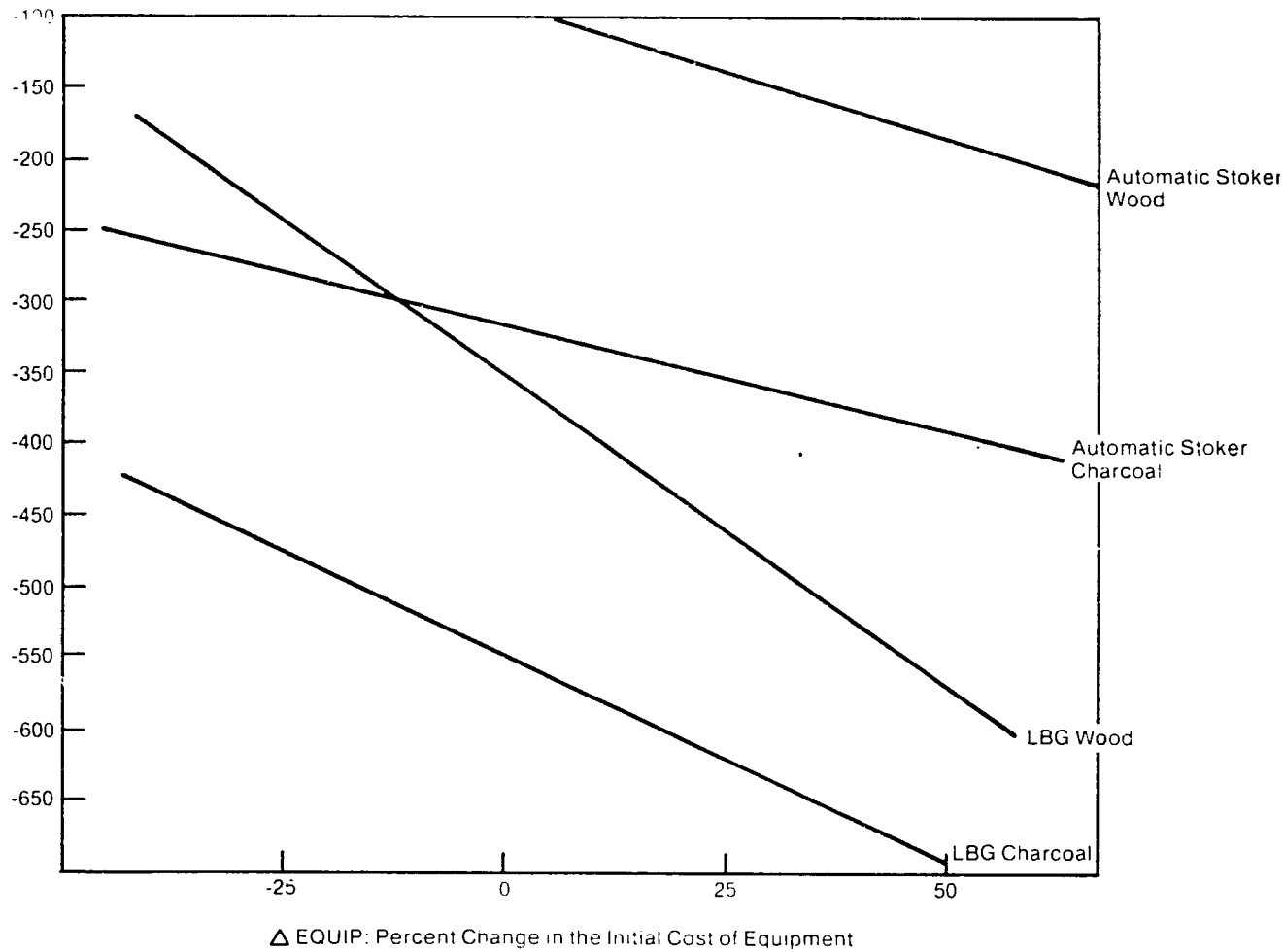


FIGURE 4-52
NPV VS. CHANGE IN THE INITIAL COST OF EQUIPMENT: RETROFIT MANUAL STOKED WOOD FURNACES, i* = 0.11

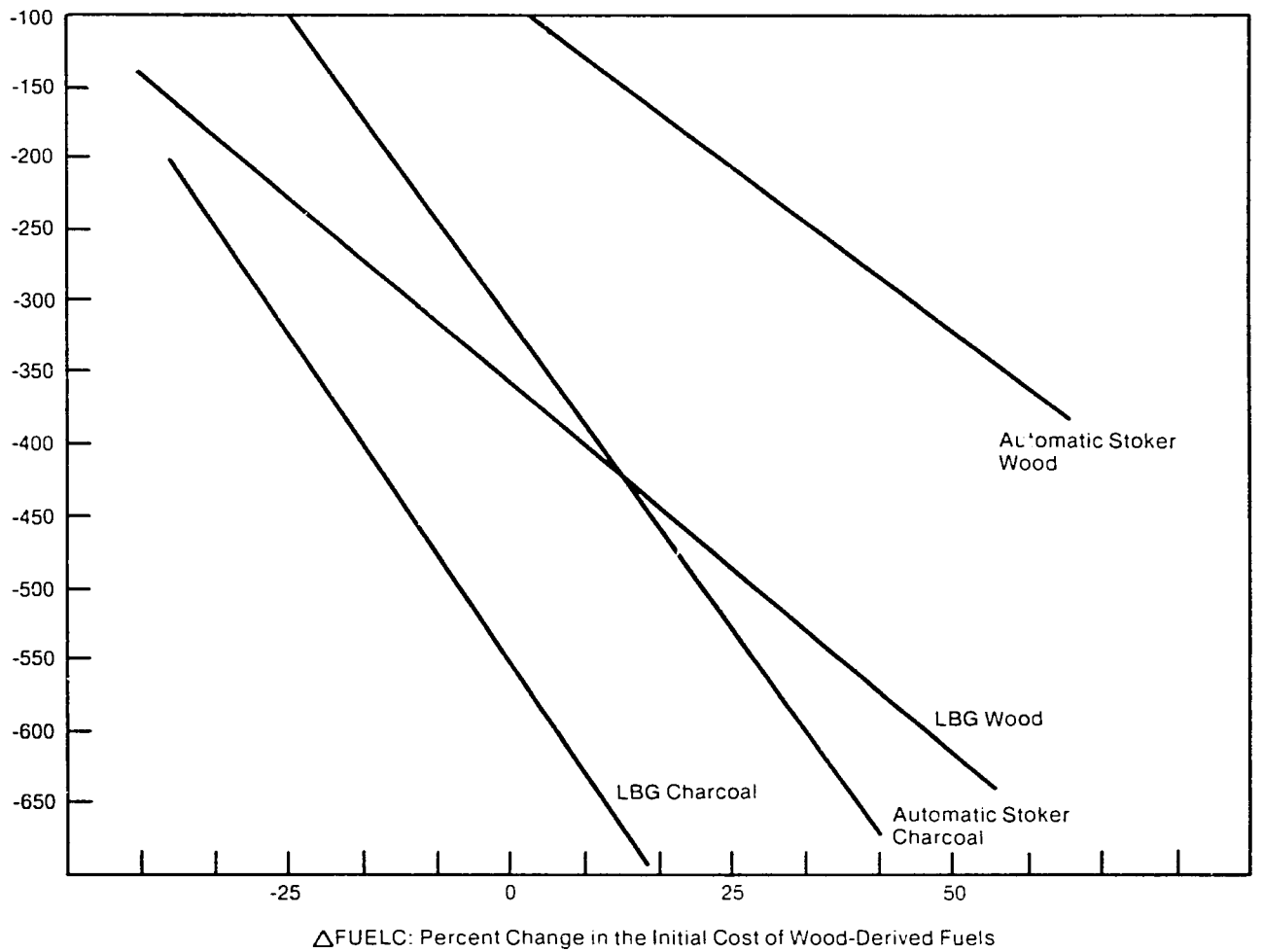


FIGURE 4-53
NPV VS. CHANGE IN THE INITIAL COST OF WOOD-DERIVED FUELS: RETROFIT MANUAL STOKED WOOD FURNACES, i* = 0.11

Case E. New package hot air furnace (4.0 MMBtu/hr)

- System Description

A new package hot air furnace, complete with fuel system, is base loaded at 75 percent of capacity for 16 hours/day and has an annual utility of 85 percent. Three options including a base case distillate oil system were considered.

Option 0: A distillate oil-fired package hot air furnace (see Figure 4-54).

Option 1: An automatic stoker, wood-fired package hot air furnace (see Figure 4-55).

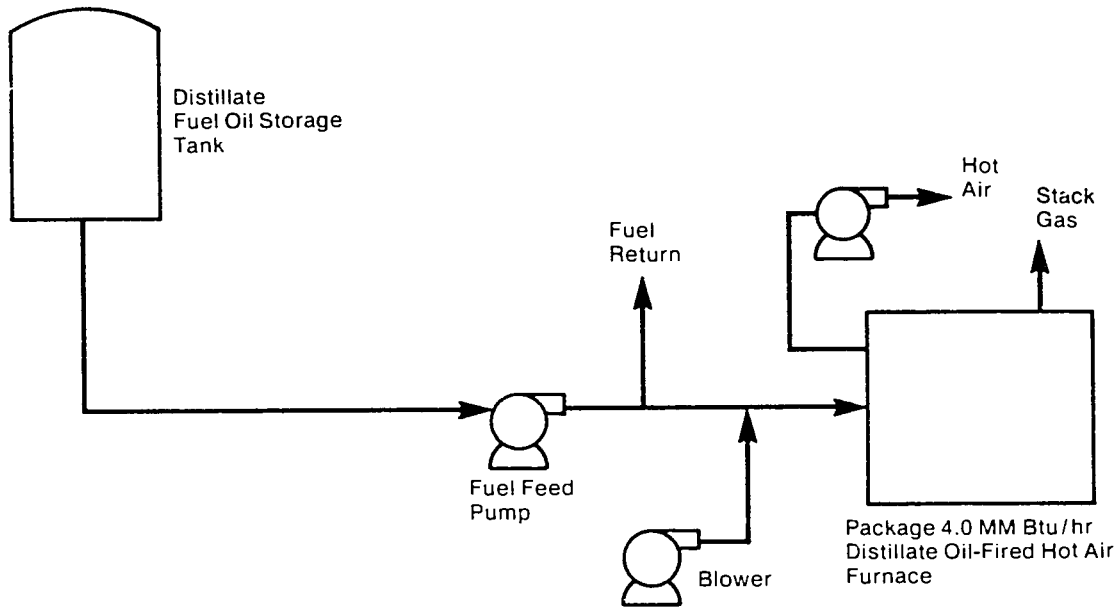
Option 2: An automatic stoker, charcoal-fired package hot air furnace (see Figure 4-56).

Initial cost and operating parameters were estimated for each option. These data are presented in Table 4-XIII. The additional land costs shown for the wood and charcoal systems are for land estimated to be required over that of the distillate oil-fired system.

- Results

The analysis indicates that both the automatic stoker, wood-fired and automatic stoker, charcoal-fired furnaces have approximately equivalent positive NPVs. A summary of the NPV analysis is presented in Table 4-XIV and Figures 4-57 through 4-59. The sensitivity analysis indicates that the NPV of the wood-fired system is more sensitive to equipment costs while the NPV of the charcoal-fired system is more sensitive to fuel price. The final selection of

either the wood-fired or charcoal-fired system must therefore incorporate the specific conditions of each potential application.



Package Distillate Oil-Fired Hot Air Furnace:
- Fuel storage tank—40 tonne
- Fuel feed pump
- Oil preheater
- Pipes and valves
- Electrical and instrumentation
- Oil burner
- Hot air heat exchanger

Estimated Delivered Costs: K32,000

Labor Requirements:

Supervisory	0.25 M/hr
General	1.0 M/hr

Utilities:

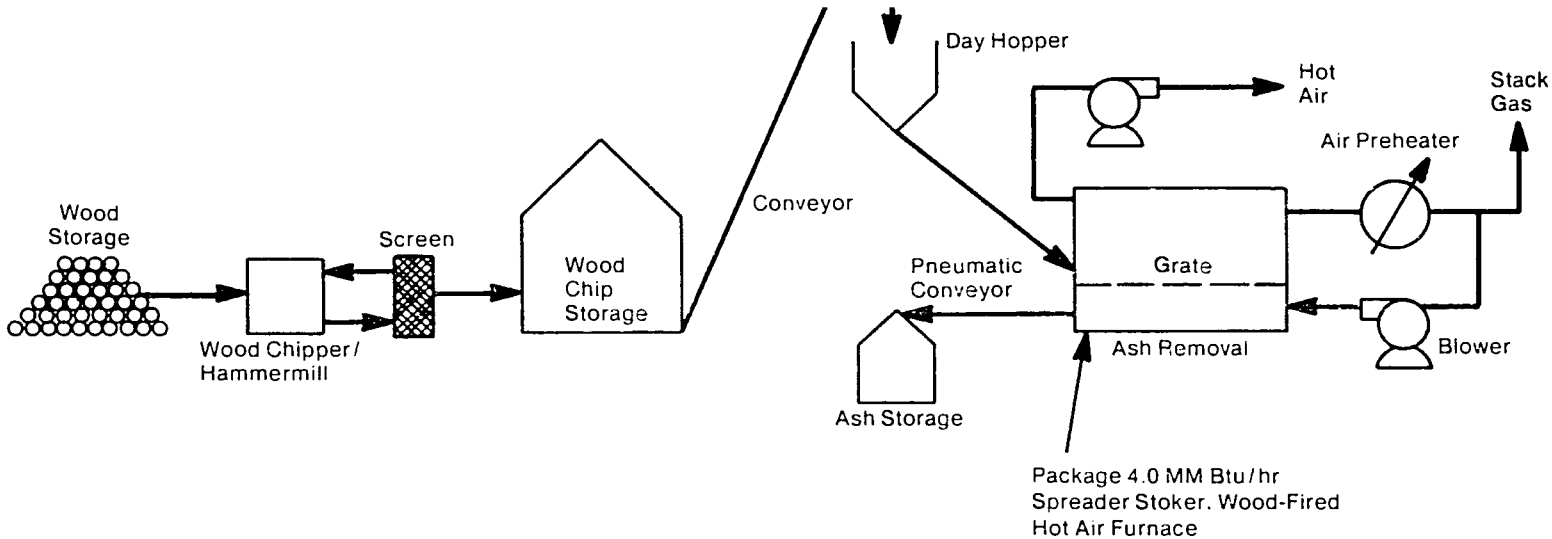
Electrical	3.0 KW

H.V. of Fuel: 39.7 MM Btu/tonne #2 fuel oil

Daily Fuel Input: 1.2 tonne #2 fuel oil

Furnace Efficiency: 0.85

FIGURE 4-54
OPTION 0: PACKAGE DISTILLATE-FIRED HOT AIR FURNACE—4.0 MM BTU/HR



Package Wood Fired Hot Air Furnace:
- Wood storage shed
- Wood chipper/hammermil and screens
- Conveyors
- Wood chip storage
- Day hopper
- Stoker
- Air cooled grate
- Ash removal and storage
- Hot air heat exchanger
- Electrical and instrumentation

Estimated Delivered Costs: K111,000

Labor Requirements:

Supervisory	0.50 M/hr
General	3.00 M/hr

Utilities:

Electricity	2.5 KW

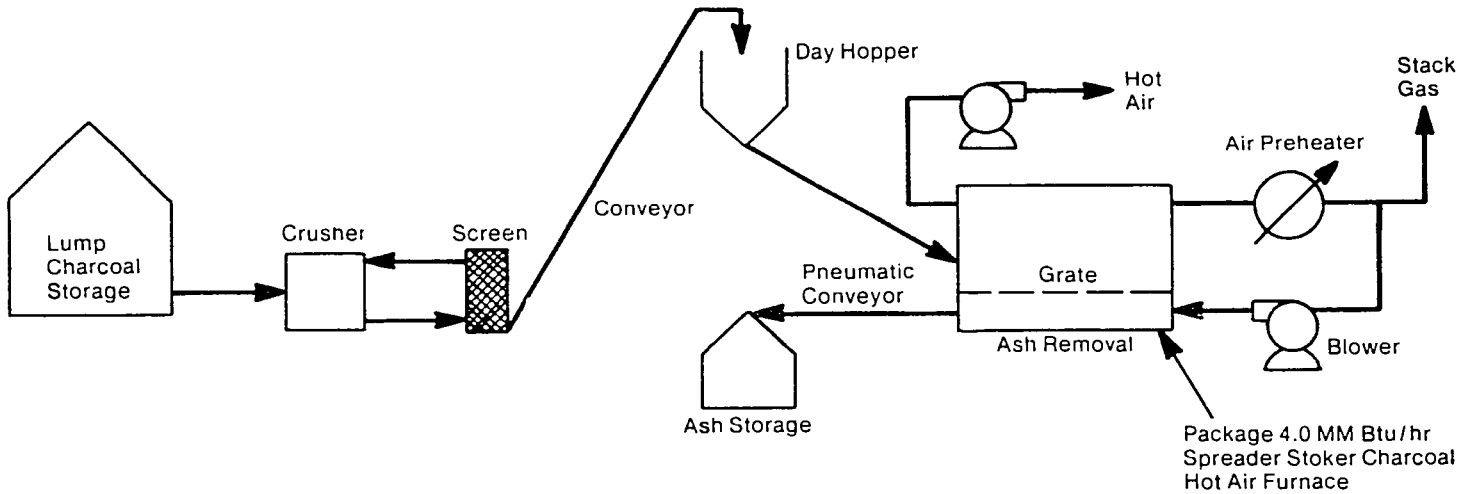
H.V. of Fuel: 18.7 MM Btu/ODT wood

Moisture Content: 43% dry basis

Daily Fuel Input: 2.6 ODT wood

Furnace Efficiency: 0.70

FIGURE 4-55
OPTION 1: PACKAGE WOOD-FIRED HOT AIR FURNACE—
4.0 MM BTU/HR



Package Charcoal Fired Hot Air Furnace
- Lump charcoal storage
- Charcoal crusher
- Screen
- Conveyor
- Stoker
- Day hopper
- Water cooled grate
- Ash removal and storage
- Hot air heat exchanger
- Electrical and instrumentation

Estimated Delivered Costs: K75,000

Labor Requirements:

