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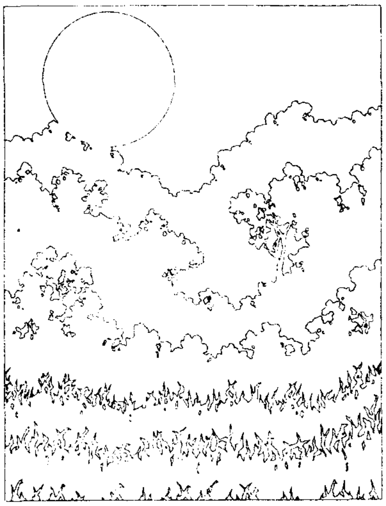

IDAHO NATIONAL ENGINEERING LABORATORY

Biomass Alternative-Fuels Program: Final Report

Hydropyrolysis of Biomass to
Produce Liquid Hydrocarbon Fuels
Final Report
October 1982
Pacific Resources, Inc.

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HYDROPYROLYSIS OF BIOMASS TO PRODUCE LIQUID HYDROCARBON FUELS

Final Report

October 1982

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For the
U.S. Department of Energy
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I. Introduction

Hawaii is presently dependent for over 90% of its energy needs on imported petroleum products. Because of Hawaii's geological structure we do not believe that it could have indigenous fossil fuel resources. Also, our geographical location, approximately 2,400 miles from the continental United States, makes the State of Hawaii very vulnerable to shortages of strategic materials such as petroleum during national emergencies or embargoes.

In order to alleviate our very high dependence on imported oil, Hawaii has embarked on a program to develop alternate sources of energy such as geothermal, ocean thermal, solar, wind and biomass. All of these alternate energy sources are for the production of electric power.

However, approximately 60% of our energy consumption is for liquid transportation fuels, including over 30% for aviation fuel.

Recognizing this lack of effort to find alternate sources of liquid hydrocarbon fuels, Pacific Resources, Inc. (PRI) solicited and received a grant from the Department of Energy to conduct a study to determine the feasibility of commercial production of hydrocarbon fuels from biomass feedstocks available in Hawaii. The PRI study team includes the Institute of Gas Technology (IGT) as the principal subcontractor responsible for the development and design of the biomass to oil conversion process and the Hawaii Natural Energy Institute (HNEI), for the technical and economic evaluation of growing and harvesting a suitable biomass crop. (See Appendix I "Report on Energy Tree Farm Workshop No. 1" by PRI and HNEI and Appendix II, "Final Report, Hydropyrolysis of Biomass to Produce Liquid Hydrocarbon Fuels" by IGT)

II. Objective and Scope of Study

The objective of the study is to provide a process design and cost estimates for a biomass hydropyrolysis plant and to establish its economic viability for commercial applications. A plant site, size, product slate, and the most probable feedstock or combination of feedstocks were determined.

A base case design was made by adapting IGT's HYFLEX process to Hawaiian biomass feedstocks. The HYFLEX process was developed by IGT to produce liquid and/or gaseous fuels from carbonaceous materials. The essence of the process is the simultaneous extraction of valuable oil and gaseous products from cellulosic biomass feedstocks without forming a heavy hard-to-handle tar. By controlling reaction time and temperature, the product slate can be varied according to feedstock and market demand. An optimum design and a final assessment of the applicability of the HYFLEX process to the conversion of Hawaiian biomass was made.

In order to determine what feedstocks could be available in Hawaii to meet the demands of the proposed hydropyrolysis plant, various biomass sources were studied. These included sugarcane and pineapple wastes, indigenous and cultivated trees and indigenous and cultivated shrubs and grasses.

III. Biomass Feedstock

a. Crop Selection

Various candidate feedstocks were evaluated, including sugarcane bagasse, sugarcane trash, whole sugarcane, pineapple field waste, guinea grass, and eucalyptus, leucaena (Koa Haole), ohia and albizia woods. Characterization of these feedstock candidates by chemical analysis and Fischer assays showed no major differences in quality, except for a high ash content of sugarcane trash. (See Appendix II, Section V)

Selection of the feedstock, therefore, was based on availability and environmental requirements such as rainfall, altitude, topography, climate and soil type. Selection of suitable sites for cultivation of the biomass was based not only on the environmental criteria but the availability of land and its ownership. (See Appendix I, Section 2)

Sugarcane bagasse and pineapple field wastes were eliminated because bagasse is consumed as a fuel by the plantations and pineapple waste is not available in sufficient quantities. Cane trash was also eliminated because most of it is burned in the fields prior to harvesting and whatever is available is difficult to gather and transport to a central location.