Supervisory	0.5 M/hr
General	2.0 M/hr

Utilities

Electricity	15 kw

H.V. of Fuel: 27.5 MM Btu/tonne charcoal

Daily Fuel Input: 1.7 tonne charcoal

Furnace Efficiency: 0.80

FIGURE 4-56
OPTION 2: PACKAGE CHARCOAL-FIRED HOT AIR FURNACE—4.0 MM BTU/HR

TABLE 4-XIII

CASE E: INITIAL COSTS AND OPERATING PARAMETER ESTIMATES

OPTIONS / COSTS IN KINA	PACKAGE DISTILLATE FIRED	PACKAGE AUTOMATIC WOOD STOKER	PACKAGE AUTOMATIC CHARCOAL STOKER
CAPITAL INVESTMENT	50,690	176,700	119,240
WORKING CAPITAL	1,362	8,500	8,600
TOTAL INITIAL CAPITAL INVESTMENT	64,310	185,200	127,840
INITIAL ANNUAL COSTS:			
PRIMARY FUEL	115,650	19,830	40,060
OPERATING LABOR	12,170	31,820	24,340
UTILITIES	730	6,120	3,670
MAINTENANCE	7,600	26,500	17,890
TOTAL INITIAL ANNUAL OPERATING EXPENDITURES	136,150	84,270	85,960
EQUIPMENT COSTS	32,000	111,000	75,000
ADDITIONAL LAND COSTS	N/A	2,000	1,000
OPERATING PARAMETERS:			
FHI (10^{-3} tonne/hr)	76.2	162.0	109.1
SUVPL (m/hr)	0.25	0.5	0.5
GENL (m/hr)	1.0	3.0	2.0
ELI (KW)	3.0	25.0	15.0
PCOIL	1.0	0.0	0.0
HRIND (hr)	16	16	16
ALOAD	0.85	0.85	0.85

TABLE 4-XIV

CASE E: SENSITIVITY ANALYSIS OF NPV ($\times 10^3$ KINA)

SENSITIVITY ANALYSIS \ OPTIONS	AUTOMATIC STOKER WOOD	AUTOMATIC STOKER CHARCOAL
$i^* = 0.11$		
BASELINE	359	366
EQUIP + 25%	282	314
EQUIP - 25%	436	448
FUELC + 25%	321	289
FUELC - 15%	397	443
$i^* = 0.20$		
BASELINE	155	185
EQUIP + 25%	92	142
EQUIP - 25%	219	228
FUELC + 25%	133	140
FUELC = 25%	178	231

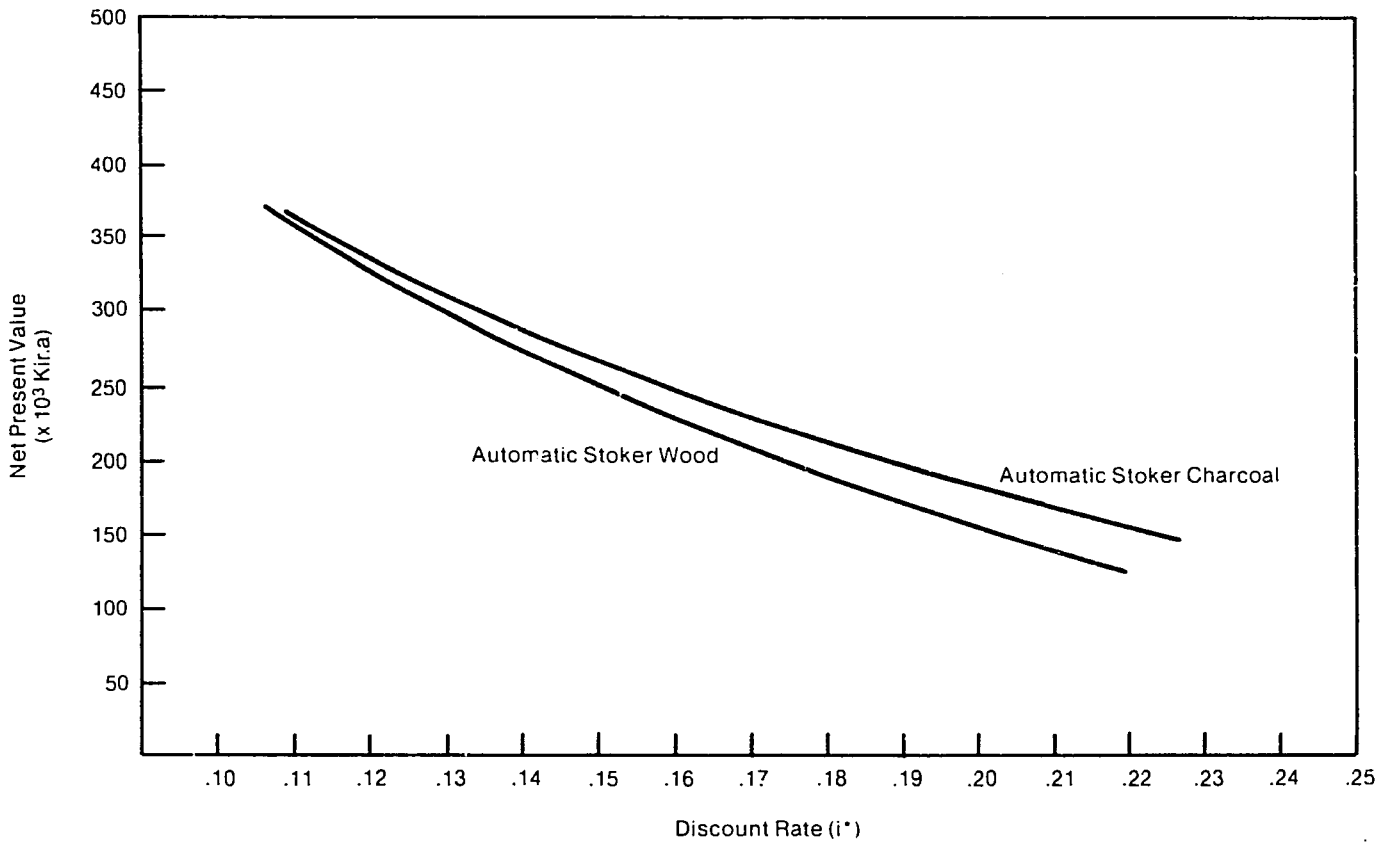


FIGURE 4-57
NPV VS. DISCOUNT RATE: NEW 4.0 MMBTU/HR HOT AIR FURNACE

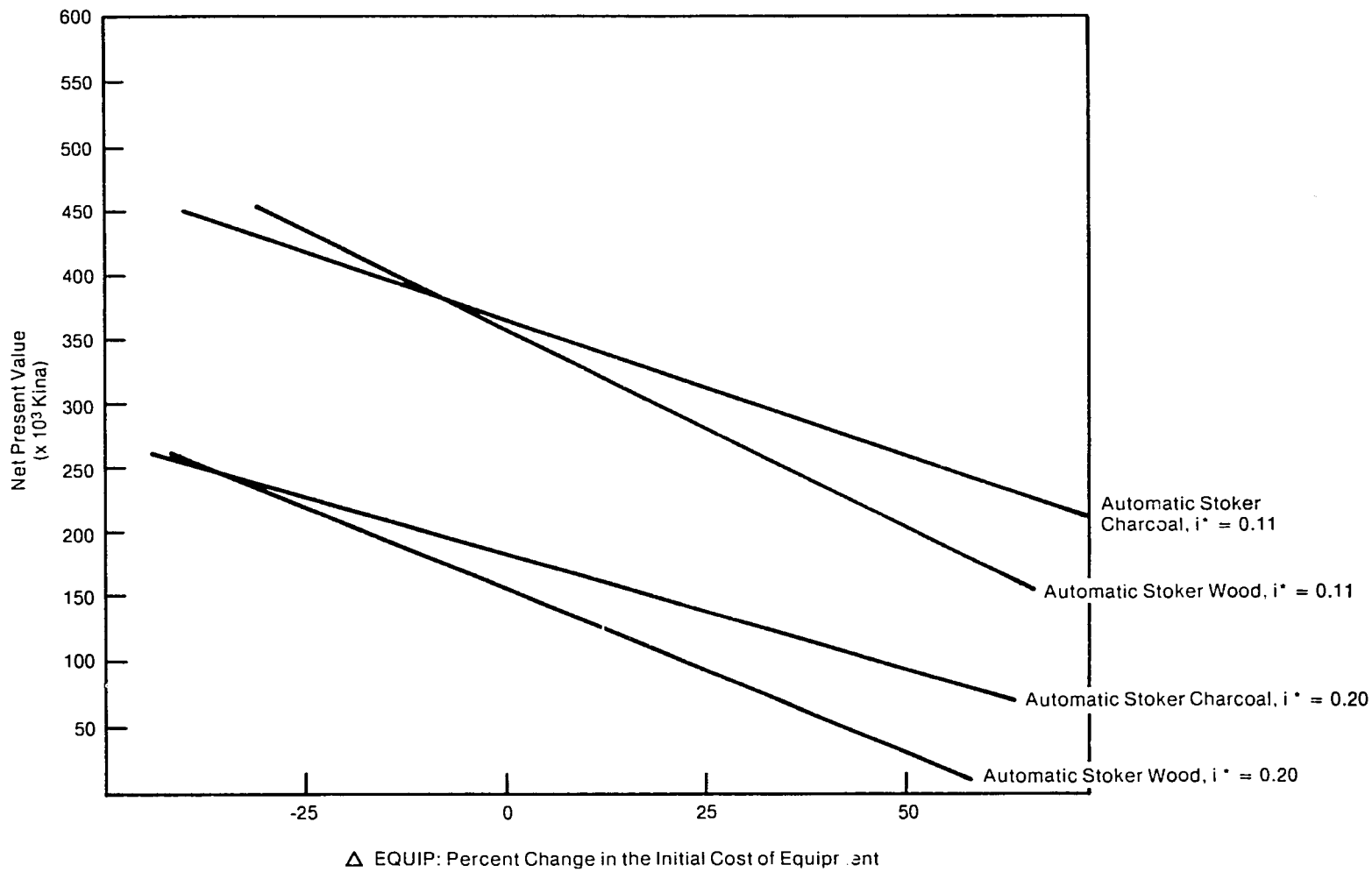


FIGURE 4-58
NPV VS. CHANGE IN THE INITIAL COST OF EQUIPMENT:
NEW 4.0 MMBTU/HR HOT AIR FURNACE

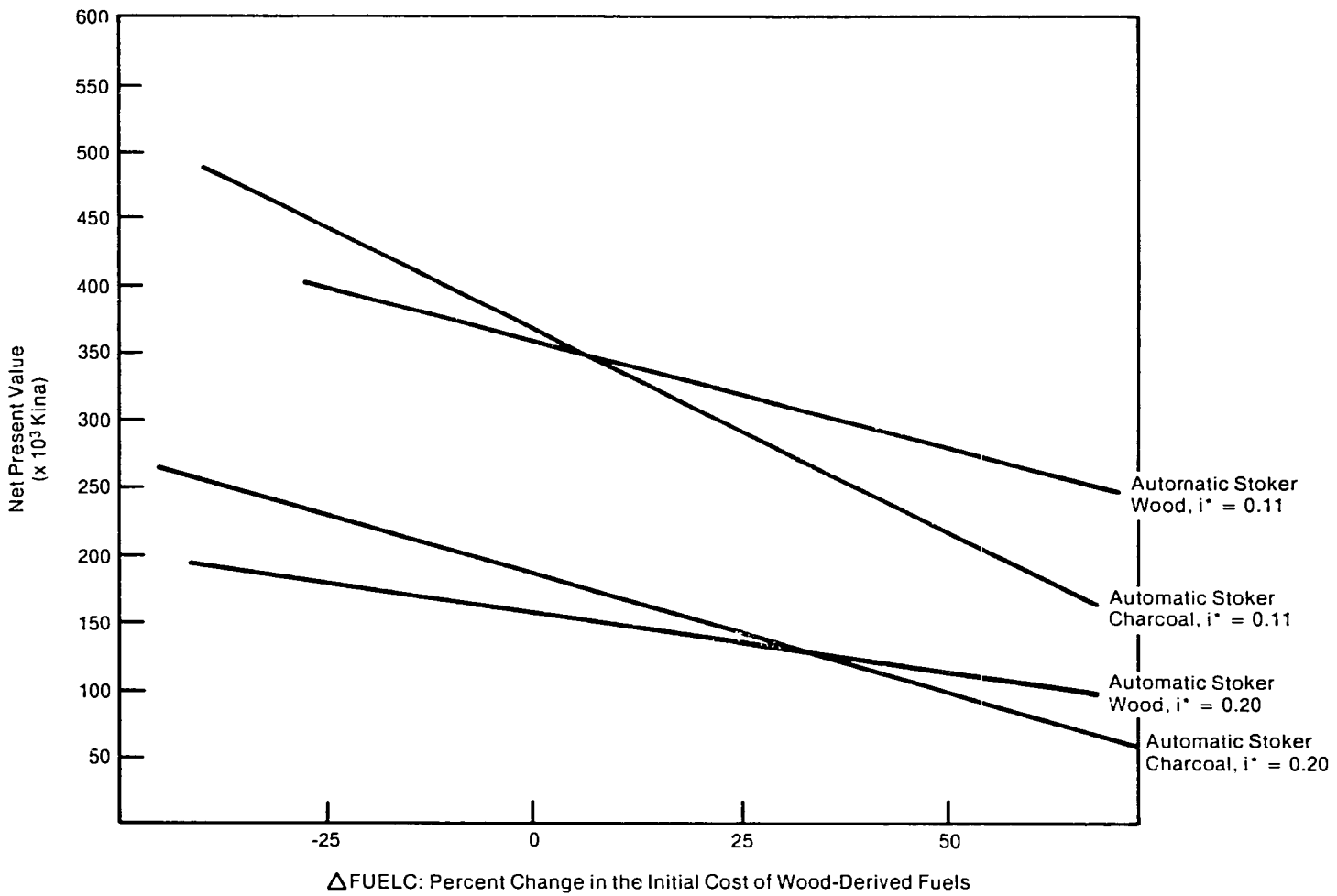


FIGURE 4-59
NPV VS. CHANGE IN THE INITIAL COST OF WOOD-DERIVED FUELS: NEW 4.0 MMBTU/HR HOT AIR FURNACE

4.4 Assessment of Specific Cases

4.4.1 Assessment Methodology

Six specific cases were assessed qualitatively; detailed analysis of each of these systems was beyond the scope of this effort. Preliminary quantitative analysis was employed, when data were available, to help formulate qualitative judgments. The results are intended to provide a preliminary economic assessment of alternatives to petroleum fuels.

4.4.2 Case Studies

Case F. Proposed expansion of Bougainville Copper Limited's (BCL's) power plant.

BCL presently maintains a 135 MW power plant at Anewa Bay to provide power to its mining operations. The power plant consumes approximately 575 tonnes of #6 fuel oil daily.[1] BCL is planning to add 45 to 90 MW of capacity at Anewa Bay to be fired with imported Australian coal. The possibility for utilizing domestically produced charcoal, either as the primary fuel or mixed with coal, has been raised. Thus, two options were considered.

- Use of imported Australian coal
- Use of domestically produced charcoal alone or mixed with coal.

[1]Estimate given in conversation with Mr. J. Dunn, plant manager.

Australian steam coal presently is selling for approximately K25/tonne FOB at Australian ports.[1] The heating value of the coal is approximately 26.4 MMBtu/tonne.[2] Domestically produced charcoal is expected to sell at K75/tonne (and has a H.V. of 27.5 MMBtu/tonne). If the selling price of charcoal is as indicated above, the Australian coal has a large margin (i.e., K1.77/MMBtu or K46/tonne) in which to recover transportation and import duty costs[3] and still remain competitive with charcoal. No definite costs for transportation of the coal from Australia were submitted by BCL but indications are that the delivered price will not be double that of the mine mouth price.[4]

For charcoal to be competitive, it would have to be produced in the vicinity of the Anewa Bay Power Plant to minimize transportation costs. Furthermore, the cost of the wood resource must necessarily be less than the K25/tonne presently being quoted. This would indicate that wood waste with a zero or negative price would be required.

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[1]Source: U.S. Department of Energy, Energy Information Administration, Office of Energy Information Services, and Mr. Robert Gerber, Zinder Co. Inc. (publishers of World Coal Statistics), Washington, D.C.

[2]Data on Australian coal characteristics were obtained from Mr. Linden Mayer, Australian Department of Trade. Queensland coal has an average moisture content of 6 percent to 15 percent; average total sulfur content of 0.3 percent to 0.5 percent; and average ash content of 8 percent to 12 percent.

[3]The present import duty for coal is 2.5 percent of its value.

[4]Preliminary estimates of shipping costs given by the BCL plant manager were K9/tonne of coal.

At present, no major lumber mills producing significant quantities of wood waste are located in the Anewa Bay area.

A potential advantage of charcoal is its zero sulfur content. The potential savings in required sulfur control equipment and the net environmental effects must be accounted for. Thus, while preliminary analyses indicate that charcoal use at Anawa Bay is not an economically viable option, a more detailed analysis is necessary.

Case G. BCL's ore concentrate dryer.

Concentrate ore of about 90 percent solids by weight is presently dried in a residual oil-fired rotating kiln dryer. The dryer is a single burner, direct fired heat exchanger, consuming about 4000 liters of #6 fuel oil/day.[1] Three fuel options were considered for this system.

- Continue the use of #6 fuel oil
- Convert to pyrolytic oil
- Convert to charcoal-oil mixtures.

Table 4-XV presents a comparison of annual fuel use and costs for the three options. The pyrolytic oil option provides a 23 percent reduction in annual fuel costs. The annual savings of K54,000 will result in a rapid payback for the retrofit equipment necessary to accommodate the use of pyrolytic oil. However, the effect of pyrolytic oil on the characteristics of the dried ore must be

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[1]Estimate given by Owen Matthews, BCL's concentrate drying plant manager.

TABLE 4-XV

CASE G: COMPARISON OF ANNUAL FUEL USE AND COSTS FOR THE BCL ORE CONCENTRATE DRYER

OPTION	ANNUAL FUEL USE[1] TONNE/YR	ANNUAL COSTS KINA/YR
#6 Fuel Oil	1,350	237,600
100% Pyrolytic Oil	2,160	183,600
50/50 Charcoal Oil Mixture	1,630	204,565

[1]Based on 360 days per year operation. The heating values of the total fuel used in all options are equivalent.

evaluated. Additionally, the cost of transporting pyrolytic oil to Bouganville, if not produced locally, must be accounted for.

Some additional observations pertaining to fuel conservation were made by the project team while visiting the BCL facility. As the unit is currently operated, turndown is insufficient for low firing rates. An examination revealed that combustion air is introduced by induction through a series of ports on the front end of the concentrator drier. There is no provision for mechanically modulating the air with the burner firing rate. This results in inefficient use of fuel due to excessive air intake. In addition, there is substantial heat loss through the walls of the combustion chamber. The excessive length of the combustion chamber and the lack of exterior insulation are the major reasons for this heat loss.

Case H. A.C.I. Glass process furnace.

A.C.I. Glass is the second largest energy consumer in PNG.[1] Part of the A.C.I. operations in Lae consist of a large furnace which generates heat for processing glass for manufacturing bottles. Fuel used by the glass furnace was estimated at 3500 tonnes of #6 fuel oil/year.[2] Two fuel options were considered potentially applicable to A.C.I. glass.

- Continue the use of #6 fuel oil
- Convert to a pyrolytic oil residual oil mixture.

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[1]BCL including its power plant is the largest energy consumer in PNG.

[2]Estimate by Mr. Colin Jolly, Chief Engineer, A.C.I. Glass, Lae.

A 70/30 pyrolytic oil-residual oil mixture was selected purely to illustrate the economics of utilizing pyrolytic oils. The potential for the proportion and use of a pyrolytic-residual oil mixture must await tests of the effects on both furnace operation and glass quality. LBG gasifiers were not considered because of the high temperature requirements of the furnace and the difficulty for retrofit due to space requirements. Charcoal-oil mixtures were not considered because of the potential for particulate fouling of the glass.

Present furnace fuel consumption costs approximately K616,000 per year. The equivalent 70/30 oil required would amount to approximately 4,900 tonnes per year.[1] At a cost of K107 per tonne pyrolytic oil mix the fuel costs are equivalent to K525,770, a 15 percent reduction in present fuel costs. If a 100 percent pyrolytic oil could be used, fuel costs would be K475,500 or a 23 percent savings in fuel costs.

Clearly, the benefits for using a pyrolytic oil are great in this particular case. A.C.I. Glass recognizes this and indicated a willingness to investigate the technical aspects of using pyrolytic oil.[2] The required research and testing should be pursued immediately.

---

[1]Assumes a 70/30 pyrolytic-residual oil mixture has a H.V. of 30.2 MMBtu/tonne.

[2]Conversation with Lou Dingjan, Managing Director, A.C.I. Glass, Lae, May 8, 1980.

Case I. Arawa Hospital Boilers.

The Arawa Hospital presently has three George and George 75 HP firetube boilers that are fired with distillate oil. All of the units were experiencing severe tube wastage (both fire-side and water-side) and rear door refractory problems. In two of the boilers, tube failure has occurred so frequently or severely that they are not repairable. The remaining boiler is not expected to have a significant service life, and combustion efficiency on this boiler was judged to be significantly below design. The boilers are approximately 10 years old. Lack of technically qualified operators, proper maintenance and adequate boiler water treatment are the main reasons for failures. Replacement of these boilers will be necessary within a year. Several options were considered for replacement of the existing boilers.

- Package oil-fired boilers
- Package wood-fired boilers
- Solar hot-water/low-pressure steam units
- Electric hot-water/low-pressure steam units.

The option most desirable for the Arawa Hospital is electric hot-water/low-pressure steam units. Electric boilers have a higher reliability and low maintenance requirement when compared to other available options. New oil-fired boilers, besides being costly to run, might encounter the same operation and maintenance problems that led to the demise of the present boilers. In addition, the potential

for a decline in the combustion efficiency of an oil-fired boiler due to lack of maintenance is much greater than that of an electric boiler.

On a purely economic basis, an electric boiler may not be the lowest cost option. The initial capital investment for an electric boiler is approximately 30 percent less than an equivalent oil-fired boiler.[1] However, if electricity is bought at K0.05/kWh and distillate for K310/tonne, the equivalent cost of delivered steam is K14.95/MMBtu for the electric boiler and K8.85/MMBtu for the oil-fired boiler.[2] With relatively higher inflation for petroleum fuels, this discrepancy in costs will decline. A partially offsetting factor to the differential in fuel costs is the lower maintenance costs expected for electric boilers.

Wood-fired boilers are not particularly suited for the Arawa Hospital because of the additional maintenance and operational staff required. Problems similar to those with the existing oil-fired boiler may be compounded with a wood-fired boiler.

Solar units, besides requiring a large initial capital investment and having an unproven reliability, will require a backup system and operation and maintenance expertise not presently available in

---

[1]The cost of equipment for the oil burner and boiler components is approximately equivalent to that of a similar capacity electric boiler. However, the fuel storage and feed system plus installation results in additional costs for oil-fired boilers.

[2]Assumes boiler efficiencies of 98 percent for electric boilers and 80 percent for oil-fired boilers.

Arawa. While the overall economics of a solar system could be attractive, an initial demonstration of this technology in PNG should be conducted in an environment more conducive for technical success.

Case J. Tea withering process of Mt. Hagen tea estates.

In the tea withering process, freshly picked tea leaves are air dried prior to being shredded for fermentation and final drying. Indirectly heated, forced air is used to wither the tea leaves. Heat is provided from either distillate oil or split log fired furnaces. On extremely warm, dry days, forced ambient air is used.

The present design of the withering process is inefficient and does not utilize the potential for solar assisted drying. The fans used for forcing air through the "withering ducts" (see Figure 4-60) generally are overloaded. The overload is due to the wet tea leaves being piled too high in the withering pans to permit air circulation through them.

A redesign of the withering process to increase air circulation and utilize solar heat would reduce the time required to wither the tea leaves and save energy. A possible redesign is shown on Figure 4-61.[1] In this design, multiple wire mesh racks are used in conjunction with solar air heaters. The multiple wire mesh racks eliminate the dense piling of tea leaves and enhance the circulation of air through the leaves. Solar air heaters that form the roof of the

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[1]This design is the author's based on information extracted from References 13, 14, 15 and 16.

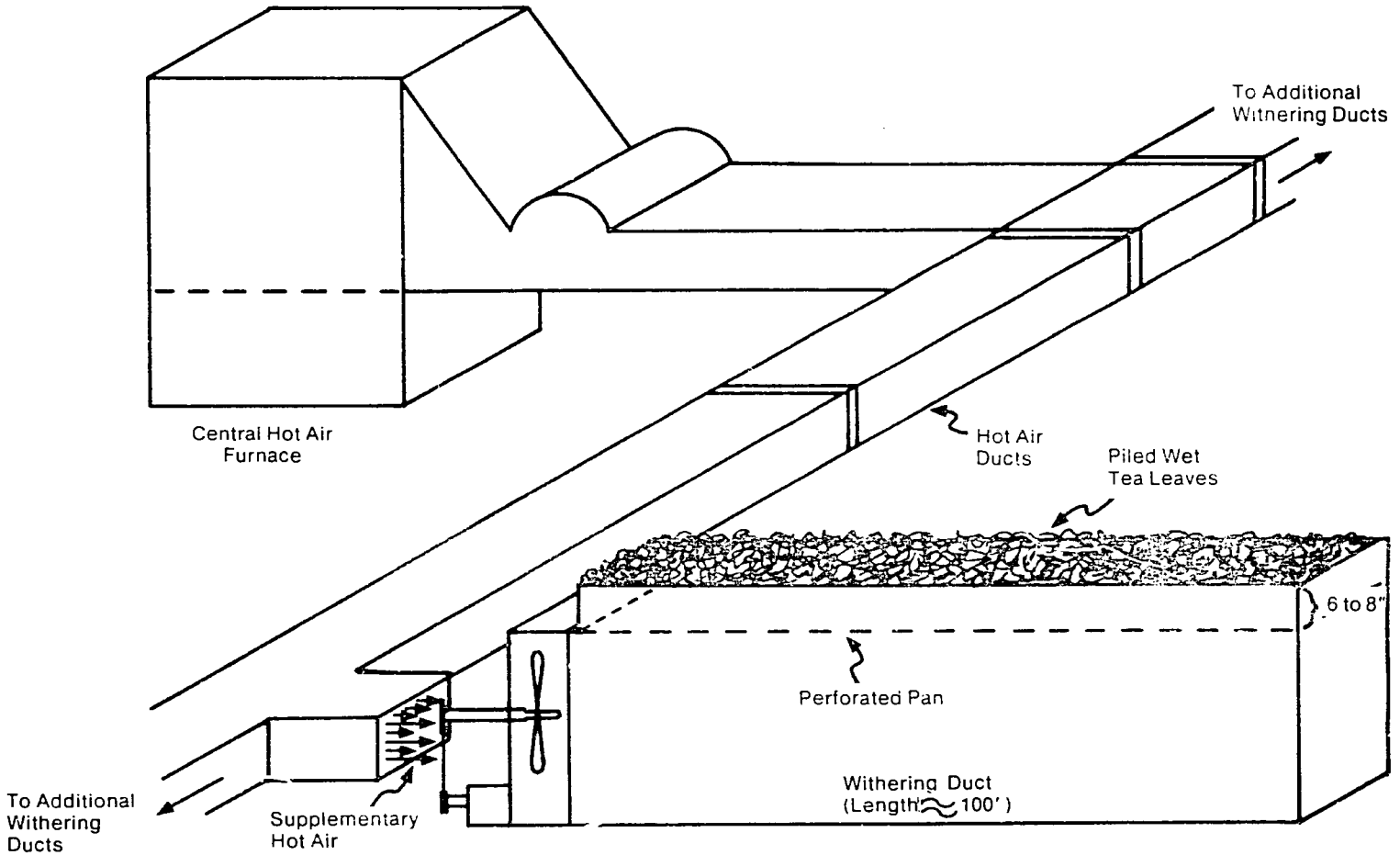

FIGURE 4-60
EXISTING TEA WITHERING DUCTS

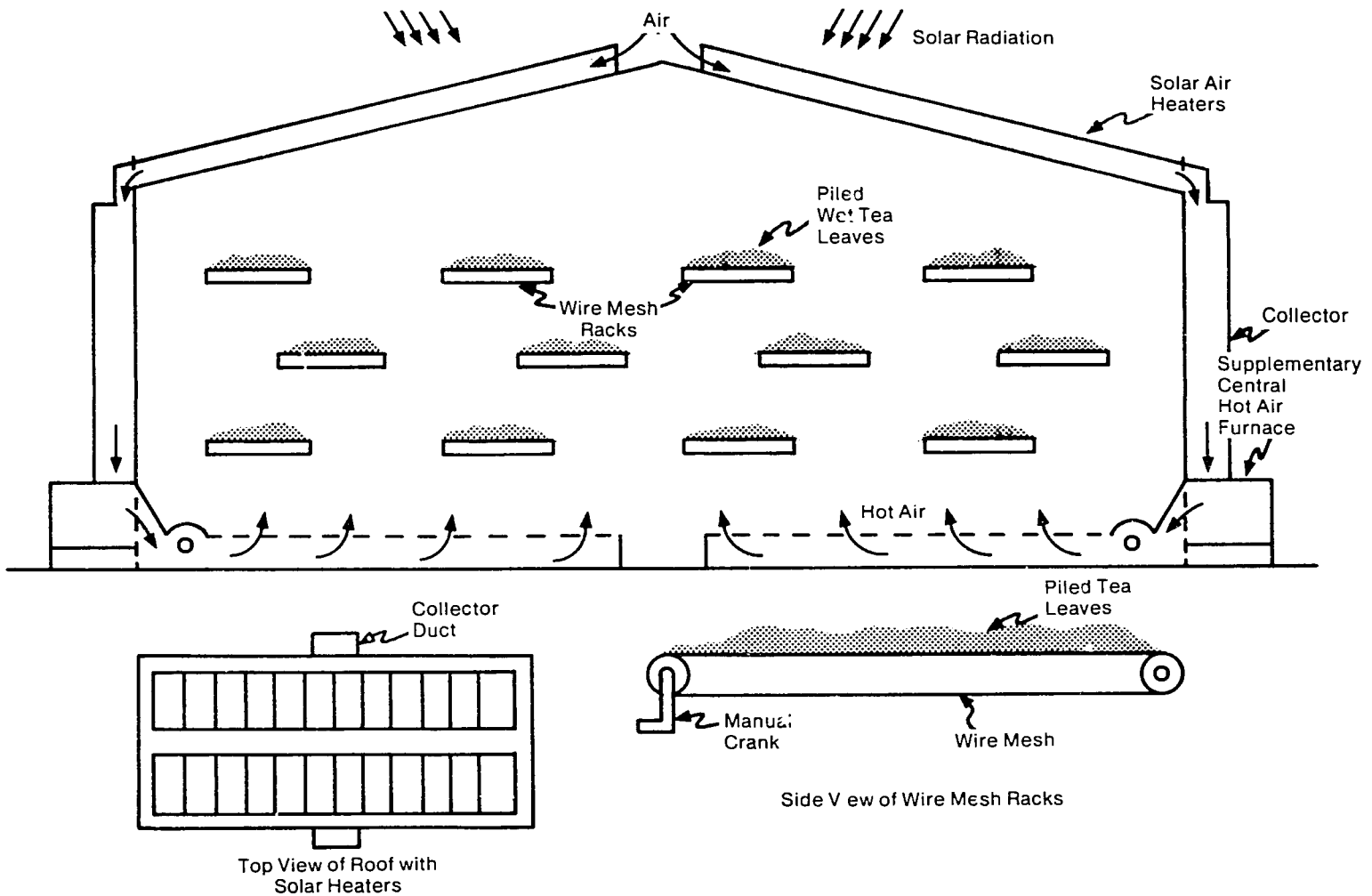

FIGURE 4-61
SOLAR ASSISTED TEA DRYING

withering shed help heat the air used to dry the leaves. The solar air heaters are simple, lightweight metal boxes, painted black on the insides with glass or plexiglas coverings. The existing wood- or oil-fired furnaces may be used as backup systems to provide heat on cloudy or rainy days. However, with a shortening of the withering process (currently five to seven days), the need to force dry the leaves on cloudy days could be eliminated. A more detailed technical and economic assessment of this option needs to be performed.

Case K. Tobacco curing process at Rothmans tobacco.

Rothmans tobacco curing facility in Goroka consists of several small (approximately 3 x 3 meters square and 10 meters high) curing barns, each equipped with four pot-type kerosene burners (see Figure 4-62). The kerosene burners are used to generate the heat required to cure the tobacco. The curing process requires that the temperature at the top of the barn be maintained at 180°F for seven days. There are approximately four curing periods of four weeks each every 14 months. Kerosene consumption is estimated to be approximately 238 tonnes during a 14 month growing cycle.[1] With the cost of kerosene at K332/tonne, fuel costs K79,000 per 14 months or approximately K67,700 per annum. Three options were evaluated to determine the best strategy for curing the tobacco.

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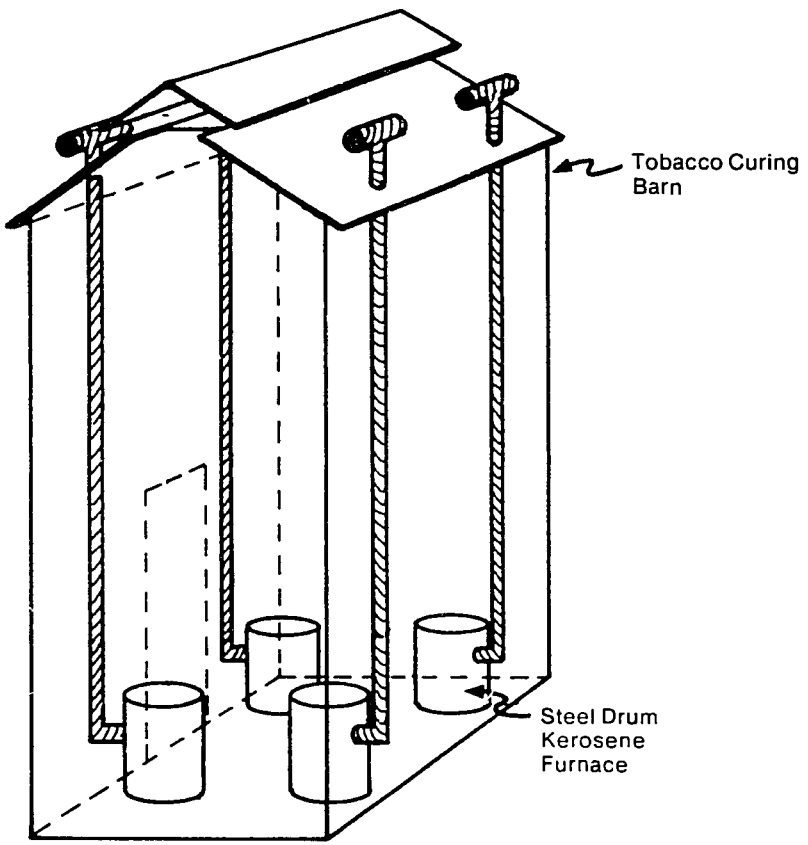
[1]Estimates made by Henry Agustonelli, Farm Manager, Rothmans Tobacco, Goroka.



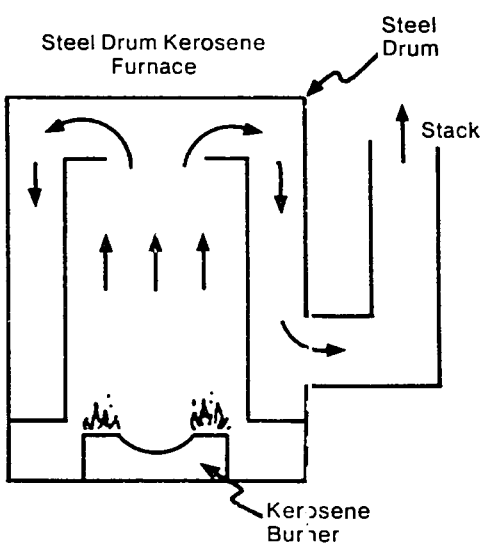


FIGURE 4-62
TOBACCO CURING BARNS AT ROTHMANS TOBACCO

- Continue to use the kerosene pot burners
- Install a central wood-fired, hot air furnace
- Utilize solar crop drying techniques in conjunction with a kerosene backup system.

A preliminary analysis indicates that the best option is to incorporate solar crop drying techniques with a kerosene backup system. Tests at the North Carolina State University Agricultural Experiment Station indicate that a 20 percent reduction in fuel costs can be achieved by using a curing barn constructed to utilize solar heat in conjunction with conventional heating (References 17 and 18). If these savings can be achieved at the Rothmans facility, the NPV of the savings will amount to K116,800 over a 10-year period (assuming a discount rate of 11 percent and an annual inflation in the price of petroleum of 8 percent). Thus, if the necessary solar modifications cost less than K116,800, a net return will be realized. A detailed study of the costs of the required solar modifications was beyond the scope of this study.

An economic analysis of a central wood-fired furnace indicated that the NPV of expenditure savings over both a 10- and 15-year period was negative because of the low overall utility of the system. Heat for tobacco curing is required for only an average of 16 to 20 weeks every 14 months, or an annual utility factor between 0.26 and 0.33. Such low utility does not permit the recovery in fuel savings of the large initial capital investment required for a wood furnace.

The estimated capital investment for a 4 MMBtu/hr furnace is K177,000 (see Case E). The costs for the kerosene pot-burners with equivalent heat output is estimated at K16,000.[1] This large differential in capital costs coupled with the low utility of the system renders the wood-fired furnace uneconomical in this particular case. The wood-fired furnace would be more economical if the utility factor for the system was greater than 0.5.

[1]Based on assumed cost per pot burned of K1000 and a heat output of 250,000 Btu/hr.

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5. J. W. Tatom, "Feasibility of Industrial Fuel Production from Purolysis of Wood Wastes in Papua New Guinea", Energy Planning Unit, Department of Minerals and Energy, Konedobu, Papua New Guinea.