Grasses were eliminated because the required climate, soil, and topographical requirements are similar to those for sugarcane and pineapple; our major agricultural crops could not be displaced with grass.

Trees, therefore, were selected. Leucaena, albizia and various species of eucalyptus were evaluated based on each species' growing criteria versus the climate, soil, and topographical characteristics of the land available for such cultivation. (See Appendix I, Section I, especially Table 1-1; Environmental and Growth Requirements of Leucaena and Eucalyptus for Biomass Production)

Because of the differing characteristics of the several tree plantation sites, four different species of trees were selected as most suitable for cultivation and they are; Leucaena (Koa Haole), Eucalyptus Grandis, Eucalyptus Saligna, and Eucalyptus Globulus.

b. Tree Farm and Plant Site

In order to support the 1,000 ton per day biomass to oil processing plant, approximately 50,000 acres must be dedicated to the tree plantation. This land requirement is based on an average yield of 10 BDT (Bone Dry Ton) per acre per year on a 5-6 year crop rotation cycle. In addition to the 1,000 BDT per day feedstock to the plant another 464 BDT per day is required for steam generation, power, and process heat.

The Islands of Hawaii (Big Island), Kauai, Maui and Molokai were closely examined as possible tree farm sites. Four separate maps for each island showing rainfall, elevation, soil type and land ownership were overlaid on each other and the most suitable crops and sites were determined. The acreage criteria was then imposed and those islands too small for the tree plantation were eliminated.

Only the Big Island met all environmental and acreage requirements for a tree farm based on the cultivation criteria set forth in Table 1-1 on page 6 of Appendix I. Since there are no available sites with 50,000 contiguous acres of suitable land, the proposed tree plantation will be located on three non-contiguous parcels in relatively close proximity to each other.

In order to minimize transportation cost we have tentatively selected the outskirts of Waimea Town as a possible plant site. Waimea is centrally located between the three plantation sites, namely, Kapaau (Kohala), Kukaiau (Honokoa) and Puaakala.

IV. Process and Plant Design, Product Quality, and Economics

a. Process Design

The specific process to be utilized in the proposed project is Hydropyrolysis of biomass to produce liquid hydrocarbon fuels. This type of conversion is conducted in a high partial pressure of hydrogen and has a Short Residence Time (SRT) of only a few seconds. The essence of this SRT hydropyrolysis, or HYFLEX™ process as IGT call it, is the simultaneous extraction of valuable oil and gas products from solid carbonaceous feedstock such as biomass without forming a heavy, hard-to-handle tar. By controlling reaction time and reaction severity (temperature) the product slate can be varied according to needs and market.

Initial processing of feed consists of drying and size reduction using conventional equipment. Since woodchip feed material contains about 50 percent moisture, it is dried in a rotary drum drier to a moisture content of 35 percent or less. It is then reduced in size by grinding machinery to less than 1/16 inch particles (20 mesh). The feed then enters a lockhopper feeder. Since this section of the process operates at a moderately high pressure (200-400 psi) multiple lock hoppers are used. Combination dryer and surge vessel is employed so that feed to the process is continuous. (See Appendix II, Fig. 1, Block Flow Diagram of Hyflex Plant, pg. III-2 and Fig. 2, Process Flow Diagram. pg III-3).

In the dryer-surge vessel, feed is contacted in a fluid bed by products in gaseous and vapor form. The feed is thus preheated and the products cooled. Feed solids then pass through a standpipe and are admitted through a slide valve into the bottom of the riser reactor where they are entrained upward by a hydrogen-rich gas system. Conversion in the riser reactor takes place in a few seconds and the reaction is immediately quenched in the disengaging and quench vessel to assure that no polymerization products are formed by "soaking" at high temperature. Unreacted feed (char) passes through a slide valve from the disengaging and quench vessel into the steam-oxygen gasifier where it is gasified to produce the net hydrogen necessary for conversion. Conversion products are cooled and separated into liquid and gaseous products. Liquid products are fractionated to desirable products. Gaseous products are burned as fuel in the process.