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APPENDIX A

WOOD CONVERSION TECHNOLOGIES

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WOOD CONVERSION TECHNOLOGIES

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APPENDIX A

A-1 INTRODUCTION

Wood fuels have been analyzed in several MITRE studies (References 1 through 8) and the discussion which follows is based on these sources.

The use of wood fuels can be classified into two broad categories: direct combustion and thermochemical conversion. In direct combustion, the chemical energy in wood is converted to thermal energy through the rapid reaction of the hydrogen and carbon in the wood with oxygen in air. The thermal energy is used for process heat or process steam. In thermochemical conversion, the chemical energy of the wood is converted to a gas (low-Btu gas), liquid (pyrolytic oil) or solid (charcoal). The converted product can then be combusted to produce thermal energy. The primary advantage of thermochemical conversion is efficiency of handling and combustion of the converted fuel. A brief discussion of the state-of-the-art of wood combustion and conversion technologies is presented below. The discussion includes lists of manufacturers of wood combustion and conversion equipment.

A-2 DIRECT COMBUSTION

Several types of wood-fired combustion systems are available. Prior to 1950, the dutch oven was the most commonly used system.

Wood is fed into the oven from the top and falls onto a water-cooled grate where most of it is gasified. The gases produced are mixed with air and travel to a combustion chamber where they are burned to produce the heat required for steam generation. Though dutch ovens are still used today, they are being replaced by larger and more efficient combustion systems such as spreader-stokers and suspension systems as well as advanced fluidized-bed systems.

A summary of the firing methods currently used is presented in Table A-I and briefly described below.

A-2.1 Stoker Systems

There are three types of stokers: underfeed, crossfeed and overfeed (i.e., spreader-stoker). They differ mainly in the relative directions of the flows of fuel and air.

Of these three types, spreader-stokers are now the most widely used because they handle a range of solid feedstocks, respond rapidly to load changes and operate efficiently with comparatively low excess air. As shown in Figure A-1, the wood fuel is spread pneumatically or mechanically across the combustion chamber onto the surface of a grate. Small fuel particles burn in suspension while larger pieces fall and burn on the grate. The feed system is designed to spread an even, thin bed of fuel on the grate. The flame over the grate radiates heat to the fuel to aid combustion. Both underfired and overfired air are used for controlling the combustion process. The

TABLE A-1

COMMERCIAL/INDUSTRIAL TECHNOLOGIES

TECHNOLOGY	DESCRIPTION	FUEL TYPE	EFFICIENCY	SIZE RANGE
Stoker systems	In stoker firing, hogged fuel or wood chips are either flipped or blown into the combustion zone of the boiler. Small particles burn in suspension while larger pieces burn on the grate.	Hogged wood, wood chips, bark, etc. Typical particle size range between 3/4" - 1-1/2".	57-68%	25-500 Million Btu/hr
Package systems	This system uses a fuel cell firing method. A refractory lined chamber is used as a fuel burner cell.	Hogged wood, sawdust bark, planer shavings, etc.	65-70%	10-50 Million Btu/hr
Suspension burner systems	The COEN DAZ Scroll feed burner is an automated burner for handling fine organic residues. This burner can be used to retrofit oil- and gas-fired boilers.	Requires fine (1/32") and dry feed material. Will burn sander dust, particle board trim, bark, sawdust, etc.	65-75%	10-50 Million Btu/hr
Fluidized-bed systems	Fluidized-bed systems are preferred for burning dirty fuel, or high moisture content fuel which is not easily burned in a conventional system. The boiler integrated with this fluid-bed burner, will in general, be a fire-tube design.	Wood waste and residue, fuel containing significant amount of foreign materials (sand, glass, etc.).	60-75%	10-50 Million Btu/hr

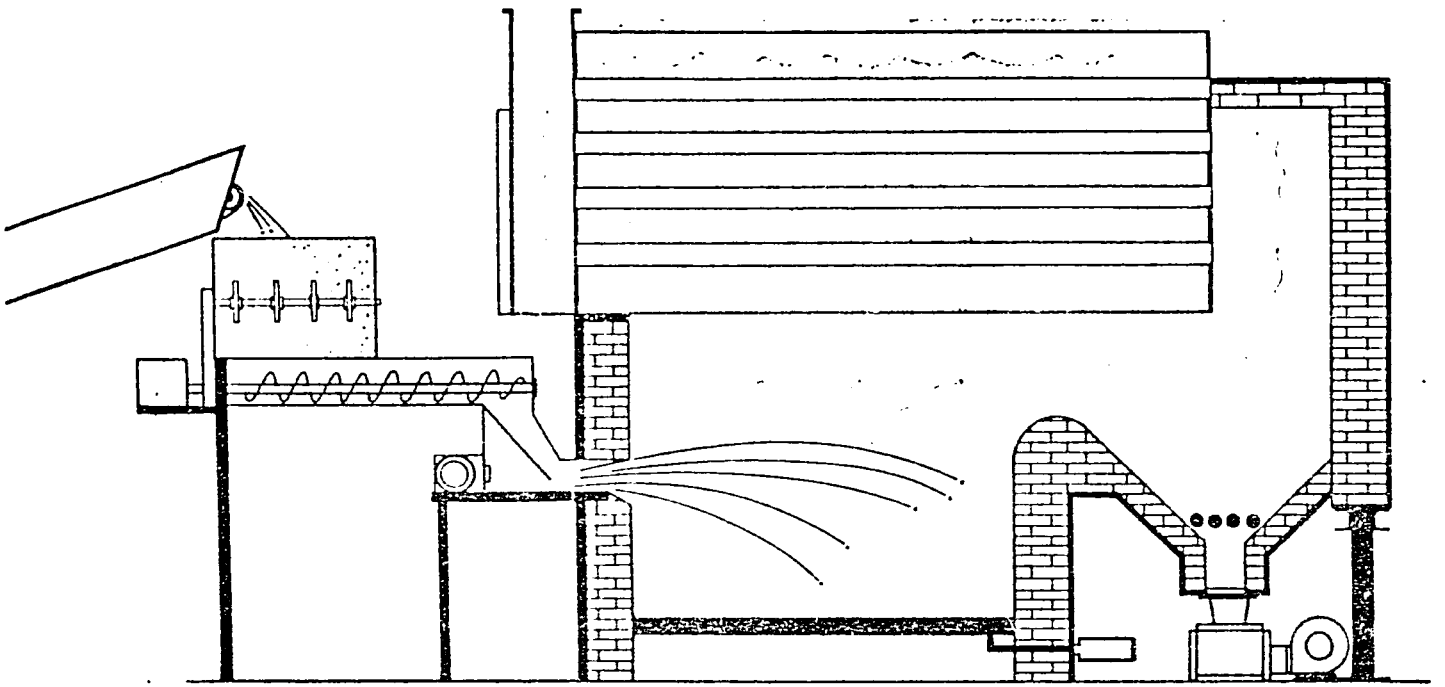


FIGURE A-1
TYPICAL SPREADER STOKER BOILER SYSTEM
(FROM APPLIED ENGINEERING CO. BULLETIN NO. 868)

furnace walls are normally lined with tubes for heat exchange. Because there is little refractory material, the furnace can respond quickly to load variations. Construction and maintenance costs of these furnaces can be quite low.

Many types of stoker systems are presently manufactured. These can be grouped into two categories: single chamber combustion or multi-chamber combustion. In the multi-chamber system, partial oxidation of the fuel with substochiometric air occurs in the first chamber followed by off-gas combustion in the additional chambers. The multiple-chamber design separates the gasification step from the main combustion step and, therefore, minimizes ash carryover and improves control of combustion. Single-chamber units are more difficult to control than multiple-chamber units, emit more particulates, and have a relatively low turndown ratio. Alternately, single-chamber units are simpler to operate and have a lower cost than multiple-chamber units.

Stoker systems can incorporate various grate designs. Among the possibilities are stationary or continuously moving grates, fixed or dumping type grates, flat or inclined orientations, and air-cooled or water-cooled designs. Selection of a particular grate design depends on furnace capacity, fuel characteristics (i.e., heating value, and moisture and ash content), combustion air requirements, and maintenance considerations.

Stoker systems are a commercially proven technology. According to the American Boiler Manufacturers Association, wood-fired stoker boilers represent 14 percent of all boilers, in size range of 100,000 to 300,000 lbs steam per hour, sold in the U.S. in the last ten years. A sample list of stoker boiler manufacturers is shown in Table A-II.

A-2.2 Package Systems

Package systems are shop assembled units shipped completely ready to connect and operate. Package boilers with capacities up to 60,000 pounds of steam per hour are in this category. When higher steam outputs are required, several units can be operated in parallel. Wood-fired package boilers are a commercially proven technology. About 100 wood-fired package boilers were reported to be in operation in North America as of 1978.

Package boilers can generate hot water, low pressure steam or, in some designs, high pressure steam. The units are fully automated and designed for simplicity and flexibility of operation. In some designs, wood fuel of fairly large size (end cuts, for instance) and high moisture content (50 to 60 percent wet basis) can be used, therefore eliminating the constraints of fuel drying required for suspension burners.

The design of package boilers differ by the type of combustion chamber and combustion system used, the type, size and moisture

TABLE A-II

SAMPLE LIST OF STOKER BOILER MANUFACTURERS

Anga and Varme A.B.
Halmsted, Sweden

Applied Engineering Co.
1525 Charleston Hwy.,
Orangeburg, SC 29115

Babcock-Wilcox Company
20 S. Van Buren Avenue
Barberton, OH 44203

Basic Environmental Engineering Inc.
21W161 Hill Street
Glen Ellyn, Illinois 60137

Berg and Starck A.B.
Norrtalje, Sweden

Detroit Stoker Company
Monroe, Michigan 48161

Envirometrix, Inc.
P.O. Box 1869
Seattle, WA 98111

Envitherm, Inc.
417 Gates Street
Mount Vernon, WA 98273

Foster Wheeler
110 South Orange Avenue
Livingston, NJ 07039

Irvington-Moore Division
U.S. Natural Resource, Inc.
P.O. Box 40666
Jacksonville, FL 32203

Komis-Kessel
Robert Bosch STr. 305, D-6830
Schwetzingen, West Germany

Lamb-Cargate Industries, Ltd.
P.O. Box 440,
New Westminster, B.C. V5C 3N3, Canada

Lockhead-Haggerty Engineering
and Mfg. Co., Ltd.
3904 Grant Street
Burnaby, B.C., V4C 3N3, Canada

Olivine Corporation
1015 Hilton
Bellingham, WA 98225

The International Boiler Works Co.
P.O. Box 498
East STroudsburg, PA 18301

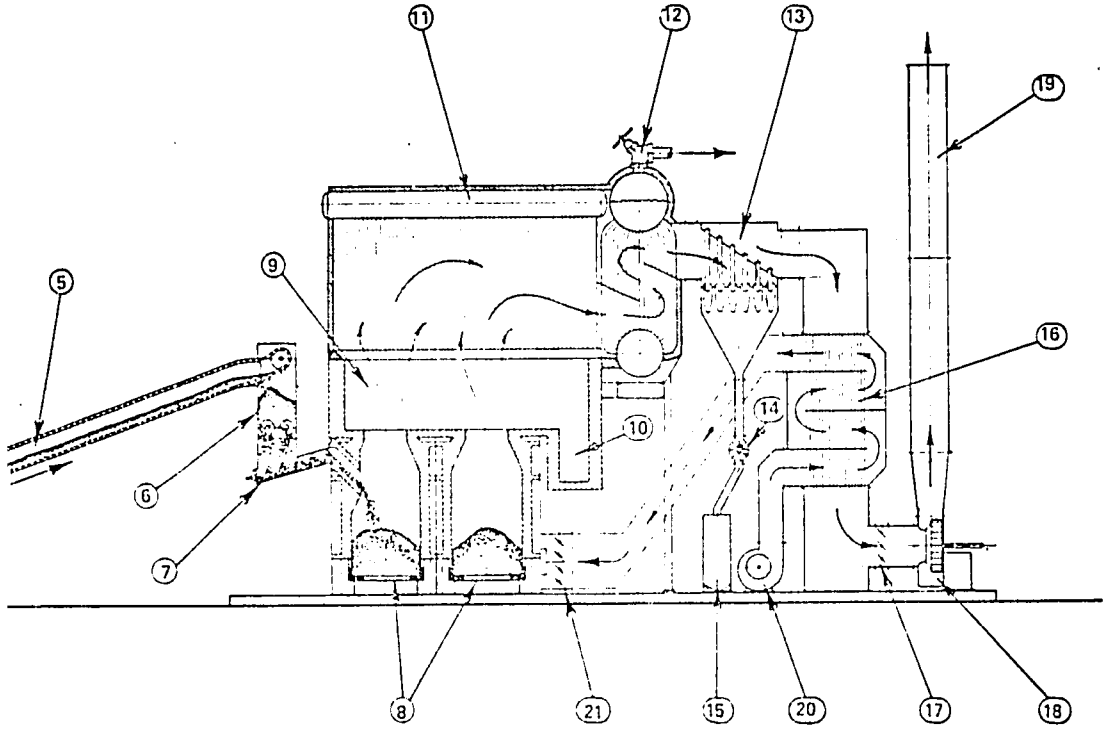
Zurn Company
2214 West 8th Street
Erie, PA 16512

content of the fuel tolerated, and the need for supplementary fuel. In most package systems, a refractory lined chamber is used as the fuel burner cell. The refractory chamber enhances high temperatures for smoke-free combustion. Package wood-fired boilers range in size from 3,000 to 60,000 lbs steam/hr with combustion efficiencies between 65 to 70 percent. Package systems are generally designed for automatic control. Properly sized wood fuel is continuously metered from a storage bin to the fuel cell burner. A sample package boiler system is shown in Figure A-2. A list of package system manufacturers is presented in Table A-III.

A-2.3 Suspension Burner Systems

In suspension burners, relatively fine particles of wood or other organic material are mixed with air and burned in suspension. Suspension firing of wood is similar to pulverized coal firing. As of 1978, more than 200 units were reported to be in operation in the U.S. Some of these units have been in service for over 15 years.

Suspension burners produce a relatively clean hot gas which can be used in various industrial processes. The burners can also be used to retrofit existing oil- or gas-fired package boilers producing less than about 50,000 pounds of steam per hour. Suspension burners are generally fully automated and have sufficient turndown capability to respond to variable energy demands encountered in process applications.



5. Conveyer from Storage Bin (not shown)
6. Metering Surge Bin
7. Furnace Feed Auger
8. Water-cooled Grates
9. Combustion-completion Chamber
10. Dropout Chamber
11. Radiant Section of Boiler
12. Steam Outlet to Process
13. Multicone Collector
14. Rotary seal
15. Dump box
16. Combustion air Preheater
17. Induced draft Damper
18. Induced draft fan
19. Exhaust Stack
20. Forced draft Fan
21. Linear flow Dampers

FIGURE A-2
WELLONS CYCLO-BLAST BOILER SYSTEM
(FROM WELLONS INC., BULLETIN 081)

TABLE A-III: SAMPLE LIST OF SOURCES OF DATA ON WOOD-FIRED BOILERS

Babcock and Wilcox Canada Ltd.
1055 West Hastings Street
Vancouver, B.C. V6E, 2E9 Canada

Gebruder Weiss Boiler Company
3142 N. Nottingham Avenue
Chicago, IL 60634

Ray Burner Company
1301 San Jose Avenue
San Francisco, CA 94112

Ultrasystems, Inc.
2400 Michelson Drive
Irvine, CA 92715

Wellons, Inc.
P.O. Box 381
Sherwood, OR 97140

The major disadvantage of suspension burners is that they require dry, fine fuel. Dry fuel may be available at some industrial locations (planer shavings, for instance). In other situations, the fuel must be dried to the moisture content required by the suspension burner design. In most cases, the dry wood fuel must be hammermilled to the size required by the burner. The cost of these fuel preparation steps as well as fuel storage and fuel handling equipment may bring the cost of the total wood-fired system to two or three times that of the burner alone. Suspension burners also require some electrical power for wood feed and air blowers and may require auxiliary fossil fuel for startup and operation.

The thermal efficiency of a boiler using suspension burners is around 75 percent. This efficiency corresponds to a 10 percent moisture feedstock, 25 percent excess air and 500°F stack gas temperature. This relatively high thermal efficiency is partly a result of suspension burning, where a high heat release rate (50,000 Btu/cu.ft.), comparable to oil- or gas-fired boilers, is achieved. A sample suspension burner system is shown in Figure A-3. A list of manufacturers of wood suspension burners is presented in Table A-IV.

A-2.4 Fluidized-bed Systems

Fluidized-bed combustion systems burn fuels (gas, liquids or solids) in the presence of a mass of mineral particles (i.e., crushed sand, limestone, dolomite or other minerals) which are supported and

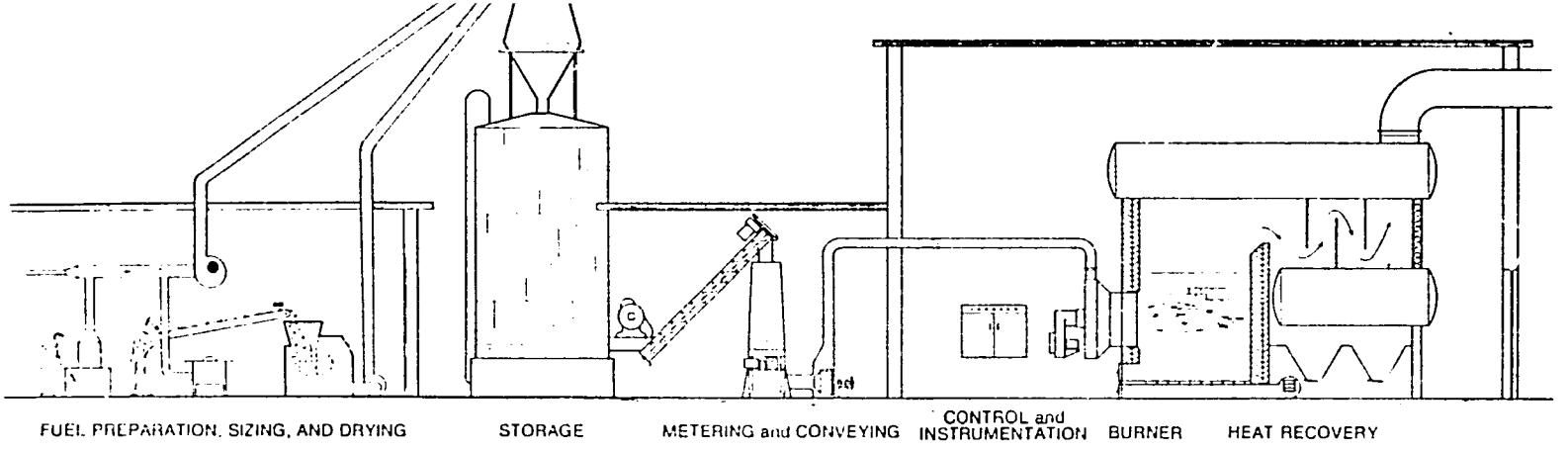


FIGURE A-3
TYPICAL WOOD SUSPENSION BURNER SYSTEM
(FROM A PEABODY GORDON-PIATT BULLETIN)

TABLE A-IV: SAMPLE LIST OF MANUFACTURERS OF WOOD SUSPENSION BURNERS

Coen Company, Inc.
1510 Rollins Road
Burlingame, CA 94010

Energex-Moore Canada Ltd.
1900 No. 6 Road
Richmond, B.C. V6V 1P2
Canada

Envirometrix, Inc.
P.O. Box 1869
Seattle, WA 98111

Guaranty Performance Company, Inc.
P.O. Box 230045
Tigard, OR 97223

Peabody Gordon-Piatt
P.O. Box 650
Winfield, KS 67156

Waycott Systems, Ltd.
2940 Main Street
Vancouver, B.C. V5T 3G3
Canada

kept in turbulent motion by a constant stream of air. There are two basic types of fluidized-bed combustion systems: atmospheric and pressurized.

The fluidized-bed package boiler is an atmospheric combustion system. Combustion air passes through a bed of lime, fuel (e.g., wood waste), and ash particles in a "homogeneous turbulent" motion that closely resembles a boiling liquid. This turbulent motion results in a five- to ten-fold increase in the heat transfer rate within the bed when compared to a conventional stoker-fired boiler. The atmospheric mutifuel fluidized-bed combustion package system can be used to produce steam or hot water and operates at an efficiency of between 65 to 75 percent (depending on system design and fuel characteristics).

Fluidized-bed combustion systems are commercially proven for wood up to 10,000 pounds of steam per hour and have been demonstrated up to 50,000 pounds per hour. A 100 MMBtu/hr unit manufactured by Combustion Power Company is in operation at the Weyerhauser facility in Longview, Washington.[1] The unit burns log-yard cleanup and

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[1]Reference to specific manufacturers is not the result of a deliberate selection process nor does it constitute an endorsement of the manufacturer's products.

other residues to provide hot gas to a boiler. All existing units are fire tube construction and are therefore limited to about 300 psi pressure.

A-3 THERMOCHEMICAL PROCESSING

Thermochemical processing of wood can be either pyrolysis or gasification. In pyrolysis, wood is heated in the absence of oxygen (i.e., air) to temperatures at which the hydrogen and carbon in the wood decomposes, producing combustible solids, liquids, and a small amount of gases. A limited amount of oxygen may be used, however, to provide the needed heat for decomposition. In gasification, wood is heated, usually with limited quantities of oxygen, in order to maximize the quantities of carbon monoxide and hydrogen produced. The aim in thermochemical conversion is to obtain chemical energy in a form convenient for transportation, storage and efficient combustion.

A-3.1 Gasification

The objective of gasification is to convert the energy content of wood and wood residues into a useful form. The gas produced may be used as a fuel or as a chemical raw material.

Depending on the gasification process, partial oxidation is carried out with either air or oxygen. Gasifiers under development for partial oxidation of wood, wood waste, and municipal waste are designed to operate at atmospheric pressure (in contrast to coal

gasifiers which can operate at pressures up to 1,000 psig). The atmospheric pressure gasifiers produce a low-Btu gas consisting of hydrogen, carbon monoxide, and carbon dioxide, with minor amounts of methane and heavier hydrocarbons and large amounts of nitrogen (about 42 percent) if air is used.

This gas has a heating value of about 180 Btu per scf. With the use of oxygen, nitrogen dilution is essentially eliminated, so the heating value of the gas may be as high as 350 Btu per scf. In either case, the gas containes a high percentage of moisture (as opposed to the product gas from coal gasification) corresponding not only to that generated during the partial oxidation but also to that present in the feed material. This moisture can be removed in the after treatment of the gas. In general, about 2 percent of the wood (dry basis) is converted to an oil-tar fraction which may be recycled.

Reactors used for the gasification process are generally characterized by the method of contacting solids and gases. The principal reactor configurations are:

- Fixed-bed
- Stirred moving bed
- Fluidized-bed
- Entrained flow.

Of these configurations, only fixed-bed gasifiers have been commercially used for wood gasification. The most common design is an updraught fixed-bed reactor in which three distinct reaction zones (drying, pyrolysis, and combustion) can be identified. Representative reactions are outlined below:

<u>Drying Zone</u>

212 - 400°F

Moist Wood + Heat $\longrightarrow$ Dry Wood + Water Vapor

<u>Pyrolysis Zone</u>

400 - 900°F

Dry Wood + Heat $\longrightarrow$ Char + CO + H_2O + CH_4 + C_2H_4 + other hydrocarbons + pyroligneous acids + tars

<u>Gasification and Oxidation Zone</u>

Char + O_2 + H_2O $\longrightarrow$ CO + H_2 + CO_2 + Heat

These reactions are sequential as the wood descends by gravity through the gasifier. A typical wood gasification system is shown in Figure A-4.

The fuel gas produced from the gasification of wood exits the gasifier at 250°F to 1,200°F depending upon the moisture content of the feedstock. The exit gas contains tars and oils as well as the combustible CO, H_2 and CH_4 gaseous components. A typical gas analysis for air blown gasification of wood is given in Table A-V.

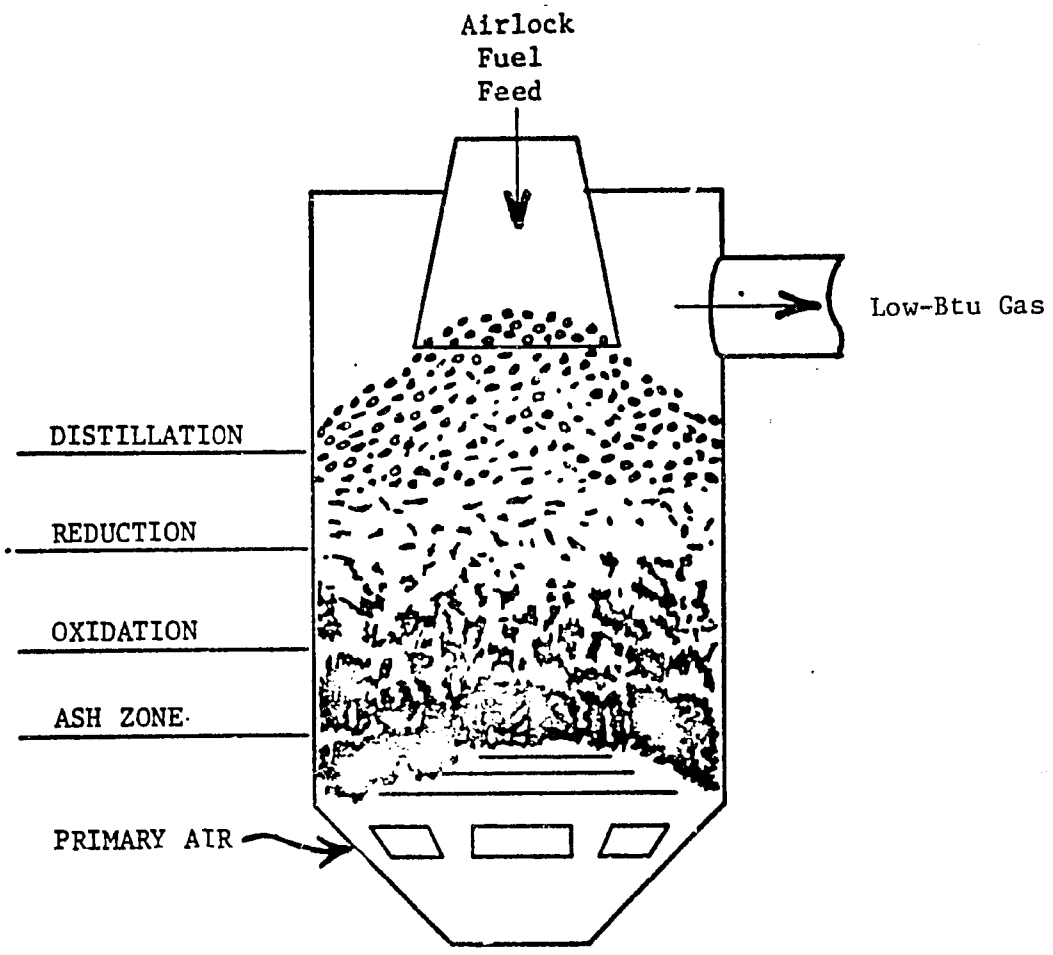

FIGURE A-4
TYPICAL WOOD GASIFICATION SYSTEM

TABLE A-V

FIXED-BED WOOD GASIFIER
GAS ANALYSES*

FEEDSTOCK ULTIMATE ANALYSIS (WT%):	VENTEAK WOOD
C	30.90
H	3.60
O	25.35
N	0.7
S	0.05
ASH	1.00
MOISTURE	38.40
TOTAL	100.00
HHV, BTU/LB	5,410
Gas Composition (Vol. $, Dry Basis, Tar Free)	
H_2	13.0
CO	29.0
CO_2	6.6
CH_4	4.0
N_2 + A	47.4
H_2S + COS	---
TOTAL	100.0
HHV, BTU/SCF	176
SCF of Dry Gas/LB Feed	17.2
Tar-Oil Product/LB Feed	0.081**

*Source: Asworth, R. Davy Power Gas Inc., Houston, TX, March, 1979.
**Includes methyl alcohol, does not include acetic acid

The wood-based low-Btu gas has a heating value of 120 to 175 Btu/scf depending upon the feedstock, moisture content and operational variables. The gas is most likely to be used in a close-coupled boiler, kiln or dryer after particulate removal in a simple cyclone. It is desirable to keep the product gas hot, usually 500°F to 800°F and to minimize both condensation of the tars and sensible heat losses.

Table A-VI presents a list of gasification units currently in use or under development.

Low-Btu gas (LBG) is often considered a more attractive alternative than medium-Btu gas (MBG) because of the capital expense and technical problems associated with construction and operation of an oxygen plant for an MBG facility. However, the average thermal conversion efficiency of producing MBG (about 80 percent) can be 10 to 15 percent higher than for LBG, thereby reducing feedstock requirements. Factors such as conversion costs and boiler derating will limit the use of LBG in direct oil burning applications. Retrofitting oil- or gas-fired boilers to burn LBG will typically include the following:

- Replacement of the existing burners
- Expanding the duct work for increased flue gas volume
- Adjusting the capacity of the induced draft fan or replacing it with a large unit.

TABLE A-VI

GASIFICATION PROCESS SUMMARY

PROCESS DEVELOPER	HOME OFFICE	DEVELOPMENT STATUS	CAPACITY (ODT/D)	ENERGY PRODUCT(S)	REACTOR TYPE	CURRENT APPLICATION
Alberta Ind. Dev. Ltd.	Edmonton, Al., Canada	C	30	LBG	FLB	Charcoal production
American Fyr-Feeder	Des Plaines, IL	C	1-15	LBG	SMB	Steam
Andco Inc.	Buffalo, NY	C	75-200*	LBG	MPB	Steam
Applied Engineering Co.	Orangeburg, SC	C	5	LBG	MPB	Boiler retrofit
Battelle Columbus Lab	Columbus, OH	D	NA	MBG	EF	-----
Battelle Northwest Lab	Richland, WA	D	2	LBG	SMB	-----
Biomass Corp.	Yuba City, CA	D	3-4	LBG	FXB	-----
Bio-solar R&D Corp.	Eugene, OR	D	10	LBG	FLB	Drying
British Columbia Research	Vancouver, B.C., Canada	D	10	LBG	FLB	Boiler retrofit
California, Univ., Davis	Davis, CA	D	18	LBG	MPB	-----
Canadian Ind. Ltd.	Kingston, Ont., Canada	D	24	LBG	NA	-----
Century Research Ind.	Gardenia, CA	D	NA	LBG/MBG	NA	-----
Davy Powergas Inc.	Houston, TX	C	84	LBG	SMB	Various
DeKalb Ag. Research	DeKalb, IL	D	NA	LBG	NA	Drying
Eugene Water & Electric Board	Eugene, OR	D	NA	LBG	NA	Boiler retrofit
Forest Fuels Inc.	Antrim, NH	C	2,3-9	LBG	SMB	Boiler retrofit
Garrett E.R.E. Inc.	Ojai, CA	D	3	MBG	SMB	-----
Halcyon Inc.	East Andover, NH	C	15-80	LBG	NA	-----
Jamex Inc.	St. Peter, MN	D	8	LBG	SMB	Farm utilization
Nichols-Herreschoff Corp.	Belle Mead, NJ	C	50-425	LBG	SMB	Charcoal production
Nova Scotia Tech. College	Halifax, N.S., Canada	D	5	LBG	MPB	Dual fuel engine
Pioneer Hi Bred Int. Inc.	Johnston, IO	C	20	LBG	MPB	Dual fuel engine
Quebec Electro Marine Diesel Inc.	Beaconsfield, Que., Canada	C	15	LBG	MPB	Dual fuel engine
Texas Tech University	Lubbock, TX	B	0.25	MBG	FLB	Synthesis gas
Union Carbide Corp.	New York, NY	D	200*	MBG	MPB	Synthesis gas
West Virginia University	Morgantown, WV	B	NA	MBG	FLB	-----
Westwood Polygas Ltd.	Vancouver, B.C., Canada	D	60	LBG	MPB	Drying, steam
Weyerhaeuser Co.	Tacoma, WA	B	NA	LBG	NA	-----
Wright Malta Corp	Ballston Spa, NY	D	3	MBG	RK	Synthesis gas

*Capacity is given in as-received MSW, usually containing 20 to 30 percent moisture.

Abbreviations:

C - Commercial
D - Developmental
B - Bench scale
LBG - Low Btu gas
MPB - Modified packed bed
MSW - Municipal solid waste
MBG - Medium Btu gas
FLB - Fluidized-bed
FXB - Fixed bed
SMB - Stirred moving bed
RK - Rotary Kiln
NA - Not available

Existing gas- or oil-fired boilers would be derated when low-Btu gas is used as a fuel. The degree of boiler derating will depend on the size of the furnace. Derating will be minimized if the original boiler has a relatively large furnace. Present day oil- and gas-fired package boilers, however, are designed to have very close tube spacing and small furnaces compared to solid fuel. This will limit the extent of retrofit potential and will introduce some boiler derating when low-Btu gas is used as fuel. The magnitude of boiler derating, depending on the original furnace design (relatively spacious, or very compact) may range between 5 to 25 percent of the initial design capacity.

A sample list of wood gasifier systems manufacturers is shown in Table A-VII.

A-3.2 Pyrolysis

Pyrolysis, or destructive distillation, is the thermal degradation of organic materials in a oxygen-defficient environment. The principal products of pyrolysis are gas, oil, char and water. The quality and quantities of these products depend both on input feed characteristics and process variables. For example, wood or wood wastes are pyrolyzed to produce a low-Btu gas, pyrolytic oils and charcoal. The relative amounts of these quantities are primarily controlled by:

TABLE A-VII

SAMPLE LIST OF WOOD GASIFIERS MANUFACTURERS

Alberta Industrial Development, Ltd.
1704 Cambridge Building
Edmonton, Alberta, Canada T5J 1R9
403-429-4094

Applied Engineering Co.
1525 Charleston Hwy.
Orangeburg, SC 29115 - 803/334-2424

Biomass Corp.
P.O. Box 487
Yuba City, CA 95991 - 916/674-7230

Garrett Energy Reserach & Engineering
Box 21
Claremont, CA 91711
714-593-7421

Monsanto Enviro-Chem Systems, Inc,
800 N. Lindburgh Blvd.
St. Louis, MO 63141
314-694-1000

Nichols Engineering & Research Corporation
Homestead and Willow Road
Belle Mead, NJ 08502
201-359-8200

Occidental R&D Company
10889 Wilshire Blvd.
Los Angeles, CA 90024
213-879-1700

TechAir Corporation
2231 Perimeter Park, Suite 16
Atlanta, GA 30341
404-458-9096

Union Carbide Corporation
270 Park Avenue
New York, NY 10017
212-551-2345

Weyerhaueser Company
Tacoma, WA 98041
206-259-0425

- The residence time of the wood in the pyrolytic converter
- The temperature of the pyrolytic converter
- The pressure in the pyrolytic converter.

In general, long residence times, high temperatures and lower pressures favor gas production while low temperatures favor oil and char production (see Figure A-5).

Reactors used for pyrolysis are usually characterized by the flow of solids and gases. The principal reactor configurations are:

- Gravitating Fixed Bed. These are stationary grate devices, where descending solids come in contact with rising gases in counter-current fashion. These may also be called moving packed-bed reactors.

- Gravitating Stirred Bed. This is a variation of moving packed-bed systems where the solid feedstock is agitated on a moving grate or rabble arms, continually exposing new surfaces for gasification.

- Fluidized-bed. In this system, gases coming from the bottom hold the solids in suspension so that partial combustion and subsequent pyrolysis can occur.

- Rotary Kiln. Solids are charged at one end, with gases moving either concurrently or counter-currently.

There are presently no commercially available pyrolysis processes producing both solid and liquid marketable fuels from wood. However, two processes are leading the field. They are the Tech-Air process developed by the Georgia Institute of Technology and offered by the Tech-Air Corporation, and the Enerco process developed by Enerco, Inc. A list of current pyrolysis processes and their development status is presented in Table A-VIII.

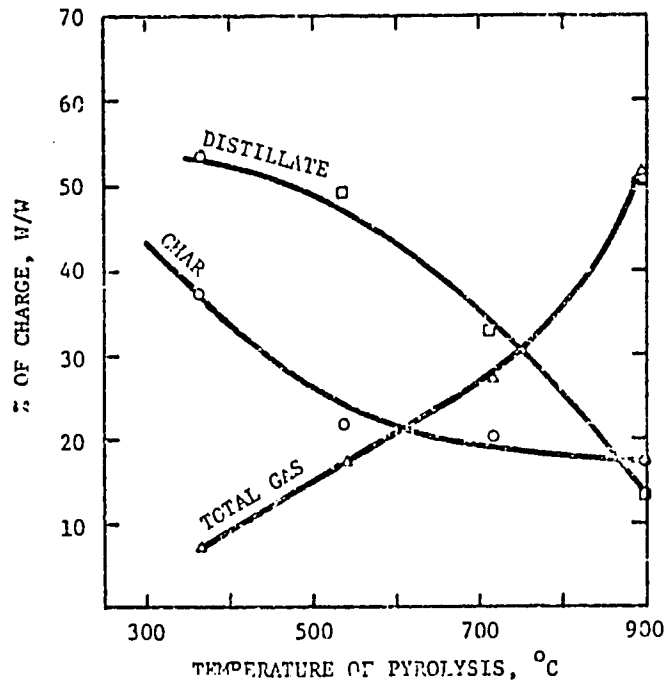

FIGURE A-5
PRODUCT YIELD FROM THE RAPID PYROLYSIS OF PAPER
(FROM REF. 3)

TABLE A-VIII
CURRENT STATUS OF PYROLYSIS SYSTEMS

Company	Reactor Type	Primary Products	Commercially Available
Enerco	Gravitating Fixed Bed	LBG,Char,Oil	Demonstration
ERCO	Fluid Bed	LBG,ChR,Oil	Demonstration
Industrial Boiler	Rotary Kiln	LBG,Char	Yes
Nichols-Herreshoff	Multiple-hearth	LBG, Char	Yes
Occidental Research	Moving packed bed	LBG,Oil,Char	Demonstration
Pyrotechnic Ind. Ltd.	Moving packed bed	LBG, Char	Demonstration
Tech-Air (Tatom)	Gravitating Stirred Bed	LBG,Char,Oil	Demonstration
Thermax	Fluidized Bed	Char,Oil	Pilot

Low-Btu Gas

The gas produced in a pyrolysis process containes a large percentage of the moisture from the feedstock. Thus, it must be used on-site while still at a high temperature to avoid condensation problems. The gas typically has a heating value of 100 to 180 Btu/scf.