Utilities required for the process consist of fuel for firing the recycle hydrogen heater and for steam generation, electricity for powering moving equipment, water for cooling, and water for supplying the chemical hydrogen required to upgrade the carbonaceous fuel. Generally about 0.5-1.0

pounds of water are required per pound of plant fuel. Fuel can be gas produced in the process, coke from initial hydropyrolysis, wood chips, or whatever else might be available to give the lowest cost of production. Electricity will be generated and any excess will be sold to the utility system.

A base case design for a 1,000 BDT per day HYFLEX processing plant was completed. Further investigation, however, indicated that instead of delivering logs to be chipped at the plant as in the base case design, it would be more desirable to do whole tree chipping (about 2' x 3/4" size) in the field. (See Appendix II, page IV-1)

Such a change in process procedure will reduce capital requirements by $9.380 million from $47.549 to $38.169 million. It will reduce plant operating cost by $2.177 million from $16.685 to $14.508 million. This reduction, however, is not a cost savings but merely a reallocation of costs to the field harvesting operations.

In addition to the foregoing capital and operating cost reductions, power demand will be reduced by 3,730 KW, from 8,000 KW to 4,279 KW, with an attendant reduction in wood requirement of 214 tons, from 1,678 to 1,464 BDT per day.

An important consideration in our decision to chip in the field was transportation of the trees to the processing plant. Large trees must be trimmed so that only logs of suitable size would be transported and a lot of the smaller branches would probably be left in the field. On the other hand, whole tree chipping, which we witnessed in several areas in Michigan, Virginia and North Carolina, recovers all parts of the tree including leaves and bark. The chips are more bulky than logs, but can be loaded, transported and unloaded very easily into large vans. Field chipping,therefore, results in better recovery, and in easier transportation and handling of the biomass.

b. Product Quantity and Quality

Our primary objective is to produce the largest yield of liquid hydrocarbon fuels. According to Appendix II, page VI-1, and Figures VI-1 and VI-2, the best yield and quality is obtained when the reaction temperature is about 970°F in the presence of hydrogen and a pressure of 100 psig.

The quality of the organic liquid is questionable because it has a calorific value of only 10,493 BTU/lb. (See page VI-15) Chromatographic Analysis of the oil (see page E14 of Appendix E of the IGT Report) shows that about 56% of the oils are oxygen containing compounds. Of these compounds the phenols predominate.

The low calorific value and high oxygen content of the oil indicates that it is not suitable as a petroleum distillate substitute. Petroleum distillates usually have a calorific value of 19,000 - 20,000 BTU/lb. with only a small amount of oxygen. Therefore, an additional upgrading process must be undertaken in order to make the HYFLEX distillate suitable for further refining.

c. Process Economics

(1) Feedstock Cost - Approximately 50% of the product cost can be attributed to feed cost if we assume wood cost to be about $55 per dry ton. Please note that the higher the feedstock cost the greater its portion of the product cost, because the capital and other operating costs are relatively fixed. (See Appendix I, Section 8, Financial Results and Appendix II, page VII-3, Table VII-1, Capital and Operating Costs)

The average after-tax cash cost of $29.47 per dry ton of chips (Appendix I, Section 8, page 79) is approximately 50% of the before tax cost. This is the price which must be paid if the tree farm is an independently operated business which sells chips to the processing plant. Therefore, the actual feedstock cost is $57.78 per dry ton as described in a letter dated August 10, 1982 from John S. Denges to Dr. Ping Sun Leung. (see Denyes' letter attached to Section 8 of Appendix I)

(2) Product Cost - Based on the $57.78 per dry ton of chips, product cost will be $9.17 per million BTU's (see Appendix II, Table VII-1, Capital and Operating Costs, page VII-3 and Figure VII-1, Combined Cost of Organic Liquid and Char, page VII-4) or $55.02 per barrel of oil equivalent (6 million BTU's per barrel).