Pyrolytic Oil

The oils produced from the pyrolysis of wood waste have different properties from those of petroleum oils (see Table A-IX). In general, pyrolytic oil is a complex, highly oxygenated, viscous organic fluid with a very low sulfur content and about 75 percent of the heating value of residual oil on a volumetric basis.

Present research indicates that this oil is suitable as a fuel but not as a chemical-feedstock. The main reason is that it degrades when heated to high temperatures. In general, pyrolytic oil burns well by itself and in combination with #6 oil. Further, no major changes in burner configuration are required before switching from residual to pyrolytic oil and vice versa. The only problem encountered, in recent applications, has been the periodic buildup of solids inside the burner causing a deterioration in the fuel spray-pattern. Additional problems include the high corrosivity of the oils. This requires special handling and storage systems such as stainless steel pipe, pumps and tanks. A potential advantage of

TABLE A-IX

CHARACTERISTICS OF PYROLYTIC OIL AND RESIDUAL OIL

	Typical No. 6 Oil	Pyrolytic oil from bark
Fuel Properties		
Chemical analysis		
Carbon, %	85.7	52.57
Hydrogen, %	10.5	6.67
Nitrogen, %		0.32
Oxygen, %	2.0	30.06[2]
Sulfur, %	1.5	0.04
Chlorine, %	-	0.02
Ash, %	0.3	0.74
Moisture, %	-	9.58
Heating Value, Btu/lb	18,200	9341
Heating value, Btu/gal	148,840	--
Specific Gravity	0.98	1.26
Pour point, F	75	75
Flash Point, F	150	230
Viscosity, SUS at 190F	160	940[3]
Pumping Temperature, F	115	-
Atomization Temperature, F	220	-

Source: KVB Inc. [1]Total for nitrogen and oxygen difference [2]Determined by [3]Units are SFB at 122F

pyrolytic oils is their low sulfur content resulting in environmental benefits.

Charcoal

Charcoal from the pyrolysis process generally has a heating value of approximately 12,500 Btu/lb. The charcoal can be used both as a solid fuel or for activation processes. In the U.S., charcoal from pyrolysis processes is briquetted and used as a fuel for back-yard barbeques. Charcoal can be substituted for wood or coal. Its main advantage over wood is that it is more economical to transport and handle due to its higher Btu content per unit weight. Charcoal cannot be used directly in existing oil or gas combustion systems without major modifications to the system. Present research is concentrating on the potential for charcoal-oil mixtures (COM) similar to those of coal-oil mixtures. The low ash and sulfur content of charcoal makes this an attractive application.

A-4 CHARCOAL-OIL MIXTURES

The coal-oil mixture concept is a developing technology designed to conserve scarce oil and gas supplies by replacing up to 50 percent of fuel oil by weight with pulverized coal and burning it in units formerly using oil or gas.

The same concept can be applied to the use of charcoal-oil mixtures. The use of charcoal in place of coal was experimentally tried at DOE's Pittsburgh Energy Technology Center (PETC) in 1977.

It involved preparing low-volatile wood charcoal and Pittsburgh-seam coal mixes, slurries of wood charcoal and pyrolytic wood oil with additional #6 fuel oil, and the combustion of a high-volatile wood char burned alone. The combustion equipment was a 100 HP liquid-fueled firetube boiler equipped with an air-atomized oil gun. Combustion tests were 8 hours in duration. The general conclusion reached was that the prepared fuels burned readily. A brief discussion of coal-oil mixture technologies is presented below. The discussion can be generalized to include charcoal-oil mixture technologies.

The coal-oil mixture technology basically involves two major processes: preparation of the coal-oil mixture and then its combustion in existing combustors. The coal-oil mixture preparation process (see Figure A-6) takes place at low temperature (65°-95°C) and atmospheric pressure, and involves the following mechanical operations: pulverization of the coal, mixing the coal and oil (with/without additives), and storage of the resulting mixture. In general, the coal-oil mixture preparation plant can be considered to operate as a centralized preparation and distribution facility.

A uniform mixture is essential for good flame stability and also to keep the coal from settling out in tanks and lines. In standard dry grinding the object is to obtain coal particle sizes passing 80 percent through 200 mesh (74 microns). Finer coal particle sizes are

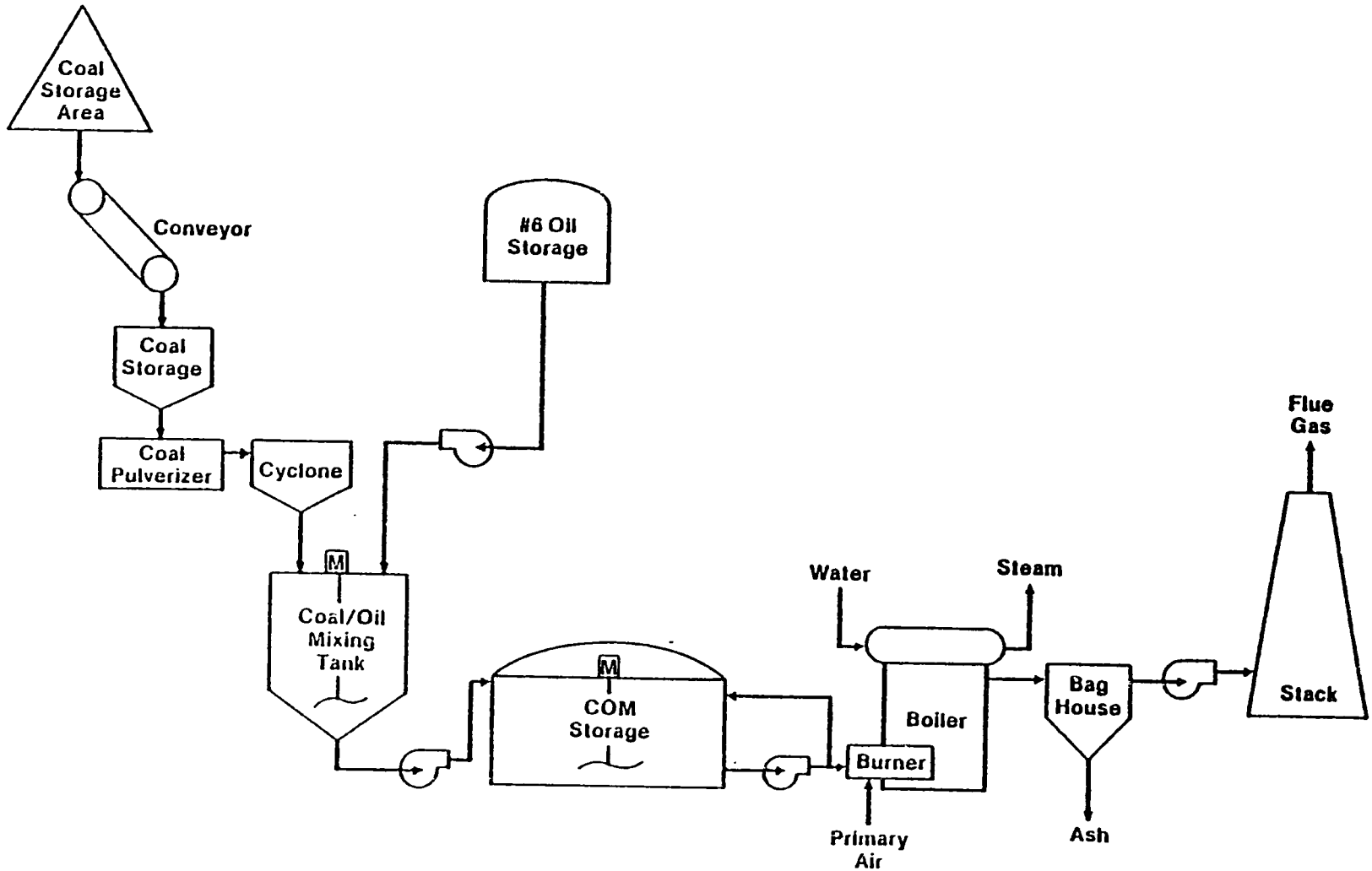

FIGURE A-6
CONCEPTUAL DIAGRAM OF COM PREPARATION AND COMBUSTION

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the burner assembly is of some concern since it cold lead to flame instability, incomplete combustion and dangerous furnace conditions. To prevent potential burner nozzle erosion special materials should be considered.

Erosion/corrosion in the superheated section and convective enclosure of the boiler is also a potential problem. The effect of the erosion can be expected to occur in oil- and, certainly, in gas-designed boilers since the original transfer tube spacings were selected based on flue gas velocities much higher than the corresponding coal-oil mixture flue gas values. Boiler derating will depend on the original boiler design.

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APPENDIX B

LIST OF EQUIPMENT SUPPLIERS CONTACTED FOR PURPOSES OF THIS STUDY

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LIST OF EQUIPMENT SUPPLIERS CONTACTED FOR PURPOSES OF THIS STUDY

COMPANY/ADDRESS	EQUIPMENT
American Fyr-Feeder Engineers 1265 Rand Road Des Plaines, IL 60016 312-298-0044	Wood-Fired Boiler
American Pulverizer Co. 1249 Mackling Ave. St. Louis, MO 63110 314-781-6100	Hogs and Shredders
Applied Engineering, Co. 1525 Charleston Highway Orangeburg, SC 29115 803-534-2424	Wood-Fired Boiler Wood Gasifiers
Biomass Corp. 1340 Colusa Hwy. Yuba City, CA 95991 916-674-7230	Wood Gasifier
Bio-Solar 1600 Valley River Drive Eugene, OR 97401 503-686-0765	Wood Gasifier System
Burnham Corp. P.O. Box 27 Lancaster, PA 717-397-4701	Wood-Fired Boiler Systems
Cleaver Brooks Division of Aqua-Chem, Inc. P.O. Box 421 Milwaukee, WI 53201 414-961-2791	Charcoal Gasifier
Combustion Service and Equipment, Co. 2016 Babcock Blvd. Pittsburg, PA 15209 412-821-8900	Wood-Fired Boiler Systems

COMPANY /ADDRESS	EQUIPMENT
Detroit Stoker Co. 1510 E. First St. Monroe, MI 48161 313-241-9500	Solid-Fuel Burning Stokers Shredders Solid Handling Systems
Fuel Efficiency, Inc. 131 Stuart Ave. Newark, NY 14513 315-331-3272	Automatic Tube Soot Cleaners
Houston Blow Pipe P.O. Box 1692 Houston, TX 77001 713-675-2273	Pneumatic Conveyors
Industrial Boiler Company, Inc. P.O. Box 936 Thomasville, GA 31792 912-226-3024	Solid-, Liquid- and Gas-fired Boiler Systems
Jeffrey Manufacturing 1905 Hughenot Rd. Richmond, VA 23235 804-320-5065	Hogs and Shredders
KVB 246 North Central Ave. Hartsdale, NY 10530 914-949-6200	Soot Blowers
Peabody Gordon-Piatt, Inc. P.O. Box 650 Winfield, KS 67156 316-221-4770	Suspension Wood Burners Heat Recovery Equipment
Pullman Swindell 441 Smithfield St. Pittsburgh, PA 15222 412-562-7000	Solids Fuel Preparation and Combustion Systems
Ray Burner Co. 1303 San Jose Ave. San Francisco, CA 94112 415-333-5800	Multifuel Boiler Systems

COMPANY/ADDRESS	EQUIPMENT
RECO P.O. Box 25189 Richmond, VA 23260 804-644-2611	Tanks
Rettew Automation, Inc. Box 65, N. Sheridan Rd. Newmanstown, PA 17073 215-589-2024	Wood and Charcoal Burning Furnace Systems
Robbins & Myers, Inc. 728 Belair Rd. Belair, MD 21014 301-879-9566	Pumps
Tate Engineering 601 West West Street Baltimore, MD 21230 301-539-0787	#6 Oil-Fired Boiler Systems
The Allen-Sherman-Hoff Co. One Country View Road Malvern, PA 19355 215-647-9900	Ash Handling Systems
The Bethlemen Corp. 25th & Lennox Street Easton, PA 18042 215-258-7111	Multifuel Boiler Systems
The International Boiler Works, Co. P.O. Box 498 E. Stroudsburg, PA 18301 717-421-5100	Solid-, Liquid- and Gas-fired Boiler Systems
Tuthill Corporation 12500 S. Pulaski Road Chicago, IL 60658 312-389-2500	Pumps
Wellons, Inc. P.O. Box 381 Sherwood, OR 97140 503-625-6131	Wood-Fired Boiler Systems Wood Posi-Flo Storage Bins Wood Heating Systems Wood Conveyor Handling

COMPANY/ADDRESS	EQUIPMENT
Wood Equipment Co. P.O. Box 9140 Richmond, VA 23227 804-746-1401	Turbine Agitators Pumps
Zurn Industries 1422 East Ave. Erie, PA 16503 814-452-6421	Wood-Fired Boiler Systems

APPENDIX C

AVERAGE QUOTES OBTAINED OF TYPICAL MAJOR EQUIPMENT COSTS

APPENDIX C

AVERAGE QUOTES OBTAINED OF TYPICAL MAJOR EQUIPMENT COSTS (in $US)*

ITEM	DESCRIPTION	SIZE	APPROX. COST	COMMENTS
1	Wood Gasifier System	25MMBtu/hr	400,000	Complete from wood pile to LBG (dirty) burner (included)
2	Wood Gasifier	6 MMBtu/hr	165,000	Wood chips w/max. 25% moisture content required. Reactor w/fuel metering only.
3	Wood Gasifier	2.5MMBtu/hr	126,000	same
4	Wood-Fired Boiler**	250hp	150,000	W/crude feed system
5A	Wood-Fired Boiler	300hp	165,000	Does not include conveying of wood to stoker
5B	Charcoal-Fired Boiler			
6	Wood Handling System	1TN/hr	50,000	Includes storage bin, conveyors and day hopper
7A	Wood Hogger	1TN/hr	15,000	
7B	Wood Storage Bin	7,000 cu ft.	47,000	Includes conveyors
8	Ash Removal System	0.1TN/day	9,000	Screw dump type
9	Sootblower	250hp (160Tubes)	8,000	Timed puff of compressed air
10A	Wood Chip Dryer	10MMBtu/hr	150,000	
10B	Wood Chip Dryer	2.5MMBtu/hr	40,000	
11	Producer Gas Burner	6MMBtu/hr	1,500	
12	Wood Hog Air Furnace	4MMBtu/hr	50,000	Does not include conveyors or stack.

*Estimates are for delivery in the continental U.S.
**All boilers listed here are low pressure (less than 50 psig).

ITEM	DESCRIPTION	SIZE	APPROX. COST	COMMENTS
13	Feed System (for 12)	4MMBtu/hr	9,000	Includes 24cu. yard bin and conveyor.
14	Ash Removal (for 12)	4MMBtu/hr	9,500	
15	Hot Air Charcoal Furnace	3MMBtu/hr	30,000	Does not include conveyors or stack.
16	Feed System (for 15)	3MMBtu/hr	8,500	Includes 24cu. yard bin and conveyor.
17	#6 Oil Fired-Boiler System	250hp	40,000	
18	Fuel Feed System (for 17)	250hp	8,000	Pump heats set.
19	Storage Tank (for 17)	25,000 gals.	7,000	
20	#6 Oil Fired-Boiler System	125hp	24,500	
21	Pump	0.5GPM	25,00	Stainless steel for pyrolytic oil.
22	Pump	1GPM	1,500	For COM slurry feed.
23	Pump	60GPM	5,000	For COM slurry unloading.
24	COM Storage Tank	30,000 gals.	22,000	W/mixer and heater
25	Oil Storage Tank	10,000 gals.	4,000	
26	Oil Storage Tank	25,000 gals.	8,500	

APPENDIX D

SUPPLIERS AND MANUFACTURERS OF WOOD FUEL PREPARATION, HANDLING, AND STORAGE SYSTEMS

APPENDIX D

SUPPLIERS AND MANUFACTURERS OF WOOD FUEL PREPARATION, HANDLING, AND STORAGE SYSTEMS

Agnew Environmental Products Co.
P.O. Box 1168, Grants Pass, OR 97526
Phone: (503) 479-3396
Products supplied: Briquettor for densification of dry fibrous waste to provide industrial fuel or fireplace logs.

Atlas Systems Corporation
P.O. Box 11496, Spokane, WA 99211
Phone: (509) 535-7775
Products Supplied: Shredded wood residue storage aides and automatic discharge system.

Bigelow Machinery, Inc.
407 N. Columbia Blvd. Portland, OR 92717
Phone: (503) 289-7319
Products Supplied: Bark and wood hogs.

California Pellet Mill Co.
1114 E. Wabash Ave.
Crawfordville, IN 47933
Phone: (317) 362-2600
c/o R. O. MacDaniel
Product Supplied: Pelletizer Equipment

CEA Carter Day Company
500-73rd Ave., NE, Minneapolis, MN 55430
Phone: (612) 571-1000
Product Supplied: Bulk Storage and material handling equipment for wood residue.

Clarke's Sheet Metal, Inc.
Box 2428 Eugene, OR 97402
Phone: (505) 343-3395
Product Supplied: Storage and handling systems for wood chips and dust.

Consolidated Baling Machine Company
155 D 7th St., Brooklyn, NY 11215
Phone: (212) 625-0929
Product Supplied: Baling presses for wood residue.

Cornell Mfg. Inc.
Laceyville, PA 18623
Phone: (717) 869-1227
Product Supplied: Wood Waste handling equipment, wood splitters, and hydraulic alab saws.

Diversified Fuels
975 Oak St., Eugene, OR 97401
Phone: (503) 484-0371
Product Supplied: Pelletized fuel from wood residue.

Diversified Fuel of Americas Inc.
P.O. Box 10247, Eugene, OR 97401
Phone: (503) 484-0371
Product Supplied: Equipment for the manufacture of pelletized wood fuel.

FMC Corp. MHS Division
3400 Walnut Street
Codaz, PA 18915
Phone: (215) 822-0581
Product Supplied: Fuel handling systems.

Gebr. Weiss Boiler Co.
6343 Frohnhausen/Dilldreis, W. Germany
Phone: 02771-5066 (TELEX 373213)
Product Supplied: Fuel storage, silos, outfeed devices.

Goodman Equipment Corp.
4834 South Halated St., Chicago, IL 60609
Product Supplied: Double Anvil wood hog and chipmills.

Gruendler Crusher & Pulverizer Co.
2915 N. Market St., St. Louise, MO 63106
Phone: (314) 531-1220
Product Supplied: Grinders, Crushers, and shredders.

Guaranty Fuels, Inc.
P.O. Box 748, 1120 East Main
Independence, KS 67301
Phone: (316) 331-0027
Product Supplied: Wood Fuel Pellets

Guaranty Performance Co., Inc.
P.O. Box 748, 1120 E. Main
Independence, KS 67301
Phone: (316) 331-0020
Product Supplied: Rotary dryers and related fuel handling equipment.

Harvey Eng. & Mfg. Corp.
Rt. 2, Box 478, Hot Springs, AR 71901
Phone: (501) 262-1010
Product Supplied: Fuel storage, handling, and preparation systems.

Harris Press Co., Subsidiary of American Hoise
Cordole, GA31015
Phone: (912) 273-5646
Product Supplied: High pressure baling press for wood and bark residue.

Heil Co., The
3000 W. Montana, Milwaukee, WI 53201
Phone: (414) 647-3101
Product Supplied: Dehydration equipment for predrying of wood-bark-sawdust-sludges, etc. used for waste heat utilization.

Hydrocyclonics Corporation
800 Skokie Highway, Lake Bluff, IL 60044
Phone: (312) 473-3700
Product Supplied: Rotostrainer screen to remove wood chips, bark and coarse sawdust from wood mill and paper and pulp mill effluent.

Industrial burner
24 W. Third Ave., Spokane, WA 99204
Phone: (509) 747-7965
Product Supplied: Fuel preparation and handling systems.

Jacksonville Blow Pipe Co.
(Div. of Montgomery Industries Int'l.)
P.O. Box 3687
Jacksonville, FL 32206
Phone: (904) 355-5671
Product Supplied: Wood and bark hogs for reducing wood residues and bark for use as boiler fuel. Peneumatic conveying systems for handling pulverized, dry or semi-dry wood scrap or pulverized bark.

Mardee, Inc.
3129 E. Washington Ave., Madison, WI 53704
Phone: (608) 244-3331
Product Supplied: Fuel preparation, handling, and storage systems.

Maachinenfabrik A. Lambion
D-3548 Arolsen-Wetterburg, W. Germany
Phone: 05691/611
Product Supplied: Fuel feeding and handling equipment.

Maren Engineering Corp.
111 W. Taft Drive
S. Holland, IL 60473
Phone: (312) 333-6250
Product Supplied: Baling press for wood shavings and sawdust. Bale so formed can then be fed directly into the fire box of the user's boiler or stored in stacks without pelletizing.

McBurney Corporation, The
P.O. Box 47848, Atlanta, GA 30340
Phone: (404) 448-8144
Product Supplied: Fuel Preparation and handling systems.

M-E-C Company
Box 330, Neodesha, KS 66757
Phone: (316) 325-2673
Products Supplied: Rotary Drum dryers, flash tube dryers, and solid fuel preparation, systems (wood residue).

Mill Supply Co.
Box 3748, Missoula, MT 59801
Product Supplied: System for feeding bark and sawdust to a boiler.
Phone: (406) 543-7197

Miller Hofft, Inc.
P.O. Box 8560, Richmond, VA 23226
Phone: (703) 288-1937
Product Supplied: Storage and feeding equipment for bark and wood residues.

Morbark Industries, Inc.
P.O. Box 1000, Winn, MI 48896
Phone: (517) 866-2381
Product Supplied: Fuel harvesting machinery and systems for various sites.

Nicholson Manufacturing Co.
3670 E. Marginal Way South
Seattle, WA 98134
Phone: (206) 682-2752
Product Supplied: Barkers and chippers, log loaders, cutoff saws, trims, and rechippers.

Peabody Gordon-Piatt, Inc.
P.O. Box 650, Winfield, KS 67156
Phone: (316) 221-4770
Product Supplied: Fuel matering bins.

PAPAKUBE Corporation (Gordon Johnson, VP)
931 East Harbor Drive
San Diego, California 92101
Product Supplied: Pelletizer equipment.

Rader Pneumatics, Inc.
P.O. Box 20128 Portlant, OR 97220
Phone: (503) 255-5330
Product Supplied: Peneumatic handling and conveying equipment.

Royer Foundary and Machine Co.
158 Pringle St., Kingston, PA 18704
Phone: (717) 287-9624
Product Supplied: Portable chippers.

Salem Hammermill Co.
2601 Industrial Drive., Box 148
Salem, VA 24153
Phone: (703) 389-8696
Product Supplied: wood and bark grinders, air conveyors, screw and elevating equipment, drumps and hoists.

Schutte Pulverizer Co., Inc.
61 Depot St., Buffalo, NY 14240
Phone: (716) 855-1555
Product Supplied: Industrial hammer mills.

Sprout-Waldron, Div. of Koppers Inc.
130 Logan St., Muncy, PA 17756
Phone: (717) 546-8211
Product Supplied: Wood waste storage structures and equipment for size classification, size reduction and materials handling.
Product Supplied: Pelletizer.

Stearns-Roger Inc.
700 South Ash Street, Box 5888
Denver, Colorado 80217
Phone: (303) 758-1122
Product Supplied: Rotary fuel dryers for hogged wood fuel and bagasse.

Steelcraft Corp.
Box 12408, Memphis, TN 38112
Phone: (901) 452-5200
Product Supplied: High and low pressure pnuematic material conveying systems, filter collectors, and storage bins.

Union Heating, Inc.
724 Walnut (P.O. Box 308)
Edmonds, WA 98020
Phone: (206) 775-4588
Product Supplied: Automatic fuel feeders for Dutch-oven fired boilers.

Wellens, Inc.
P.O. Box 381 Sherwood, OR 97140
Phone: (503) 625-6131
Product Supplied: Wood fuel storage bins and wood fuel conveyor handling.

Williams Patent Crusher Co.
2701 N. Broadway, St. Louis, MO 63102
Phone: (314) 621-3348
Product Supplied: Size reduction equipment and fuel drying equipment.

Woodex, Inc.
Rt. #1, Box 33
Brownville, OR 97327
Phone: (503) 466-5181
Product Supplied: Pelletized industrial fuel and gas generators.

APPENDIX E

EQUATION FOR NET PRESENT VALUE ANALYSIS

APPENDIX E: EQUATION FOR NET PRESENT VALUE ANALYSIS

Detailed discussions of net present value (NPV) analyses can be found in standard financial textbooks (References 1 and 2). The equation presented in this appendix was developed to evaluate the NPV of savings in expenditures of alternative fuel options to presently existing fuel systems. It permits incorporating varying inflation rates for wood-derived and petroleum fuels. In addition, separate inflation rates for labor, maintenance and utility costs can also be specified. A computer program to facilitate calculating this NPV was developed for this study. The FORTRAN program is presented in Appendix F. The symbols utilized in the NPV equation correspond to that used in the FORTRAN program.

The equation used to determine the NPV can be written as:

$$(1) \quad NPV^{A}(i^*,n) = \sum_{t=1}^{n} (SAD_t^A \times PWF_t^{i^*}) + (ACB_n^A \times PWF_n^{i^*}) - ATICI_o^A$$

Where:

$NPV^{A}(i^*,n)$	=	the net present value of option A for a given rate, i^*, and an analysis period, n.
SAD_t^A	=	the net savings in annual disbursements in year t of option A over that of the base option.
$PWF_t^{i^*}$	=	the present worth factor for a given discount rate, i^*, in year t.
ACB_n^A	=	the additional balance of option A over that of the base option for equipment, income from land sales and a recovery of working capital at the end of the analysis period, n.

$ATICI_o^A$ = the additional initial capital investment of option A over that required for the base option.

(2) $SAD_t^A = TAD_t^B - TAD_t^A$

Where:

TAD_t = total annual disbursements for fuel, labor, maintenance and utilities in either the base option (TAD^B) or the alternative option (TAD^A).

(3) $$TAD_t^B = TAOE_t^B = \left[PFC_o^B \times (1 + f_{FB})^t + OL_o^B \times (1 + f_{OL})^t + UT_o^B \times (1 + f_{UT})^t + MA_o^B \times (1 + f_{MA})^t\right]$$

(4) $TAD_t^A = TAOE_t^A + CIT_t^A$

(5) $$TAOE_t^A = \left[PFC_o^A \times (1 + f_{FA})^t + OL_o^A \times (1 + f_{OL})^t + UT_o^B \times (1 + f_{UT})^t + MA_o^A \times (1 + f_{MA})\right]$$

(6) $$CIT_t^A = \left[(TAOE_t^B + DEP_t^B) - (TAOE_t^A + DEP_t^A) \times TR\right]$$

Where:

$TAOE_t$ = total annual operating expenditures for fuel, labor, maintenance and utilities in either the base option $(TAOE^B)$ or the alternative option $(TAOE^A)$.

CIT_t^A	=	the net change in income taxes from the base option as a result of the expenditures in the alternative option.
PFC_o	=	the initial annual primary fuel costs in either the base option (PFC^B) or the alternative option (PFC^A).
OL_o	=	the initial annual operating labor costs.
UT_o	=	the initial annual utility costs.
MA_o	=	the initial annual maintenance costs.
DEP_t	=	the annual allowable depreciations in year t.
TR	=	the effective corporate income tax rate.
f_{FB}	=	the average inflation rate for the cost of the base option fuel.
f_{FA}	=	the average inflation rate for the cost of the alternative fuel.
f_{OL}	=	the average inflation rate for the annual operating labor costs (wage inflation rate).
f_{UT}	=	the average inflation rate for the annual utility costs (electricity costs, inflation rate).
f_{MA}	=	the average inflation rate for the annual maintenance costs.