V. Conclusion

Biomass to oil conversion by the HYFLEX process is not commercially feasible with feedstock from a tree farm in Hawaii. The $55.02 per barrel oil equivalent price is much to high compared to crude oil which is currently available for as low as $28 per barrel.

Because of the high cost of harvesting, which is estimated at about $22.40 per dry ton (see Appendix I, Tables 7-1 and 8-6), it is highly improbable that the product cost can be reduced to about $32 per barrel to be competitive with petroleum products even with the most efficient tree farm operation. Feedstock cost must be less than $24.60 per dry ton in order to produce a cost competitive product.

PRI Pacific Resources, Inc.

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Telephone 808 547-3111 Telex 0634238

August 26, 1982

TO: Receipients of Report on Energy Tree Farm Workshop No 1.

SUBJECT: Addendum to Report

Attached is a letter dated August 10, 1982 from John S. Denyes, one of the authors of Section 8 of the Report, to Mr. Ping Sun Leung concerning that section. The letter clarifies some confusion about the meaning of the cost figures presented in Section 8. The letter is self-explanatory, therefore I will not comment any further.

Sincerely,

Robert Fujita
Project Manager

ALEXANDER & BALDWIN, INC.

August 10, 1982

Mr. Ping Sun Leung
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Dear Mr. Leung:

There has apparently been some confusion about the meaning of some of the numbers discussed in Section 8 (Financial Results) of the 1982 report on Hydropyrolysis of Biomass to Produce Liquid Hydrocarbon Fuels. In this letter I will try to clarify the significance of my calculations so that readers of that report can properly assess that analysis and accurately compare it to other alternative energy sources.

The first paragraph of Section 8 states that growing, harvesting, and chipping of eucalyptus and leucaena as a source of biomass "can be done at an average after-tax cash cost of $29.47 per ton". The confusion apparently arises in the definition of what is meant by "after-tax cash cost". Let me try to illustrate this with a simple example.

Consider a corporation with a 50% marginal tax rate. Every increase in net income is taxed at 50%; conversely, a decrease in net income due to higher costs has only a 50% impact on net profit and cash flow. An additional dollar in costs only reduces income by fifty cents; the other fifty cents are offset by a reduction in income tax. In this case, if this corporation were to buy a ton of chips costing $60 from the supplier, the "after-tax cash cost" of that $60 ton of chips would be $30 (or $60 minus a 50% reduction in income taxes).

Thus, when the Hydropyrolysis report discusses "an after-tax cash cost of $29.47" it must be realized that this is <u>not</u> the equivalent market cost of the chips; instead, it is the cost after all income tax effects have been considered. The equivalent before-tax market price of the chips would be some higher number.

The structure of the enterprise producing these chips is assumed to be subject to a combination of a 30% capital gains tax rate and an ordinary income tax rate of approximately 49%. Further, much of the investment required for the project will give rise to investment tax credits, having an effect on the average tax rate. Finally, the average tax rate and the cash flows will vary over time as the project is established and then comes into production at some later date. Due to these complicating factors, I did not convert the $29.47 into a before-tax equivalent price. It is, however, easily possible to convert it into the equivalent price of fuel oil for a company with a 49% tax rate:

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$29.47/(100%-49%) = $57.78 per bone-dry ton; at two green tons per bone-dry ton this is $57.78/2 = $28.89 per green ton. Since one green ton is approximately equivalent to one barrel of oil, this means that implementing this project to produce chips (if used as a replacement for fuel oil) is equivalent to purchasing oil directly at $28.89 per barrel.

I hope this has helped clarify the matter; if you have any further questions, please do not hesitate to call.

Sincerely,

John S. Denyes
Director, Corporate Development

JSD/cbl
1222C

cc: Robert Fujita
James Holderness
Paul K. Yuen

APPENDIX I

HYDROPYROLYSIS OF BIOMASS TO PRODUCE LIQUID HYDROCARBON FUELS

DOE GRANT NO. DE-FG01-80RA50324

REPORT ON ENERGY TREE FARM WORKSHOP NO. 1

October 1981

by

WORKSHOP NO. 1 STUDY TEAM

JAMES HOLDERNESS,
MARY TROY, EDITORS

for

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This report was prepared as part of a U.S. Department of Energy funded study of the feasibility of producing hydrocarbon fuels from Hawaii biomass. The prime contractor in this study was Pacific Resources, Inc. (PRI); the Institute of Gas Technology assisted by developing and refining the process, and HNEI characterized and evaluated the feedstocks and areas best suited for this project. The workshop, the results of which are published here, was part of HNEI's efforts and was sponsored jointly by PRI and HNEI.

Great care was taken in assembling the team of experts listed on the next page. Each of them brought to the workshop not only impressive credentials, expertise, and experience, but an enthusiasm and interest that was above and beyond our expectations. All worked hard, before, during, and after the three days in Hilo. Each section in the report credits specific people who contributed greatly to it, and who had primary responsibility for its contents. Others present, however, helped by giving advice, suggestions, and comments.

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INTRODUCTION

Hawaii is presently 90 percent dependent upon imported petroleum for its energy needs. Such import levels could be the Achilles' heel of the state's commerce and industry, as was demonstrated during the oil crunches of the 70's. Energy self-sufficiency, therefore is a state goal and one of the objectives of this study.

Biomass, geothermal, ocean thermal, solar, and wind energy are alternate sources to imported finite fossil fuels. Since its inception 100 years ago, the sugar industry in Hawaii has utilized biomass (bagasse) as an energy source, but more and larger scale use of biomass is needed now. Tree crops, grass, row crops and even marine plantations of kelp are other examples of biomass production that are being carefully assessed for their economic feasibility. A form of biomass, the carbonaceous residue of farm and forest production, is a renewable energy resource that, if large-scale plantations were demonstrated to be economically feasible and if its availability for continuous processing were made certain, could fill an expanding portion of the state's needs.

Perhaps greater use of biomass energy is currently being made in the state than is realized. On the Island of Hawaii, electrical generators powered by boilers fueled by bagasse supply about one third of the consumer electrical demand. On Kauai, bagasse fuels only a slightly smaller percentage of electrical production. Guinea and Napier grasses fuel a power plant on Molokai. Chipped wood substitutes for bagasse for power generation in a growing number of instances, and more wood chips would be used as boiler fuel if available. As a rule of thumb, one ton of wet wood chips (2,000 lb) has the energy equivalent of one barrel of oil. Many acres of Hawaii, not presently economically viable for food crops or pasture, now standing idle, are capable of producing 20 green tons of harvestable biomass per acre-year. This is an energy equivalent of 20 barrels of oil per acre-year. Based on 1981 fuel oil prices of $32 per barrel delivered Hawaii, the acre of biomass has a value of $640.

Biomass may be converted to energy by at least four processes: direct combustion (burning); hydropyrolysis (gasification); hydrolysis; or anaerobic digestion. Direct combustion is the most efficient method of converting biomass to electricity. By use of the hydropyrolysis process, though, biomass can be converted to liquid hydrocarbon fuels or low BTU gas and char. Liquid hydrocarbons are clearly suited as liquid fuels. Liquid hydrocarbons could also conceivably be used to energize planting and harvesting equipment for the proposed extensive biomass plantation.

Since August 1980, Pacific Resources, Inc., the Hawaii Natural Energy Institute of the University of Hawaii, and the Institute of Gas Technology have been studying the economic feasibility of hydropyrolysis of Hawaii biomass to produce liquid fuels under a U.S. Department of Energy grant. The particular hydropyrolysis conversion method being examined is called Hyflex^{TM}, which is the simultaneous extraction of oil and gas products from solid carbonaceous feedstocks without forming a heavy, hard-to-handle tar. By controlling reaction time and severity (temperature) the product slate can be varied according to needs and market. A process design has been completed for the conversion of forest biomass (specifically eucalyptus wood) to LPG, oil, and char products. A prototype conversion plant implementing the Hyflex^{TM} process has been proposed, and it requires the sustained production from a tree plantation of 45,000 to 55,000 acres.