REFERENCES

1. Grant, E. L., Ireson, W. G., Principles of Engineering Economy, 5th Edition, 1970, New York, NY.

2. Van Horne, J. C., Fundamentals of Financial Management, 3rd Edition, Prentice-Hall, Inc. Englewood Cliffs, NJ.

APPENDIX F

NET PRESENT VALUE FORTRAN PROGRAM

```
C*********************************************************************NPV00010
C                    START OF NPV PROGRAM
C*********************************************************************
C     THIS PROGRAM IS WRITTEN FOR A FORTRAN G COMPLIER
C*****DIMENSION STATEMENTS                                              NPV00010
      INTEGER T                                                         NPV00010
      REAL NPV,MAA,MAB,INSTAL,MAINT,IADEA,IADEB                         NPV00020
      DIMENSION NPV(10,20,50)                                           NPV00030
      DIMENSION SIMPCA(20),IADEA(20),WKCAPA(20),EQUIPA(20),FIHA(20),    NPV00040
     1SUVPLA(20),GENLA(20),FLIA(20),OTCA(20),ADLCA(20),HRINDA(20),      NPV00050
     2ALOADA(20),FUELCA(20),DEPRA(20),PCOILA(20),ADTCA(20),NA(20)       NPV00060
      DIMENSION SIMPCB(10),IADEB(10),WKCAPB(10),EQUIPB(10),FIHB(10),    NPV00070
     1SUVPLB(10),GENLB(10),FLIB(10),OTCB(10),ADLCB(10),HRINDB(10),      NPV00080
     2ALOADB(10),FUELCB(10),DEPRB(10),PCOILB(10),ADTCB(10),NB(10)       NPV00090
      DIMENSION TICIA(20),CRA(20),DEPA(20),PECA(20),OLA(20),UTA(20),    NPV00100
     1MAA(20),NALT(20),ADEPA(20),ATICIA(20),ACRA(20)                    NPV00110
      DIMENSION TICIB(10),CRB(10),DEPB(10),PECB(10),OLB(10),UTB(10),    NPV00120
     1MAB(10),NBASE(10),ADEPB(10)                                       NPV00130
      DIMENSION AINT(50),AYEAR(50),TR(50),EOL(50),EUT(50),EMA(50),      NPV00140
     1EPECB(50),EPECA(50),NSEN(50),EWOOD(50),EOIL(50)                   NPV00150
C*******************START READING INPUT DATA***************************
C*****READ IN THE NUMBER OF SEPERATE CASES TO BE EVALUATED              NPV00160
      READ(5,1002)NUMBER                                                NPV00170
 1002 FORMAT(I5)                                                        NPV00180
      DO 1000 N=1,NUMBER                                                NPV00190
C*****WRITE REPORT HEADING
      WRITE(6,1001)                                                     NPV00200
 1001 FORMAT(2X,'$$$$$$$$$$ ANALYSIS OF THE N.P.V. OF SAVINGS FROM ALTERNPV00210
     1NATIVE FUEL USE  $$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$',///)            NPV00220
      READ(5,1003)                                                      NPV00230
 1003 FORMAT(2X,'                                                       NPV00240
     1                                                                  NPV00250
      WRITE(6,1003)                                                     NPV00260
C*****READ IN THE NUMBER OF BASE OPTIONS,N1;ALTERNATIVE OPTIONS,N2;AND  NPV00270
C*****FINANCIAL SCENARIOS,N3.
      READ(5,10)N1,N2,N3                                                NPV00280
   10 FORMAT(3I5)                                                       NPV00290
      WRITE(6,15)N1,N2,N3                                               NPV00300
   15 FORMAT(3X,I5,' BASE CASES ',/,3X,I5,' ALTERNATIVES ',/,3X,I5,     NPV00310
     1' SCENARIOS',//)                                                  NPV00320
C*****READ COST ESTIMATE FACTORS*****************************************NPV00330
      READ(5,11)INSTAL,ENGIN,CONTIN,MAINT,WKCAP,ELECT,SUWAGE,GLWAGE,OHR NPV00340
   11 FORMAT(9F5.0)                                                     NPV00350
C     INSTAL= INSTALLATION COST FACTOR                                  NPV00360
C     ENGIN = ENGINEERING COST FACTOR                                   NPV00370
C     CONTIN= CONTINGENCY COST FACTOR                                   NPV00380
C     MAINT = ANNUAL MAINTENANCE COST FACTOR                            NPV00390
C     WKCAP = ANNUAL WORKING CAPITAL FACTOR                             NPV00400
C     ELECT = BASE YEAR ELECTRICITY UNIT COST IN K/KWH                  NPV00410
C     SUWAGE= BASE YEAR SUPERVISOR WAGE RATE IN K/HR                    NPV00420
C     GLWAGE= BASE YEAR GENERAL LABOR WAGE RATE IN K/HR                 NPV00430
C     OHR   = LABOR OVERHEAD RATE                                       NPV00440
      WRITE(6,12)INSTAL,ENGIN,CONTIN,MAINT,WKCAP,ELECT,SUWAGE,GLWAGE,OHRNPV00450
   12 FORMAT(3X,'INSTAL=',F5.2,/,3X,'ENGIN =',F5.2,/,3X,'CONTIN=',F5.2,/NPV00460
     1,3X,'MAINT =',F5.2,/,3X,'WKCAP =',F5.2,/,3X,'ELECT =',F5.2,/,3X,  NPV00470
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```
     2'SUWAGE=',F5.2,/,3X,'GLWAGE=',F5.2,/,3X,'OHR   =',F5.2,/)          NPV00480
C*****READ IN DATA FOR BASE OPTIONS ***********************************NPV00490
      DO 20 I=1,N1                                                       NPV00500
      READ(5,16)NBASE(I),EQUIPB(I),ADLCB(I),FIHB(I),SUVPLB(I),GENLB(I),  NPV00510
     1ELIB(I),OTCB(I),FUELCB(I),DEPEB(I),PCOILB(I),HRINDB(I),ALOADB(I),  NPV00520
     2NB(I)                                                              NPV00530
   16 FORMAT(I2,F8.0,7F6.0,2F5.0,2F4.0,I2)                               NPV00540
C     NBASE   = BASE OPTION NUMBER                                       NPV00550
C     A 'B' AT END OF VARIABLE NAME INDICATES 'BASE OPTION'              NPV00560
C     A 'A' AT END OF VARIABLE NAME INDICATES 'ALTERNATIVE OPTION'       NPV00570
C     A '_' AT END OF VARIABLE DEFINITION INDICATES IT CAN BE EITHER AN
C           'A' OR A 'B'
C     EQUIP_  = INITIAL EQUIPMENT COST                                   NPV00580
C     ADLC_   = ADDITIONAL LAND COSTS                                    NPV00590
C     FIH_    = FUEL INPUT IN TONNE/HR                                   NPV00600
C     SUVPL_  = SUPERVISORY LABOR IN M/HR                                NPV00610
C     GENL_   = GENERAL LABOR IN M/HR                                    NPV00620
C     ELI_    = ELECTRICITY REQUIREMENTS IN KW                           NPV00630
C     OTC_    = OTHER OPERATING COSTS (NOT OTHERWISE ACCOUNTED)/HR.      NPV00640
C     PCOIL_  = PERCENTAGE OF FUEL INPUT THAT IS IMPORTED PETROLEUM      NPV00650
C     HRIND_  = OPERATING HOURS IN A DAY                                 NPV00660
C     ALOAD_  = ANNUAL USE FACTOR (I.E.ANNUAL LOAD FACTOR)               NPV00670
C     FUELC_  = FUEL COSTS IN K/TONNE                                    NPV00680
C     DEPE_   = PERCENTAGE OF CAPITAL INVESTMENT DEPRECIABLE/YR          NPV00690
   20 CONTINUE                                                           NPV00700
C*****READ IN DATA FOR ALTERNATIVE OPTIONS*****************************NPV00710
      DO 30 J=1,N2                                                       NPV00720
      READ(5,25)NALT(J),EQUIPA(J),ADLCA(J),FIHA(J),SUVPLA(J),GENLA(J),   NPV00730
     1ELIA(J),OTCA(J),FUELCA(J),DEPEA(J),PCOILA(J),HRINDA(J),ALOADA(J),  NPV00740
     2NA(J)                                                              NPV00750
   25 FORMAT(I2,F8.0,7F6.0,2F5.0,2F4.0,I2)                               NPV00760
   30 CONTINUE                                                           NPV00770
C*****READ IN DATA FOR FINANCIAL SCENARIOS*****************************NPV00780
C     NSEN    = NUMBER OF FINANCIAL SCENARIO
C     AINT    = ANNUAL INTREST RATE (I.E. DISCOUNT RATE)
C     AYEAR   = NUMBER OF YEARS OVER WHICH TO CONDUCT ANALYSIS
C     TR      = CORPORATE TAX RATE
C     EOL     = ANNUAL INFLATION RATE OF WAGES FOR OPERATING LABOR
C     EUT     = ANNUAL INFLATION RATE OF COSTS OF UTILITIES
C     EMA     = ANNUAL INFLATION RATE OF COSTS OF MAINTENANCE
C     EOIL    = ANNUAL INFLATION RATE OF COSTS OF IMPORTED PETROLEUM
C     EWOOD   = ANNUAL INFLATION RATE OF COSTS OF WOOD FUELS
      DO 40 K=1,N3                                                       NPV00790
      READ(5,35)NSEN(K),AINT(K),AYEAR(K),TR(K),EOL(K),EUT(K),EMA(K),     NPV00800
     1EOIL(K),EWOOD(K)                                                   NPV00810
   35 FORMAT(I2,F8.0,7F6.0)                                              NPV00820
   40 CONTINUE                                                           NPV00830
C***********************END OF DATA READ IN*****************************
C*********************************************************************
C***************BEGIN CALCULATIONS AND PRINT RESULTS*******************
      DO 100 I=1,N1                                                      NPV00840
      WRITE(6,21)NBASE(I)                                                NPV00850
   21 FORMAT(2X,'$$$$$$$$$$$$$$$$$$$ BASE CASE NO.',I3,'  $$$$$$$$$$',//)NPV00860
C*****WRITE BASE CASE INPUTS                                             NPV00870
      WRITE(6,22)                                                        NPV00880
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   22 FORMAT(1H0,50H      NBASE     EQUIPB       FIHB     SUVPLB      GENLB, NPV00890
     1 60H       ELIB       OTCB      ADLCB     HRINDB     ALOADB     FUELCB, NPV00900
     2 20H      DEPFB     PCOILB)                                           NPV00910
      WRITE(6,23)NBASE(I),EQUIPB(I),FIHB(I),SUVPLB(I),GENLB(I),ELIB(I),  NPV00920
     1OTCB(I),ADLCB(I),HRINDB(I),ALOADB(I),FUELCB(I),DEPFB(I),PCOILB(I) NPV00930
   23 FORMAT(3X,I8,F10.0,11F10.2,//)                                      NPV00940
C******DEFINITION OF VARIABLES
C       SIMPC_ = SITE IMPROVEMENT COSTS (ASSUMED TO BE 1/3 OF ADLC_)      NPV00960
C       TICI_  = TOTAL INITIAL CAPITAL INVESTMENT                         NPV00970
C       DEP_   = ANNUAL ALLOWABLE DEPRECIATIONS                           NPV00980
C       PFC_   = ANNUAL PRIMARY FUEL COSTS                                NPV00990
C       OL_    = ANNUAL OPERATING LABOR COSTS                             NPV01000
C       UT_    = ANNUAL OPERATING UTILITY COSTS                           NPV01010
C       MA_    = ANNUAL ESTIMATED MAINTENANCE COSTS                       NPV01020
C       IAOE_  = INITIAL ANNUAL OPERATING EXPENDITURES                    NPV01030
C       WKCAP_ = INITIAL WORKING CAPITAL REQUIRED                         NPV01040
C       CB_    = SALVAGE VALUE OF EQUIPMENT AND LAND                      NPV01050
C*****CALCULATE INITIAL YEAR ESTIMATES FOR BASE OPTION
      SIMPCB(I)=ADLCB(I)/3.0                                              NPV01060
      TICIB(I)=(((EQUIPB(I)*(1+INSTAL)+SIMPCB(I))*(1+ENGIN))*(1+CONTIN) NPV01070
     1)                                                                   NPV01080
      DEPB(I)=TICIB(I)*DEPFB(I)                                           NPV01090
      PFCB(I)=FIHB(I)*HRINDB(I)*360.0*ALOADB(I)*FUELCB(I)                 NPV01100
      OLB(I)=((SUVPLB(I)*SUWAGE+GENLB(I)*GLWAGE)*(1.0+OHR))*HRINDB(I)     NPV01110
     1*360                                                                NPV01120
      UTB(I)=ELIB(I)*HRINDB(I)*360.0*ALOADB(I)*ELECT                      NPV01130
      MAB(I)=TICIB(I)*MAINT                                               NPV01140
      AOTCB(I)=OTCB(I)*HRINDB(I)*360.*ALOADB(I)                           NPV01150
      IAOEB(I)=PFCB(I)+OLB(I)+UTB(I)+MAB(I)+AOTCB(I)                      NPV01160
      WKCAPB(I)=IAOEB(I)*WKCAP                                            NPV01170
      CBB(I)=WKCAPB(I)+ADLCB(I)                                           NPV01180
C*****WRITE RESULTS OF INITIAL YEAR COSTS FOR BASE OPTION**************
      WRITE(6,26)                                                         NPV01190
   26 FORMAT(1H0,50H    SIMPCB      TICIB       DEPB       PFCB        OLB, NPV01200
     1 60H        UTB        MAB      IAOEB     WKCAPB        CBB     AOTCB) NPV01210
      WRITE(6,24)SIMPCB(I),TICIB(I),DEPB(I),PFCB(I),OLB(I),UTB(I),        NPV01220
     1MAB(I),IAOEB(I),WKCAPB(I),CBB(I),AOTCB(I)                           NPV01230
   24 FORMAT(2X,F9.2,10F10.2,//)                                          NPV01240
      DO 200 J=1,N2                                                       NPV01250
      WRITE(6,31)NALT(J)                                                  NPV01260
   31 FORMAT(2X,'$$$$$$$$$$$$$$$$$$ ALTERNATIVE#',I5,'  $$$$$$$$$$',//) NPV01270
C*****WRITE ALTERNATIVE OPTION INPUTS*********************************NPV01280
      WRITE(6,32)                                                         NPV01290
   32 FORMAT(1H0,50H      NALT     EQUIPA       FIHA     SUVPLA      GENLA, NPV01300
     1 60H       ELIA       OTCA      ADLCA     HRINDA     ALOADA     FUELCA, NPV01310
     2 20H      DEPFA     PCOILA)                                           NPV01320
      WRITE(6,33)NALT(J),EQUIPA(J),FIHA(J),SUVPLA(J),GENLA(J),ELIA(J),   NPV01330
     1OTCA(J),ADLCA(J),HRINDA(J),ALOADA(J),FUELCA(J),DEPFA(J),PCOILA(J) NPV01340
   33 FORMAT(2X,I8,F10.0,11F10.2,//)                                      NPV01350
C******CALCULATE INITIAL YEAR ESTIMATES FOR THE ALTERNATIVE OPTION******NPV01360
      SIMPCA(J)=ADLCA(J)/3.0                                              NPV01470
      TICIA(J)=(((EQUIPA(J)*(1+INSTAL)+SIMPCA(J))*(1+ENGIN))*(1+CONTIN) NPV01480
     1)                                                                   NPV01490
      DEPA(J)=TICIA(J)*DEPFA(J)                                           NPV01500
      PFCA(J)=FIHA(J)*HRINDA(J)*360.0*ALOADA(J)*FUELCA(J)                 NPV01510
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      OLA(J)=((SUVPLA(J)*SUWAGE+GENLA(J)*GLWAGE)*(1.0+OHR))*HRINDA(J)    NPV01520
     1*360                                                               NPV01530
      UTA(J)=FLTIA(J)*HRINDA(J)*360.0*ALOADA(J)*FLFCT                    NPV01540
      MAA(J)=TICIA(J)*MAINT                                              NPV01550
      AOTCA(J)=OTCA(J)*HRINDA(J)*360.*ALOADA(J)                          NPV01560
      TAOFA(J)=PFCA(J)+OLA(J)+UTA(J)+MAA(J)+AOTCA(J)                     NPV01570
      WKCAPA(J)=TAOFA(J)*WKCAP                                           NPV01580
      CBA(J)=WKCAPA(J)+ADLCA(J)                                          NPV01590
C*****WRITE RESULTS OF INITIAL YEAR COSTS FOR THE ALTERNATIVE OPTIONS***
      WRITE(6,36)                                                        NPV01600
   36 FORMAT(1H0,50H     SIMPCA      TICIA       DEPA       PFCA        OLA, NPV01610
     1 60H        UTA        MAA      TAOFA     WKCAPA        CBA     AOTCA) NPV01620
      WRITE(6,34)SIMPCA(J),TICIA(J),DEPA(J),PFCA(J),OLA(J),UTA(J),       NPV01630
     1MAA(J),TAOFA(J),WKCAPA(J),CBA(J),AOTCA(J)                          NPV01640
   34 FORMAT(2X,F9.2,10F10.2,//)                                         NPV01650
      DO 300 K=1,N3                                                      NPV01660
      WRITE(6,43)NSEN(K)                                                 NPV01670
   43 FORMAT(2X,'$$$$$$$$$$$$$$$$$$ SCENARIO NO.',I3,'  $$$$$$$$$$$$$',//)NPV01680
      WRITE(6,41)                                                        NPV01690
   41 FORMAT(1H0,40H          I*          N          TR         FOL,     NPV01700
     1 40H        FUT        FMA       FOIL      FWOOD)                  NPV01710
      WRITE(6,42)AINT(K),AYEAR(K),TR(K),FOL(K),FUT(K),FMA(K),FOIL(K),    NPV01720
     1FWOOD(K)                                                           NPV01730
   42 FORMAT(1X,8F10.3,//)                                               NPV01740
C*********************************************************************
C*****************NPV OF SAVINGS IN EXPENDITURES***********************
C*********************************************************************
C     NYEAR  = NUMBER OF YEARS OF CASH FLOW ANALYSIS
C     PWF    = PRESENT WORTH FACTOR IN YEAR K
C     FPFC_  = INFLATED PRIMARY FUEL COSTS IN YEAR K
C     TAOF_  = TOTAL ANNUAL OPERATING EXPENDITURE IN YEAR K
C     ADEP_  = ANNUAL ALLOWABLE DEPRECIATION IN YEAR K
C     CITA   = CHANGE IN TAXES OF THE ALTERNATIVE VS. THE BASE OPTION
C     TAD_   = TOTAL ANNUAL DISBURSEMENTS IN YEAR K
C     SADA   = SAVINGS IN ANNUAL DISBURSEMENTSOF THE ALTERNATIVE OVER
C              THE BASE OPTION
C     SUM    = THE CUMULATIVE NPV OF SADA
C     ATICIA = DIFFERENCE IN THE CAPITAL INVESTMENT OF THE ALTERNATIVE
C              TO THE BASE OPTION
C     ACBA   = DIFFERENCE IN THE END OF PERIOD CASH BALANCES OF THE
C              ALTERNATIVE TO THE BASE OPTION
      NYEAR=AYEAR(K)                                                     NPV01750
      SUM=0.0                                                            NPV01760
      DO 400 T=1,NYEAR                                                   NPV01800
      PWF=1.0/(1.0+AINT(K))**T                                           NPV01810
      FPFCB(K)=PCOILB(I)*FOIL(K)+(1-PCOILB(I))*FWOOD(K)                  NPV01820
      TAOFB=PFCB(I)*(1.0+FPFCB(K))**T+OLB(I)*(1.0+FOL(K))**T+            NPV01830
     1UTB(I)*(1.0+FUT(K))**T+(MAB(I)+AOTCB(I))*(1.0+FMA(K))**T           NPV01840
      FPFCA(K)=PCOILA(J)*FOIL(K)+(1-PCOILA(J))*FWOOD(K)                  NPV01850
      TAOFA=PFCA(J)*(1.0+FPFCA(K))**T+OLA(J)*(1.0+FOL(K))**T+            NPV01860
     1UTA(J)*(1.0+FUT(K))**T+(MAA(J)+AOTCA(J))*(1.0+FMA(K))**T           NPV01870
      IF(T-NB(I))321,321,322                                             NPV01880
  321 ADEPB(I)=DEPB(I)                                                   NPV01890
      GO TO 323                                                          NPV01900
  322 ADEPB(I)=0.00                                                      NPV01910
```

```
  323 IF(T-NA(J))331,331,332                                          NPV01920
  331 ADEPA(J)=DEPA(J)                                                NPV01930
      GO TO 333                                                       NPV01940
  332 ADEPA(J)=0.00                                                   NPV01950
  333 CITA=((TADEB+ADEPB(I))-(TADEA+ADEPA(J)))*TR(K)                  NPV01960
      TADA=TADEA+CITA                                                 NPV01970
      TADB=TADEB                                                      NPV01980
      SADA=TADB-TADA                                                  NPV01990
      SUM= SUM+SADA*PWF                                               NPV02000
C     WRITE (6,399) T,TADEB,TADEA,CITA,TADA,SADA,SUM,ADEPA(J),ADEPB(I) NPV02010
C 399 FORMAT(1X,I5,8F12.4)                                            NPV02020
  400 CONTINUE                                                        NPV02030
      ATICIA(J)=(TICIA(J)-TICIB(I))+(ADLCA(J)-ADLCB(I))               NPV02040
      ACBA(J)=CBA(J)-CBB(I)                                           NPV02050
      NPV(I,J,K)=-ATICIA(J)+SUM+ACBA(J)*PWF                           NPV02060
      WRITE(6,401)NPV(I,J,K),SUM,PWF                                  NPV02070
  401 FORMAT(//,3X,'  NPV=',F15.6,4X,'SUM=',F15.6,4X,'PWF=',F10.5,/)  NPV02080
  300 CONTINUE                                                        NPV02090
  200 CONTINUE                                                        NPV02100
  100 CONTINUE                                                        NPV02110
C*****WRITE RESULTS OF THE NPV ANALYSIS*********************************
  502 FORMAT(2X,'    B.C. NO.  ALT. NO. SCEN. NO.  N.P.V. OF SAVINGS',/)NPV02120
      DO 500 I=1,N1                                                   NPV02130
      WRITE(6,502)                                                    NPV02140
      DO 600 J=1,N2                                                   NPV02150
      DO 700 K=1,N3                                                   NPV02160
      WRITE(6,501)NBASE(I),NALT(J),NSEN(K),NPV(I,J,K)                 NPV02170
  501 FORMAT(2X,3I10,F15.6)                                           NPV02180
  700 CONTINUE                                                        NPV02190
  600 CONTINUE                                                        NPV02200
  500 CONTINUE                                                        NPV02210
 1000 CONTINUE                                                        NPV02220
      STOP                                                            NPV02230
      END                                                             NPV02240
C*********************************************************************
C                        END OF NPV PROGRAM
C*********************************************************************
```

SAMPLE INPUT DATA SET

```
FILE: NPVC1     INPUT     A                    CONVERSATIONAL MONITOR SYSTEM

    1
   CASE STUDY CO: 4.0MM BTU/HP HOT AIR FURNACE:BASE CASE
    1     5     3
  .20  .20  .10  .15  .10  .05 2.50 1.00  .30
 1  14300. 0.000 .0762 0.250 1.000 3.000 0.000 310.0 .075 1.00 16..85 13
 1  23500. 0.000 .1017 0.333 1.000 5.000 0.000 137.0 .075 .231 16..85 13
 2  23500. 0.000 .0993 0.333 1.000 5.000 0.000 107.3 .075 .245 16..85 13
 3  20100. 0.000 .1148 0.333 1.000 4.000 0.000  85.0 .075 .000 16..85 13
 4  65000.  1000 .1378 0.500 1.500 15.00 0.000  75.0 .075 .000 16..85 13
 5 106500.  2000 .2316 0.500 2.000 25.00 0.000  25.0 .075 .000 16..85 13
 1      .11   15. 0.365   .05   .05   .05   .08   .08
 2      .20   15. 0.365   .05   .05   .05   .08   .08
 3      .15   15. 0.365   .05   .05   .05   .08   .08
```

APPENDIX G

PNG ITINERARY

APPENDIX G

PNG ITINERARY

Dates: April 27 - May 9, 1980

Mr. Bob Chronowski, Cleaver-Brooks Boiler Co.
Mr. Chuck McCann, U.S. Department of Energy
Mr. Ed Sharp, MITRE Corporation
Mr. Matt Mendis, MITRE Corporation

Sunday April 27: Port Moresby

0835	Arrive POM ex Sydney QF 025 (Islander Hotel)

Monday April 28: Kieta/Arawa/Panguna

0400	Depart hotel for airport
0430	Check in
0500-0635	PX 808 POM-KIE
0930	Meet with Paul Piercy, Arthur Minchington and others - Bougainville Copper Limited
1100	Meet with Doug Hinckfuss, BCL
1400	Tour of concentrate drying operation - Loloho Arthur Minchington, Owen Mathews (Davara Hotel)

Tuesday April 29: Kieta/Arawa/Panguna

0830	Loloho Power Station (BCL) Joe Dunn, Station Manager
1130	SHRM catering Mike Herrington, Manager
1330	Dept. Works/Arawa Hospital Harry Sonigan, Brian Green (Davara Hotel)

Wednesday April 30: Kieta/Arawa/Panguna

0900	Goodyear - Panguna John Stuart, Manager
1030	IRECO Chemicals Bob Vinneri, Manager
1330	Bougainville Laundry Louis Piouka, Manager
1725-1910	PX 807 KIE-POM (Travellodge)

Friday May 2: Port Moresby

1030	Office of Taxation John Lohberger, Director Barry Bevan, Asst. Director
1200	National Planning Office Jim Guest and John Wilson
1500	Office of Environment John Low and Bill Green (Travellodge)

Monday May 5: Goroka

0845-0935	PX 870 POM-GKA
1030	Goroka Base Hospital Bill Murfitt
1330	Rothmans Tobacco, Goroka Bruce Taylor, labor liason (transport) Renzo Accamero, Farm Manager Henry Agustonelli, Overall Farm Manager
1500	Highland Tobacco Ed Cowper, Manager (Bird of Paradise Hotel)

Tuesday May 6: Mt. Hagen

0700-0730	Talair chater GKA-HGN
0830	Tea Industry Association John McNickol, Manager Carpenters Sandy Fraser Bill Brown Note: Involved several site visits and final summation meeting in Mt. Hagen
1705-1805	PX 831 PGN-POM (Davara Hotel)

Wednesday May 7: Lae

0605-0650	PX 830 POM-LAE
0930	University of Technology, Lae (UNITECH) David Fussey, Mech Engr. Graham Sneddon, Mech. Engr. Mike Blowers, Chem Tech.
1100	Serafini Bottlers Paul Serafini, Manager
1330	South Pacific Timbers Jeff Bland, Manager

1430	Angau Memorial Hospital, Lae Paul Lundy Andrew Dorey Jim Easton
1530	South Pacific Brewery Werner Bensch (Melanesian Hotel)

Thursday May 8: Lae

0800	Ramu Sugar Ltd.
1000	South Pacific Brewery Peter Colley, Executive Engineer David Fussey, UNITECH
1300	Melanesian Soaps Ron Elias, Manager
1430	A.C.I. Glass: New Guinea Containers New Guinea Fibre Packages Lou Dingjan, Managing Director Colin Jolly
1955-2040	PX 833 LAE-POM Travellodge)

Friday May 9: Port Moresby

0830	Geological Survey Alex McKinlay, Chief Government Geologist
1030	U.S. Embassy Harvey Feldman, U.S. Ambassador to PNG Mike Leu, Econ/Commercial Officer, U.S. Embassy
1130	Department of Minerals and Energy Nigel Agonia, Secretary
1500	QF 026 POM-BNE-SYD

Department Approval: _____

MITRE Project Approval: _____