Since the early 70's, a significant number of research projects have considered single or multiple phases of the potential for tree plantations as a source of biomass energy for Hawaii. A 1977, five-volume study by the Stanford University/University of Hawaii Biomass Energy Study Team indicated 12 extensive land areas on the Island of Hawaii deemed suited to, and economically positive for, energy tree plantations. This work suggested that perhaps 773,599 acres of grassland and wooded grazing land might be considered for terrestrial biomass production. By and large these lands were situated above 2,000 ft elevation, were not under cultivation, were often partly woods, and usually were under-utilized.

Presently, areas of the Island of Hawaii that offer the highest potential for economically feasible energy tree plantations are parts of the Hamakua Coast and the North Kohala District. On the Hamakua Coast virtually all of the land below 2,000 ft elevation is used for unirrigated sugarcane production. Above the cane lands, however, is a belt of higher elevation often wetter lands that are grazing land or disturbed forest areas. At still higher elevations are less moist lands utilized only as pasture. Such lands, ranging in elevation from 2,000 to 3,600 ft, appear to be environmentally suited for energy tree plantations. On the Kohala side, abandoned cane land might allow tree plantings to extend downward nearly to sea level where biomass yields could be very high.

Forearmed with the production and conversion research from the decade of the 70's, various groups are now meeting to assess biomass energy for Hawaii in the 80's. In 1979 the Hawaii Natural Energy Institute sponsored an international panel which considered a 1,000 acre tree farm of giant leucaena for the Island of Molokai. During October 1981, a group of 24 scientists, practitioners, and government and industry representatives convened a synthetic fuels workshop in Hilo. This workshop was planned to consider all aspects of amalgamating a hydro-pyrolysis plant processing 1,000 bone dry tones of wood chips per day and an energy tree plantation estimated at 50,000 acres. The workshop was sponsored by Pacific Resources, Inc. (PRI) and the Hawaii Natural Energy Institute (HNEI). Other workshops are in the planning stage.

The biomass plantation under consideration here would approximate the size of two large sugar plantations. Land suitability and availability, lease rates, and productivity were investigated for the plantings proposed. Tree species, soil, and moisture requirements, were weighed. Actual planting acreage requirements were determined so that tree nurseries and seedlings accommodating the site proposal could be planned, seedling distribution plotted, and manpower requirements determined. Plantation establishment, harvesting, and utilization were budgeted. Environmental concerns were entertained and processing plant sites proposed. In final, the financial feasibility of the project was analyzed. Workshop participants selected were assigned to work areas based upon their considerable expertise and experience.

This report, based upon the deliberations of the participants of the Energy Tree Farm Workshop No. 1, shows how a new biomass industry might be initiated on the windward side of the Island of Hawaii to make better economic use of the upper belt, underutilized lands; to provide new jobs for local people; and to reduce the state's dependency on imported transport energy sources. It is, the reader is reminded, only a proposal. The report attempts to weave together biomass research and development of the past decade and the practical economics and technological capabilities of the next. The results are economically positive and become even more positive as fuel prices rise during the decade of the 1980's.

The workshop participants are confident that even if the particular processing plant envisioned to process annually the equivalent of 935,000 barrels of oil energy from 45,000 acres of energy tree plantation does not become a reality, the results of the sessions will be available and useful for the consideration of other biomass assessments throughout the 80's. The group demonstrated unanimous confidence that biomass energy for both transport fuel and electric power can be economical and will eventually play a much larger energy role for the Island of Hawaii and the state than at present.

-Jim Holderness, Editor

Dense eucalyptus growth at the University of Hawaii Agricultural Research Station, Waimanalo, Hawaii.

Section 1
SPECIES
Selection and Predicted Yields

K.G. MacDicken, C.K. Wakida, R.G. Skolmen

This section presents an overview of climatic and edaphic factors for three sites recommended for biomass plantations on the northeast quarter of the Island of Hawaii. The environmental requirements of four species of trees believed suitable as planting stock–Eucalyptus saligna, E. grandis, E. globulus, and Leucaena leucocephala–are matched with the potential plantation sites. Yield projections are made for each species in each area.

SPECIES SELECTION

The establishment of a 40,000 to 50,000 acre biomass plantation which can adequately supply the requirements of a 1400 bone dry ton (BDT)/day hydropyrolysis plant requires the selection of tree species that provide optimum yields in short rotations.

The three sites recommended for inclusion in this study (see Section 2) were assessed in an effort to match species requirements (Table 1-1) and specific site characteristics:

- o Mean annual rainfall
- o Elevation
- o Soil characteristics
- o Existing vegetation
- o Growth data from existing stands and experimental plantings of eucalyptus and leucaena

Data used in this selection process were obtained from available literature, unpublished studies from the U.S. Forest Service (USFS) and the University of Hawaii (UH), and observations of State Division of Forestry, USFS, and UH personnel. Subsequent yield projections were based on information from these same sources. The following species were found to be suited to the plantation sites:

- o Leucaena leucocephala (leucaena)
- o Eucalyptus grandis (rosegum)
- o E. saligna (saligna)
- o E. globulus (bluegum)

Leucaena leucocephala (koa haole) is a member of the Leguminosae family (Fabaceae) originating in Mexico and Central America. The common shrubby type grows extensively in

Table 1-1: Environmental and Growth Requirements of Leucaena and Eucalyptus for Biomass Production[1]

Species	Altitude (ft)		Rainfall (in)		Temperature (°F)
	Optimum	Marginal	Optimum	Marginal	
L. leucocephala	below 1500	over 1500	50-65	as low as 20	restricted to the tropics and subtropics
E. saligna	1500-3500	500-1500, 3500-6500	80-100	25-80, 100-300+	temperature limiting above 5000-6000 ft
E. grandis	0-2400	2400-4000	80-100	25-80, 100-300+	temperature limiting above 4000 ft; cannot take frost
E. globulus	3500-5000	5000-7000	50-80 best if winter maximum	20-50, 80-200	can tolerate about 20°F for short periods when mature; seedlings are frost-susceptible

Species	Soil depth (ft)	Soil texture	Soil drainage	Soil pH	Soil nutrient status, ppm[2]			
					P	Ca	Mg	K
L. leucocephala	2	light-heavy	mod. well-drained	5.5-8.0	-	-	-	-
E. saligna	3	light-medium	well-drained	4.5-5.5	20-30	>1200	150	>200
E. grandis	3	light-medium	well-drained	4.5-6.5	-	-	-	-
E. globulus	3	light-medium	well-drained	5.0-6.5	-	-	-	-

[1]Adapted from National Academy of Sciences (1980) and USDA Forest Service, Honolulu.

[2]P is modified Truog method: Ca, Mg, and K are exchangeable bases (Y. N. Tamimi).

Hawaii at low elevations. In much of the tropics, leucaena is used as a major source of feed and fuel. The "Hawaiian giant" varieties being considered for this project are capable of very rapid growth, and have the ability to fix nitrogen, thus eliminating the need for nitrogen fertilizers.

Giant leucaena has been planted extensively as a fuel and pulpwood species in the Philippines and Taiwan. The high nitrogen content of the leaves allows the use of the foliage as a valuable co-product of woody biomass.

The genus Eucalyptus (family Myrtaceae) is native to Australia. Five to six hundred species and varieties comprise 75 percent of the total flora. In the dense coastal rain forest of its homeland, eucalyptus grow tall and straight to heights of more than 200 ft; dwarf, shrubby forms appear at timberline and in the dry outback. Eucalyptus have now been in Hawaii over 110 years and have spready significantly from where first planted. They, however, have not significantly reproduced in or taken over native forests, even where they have been planted inside native forest areas. Where planted on degraded lands just makai of the native forest as along the Hamakua Coast, they have served positively as a buffer against weed invasion into the native forest.

Eucalyptus saligna, E. grandis (rosegum) and hybrids of E. grandis and E. saligna grow very rapidly on favorable sites. Annual increments in Hawaii average 1 inch in diameter at breast height (dbh) and 10 ft in height.

Since 1960, E. saligna has been used for watershed protection and timber production. The Island of Hawaii has harvested over 14 million board feet of saligna sawtimber along the Hamakua Coast above sugarcane fields.

In other countries (South America and Brazil) E. saligna represents an important timber species. When chipped, it provides fiber for paper, particle board, hardboard, and rayon.

An important difference between E. grandis and E. saligna appears to be the susceptibility of E. saligna to a stem canker found on Kauai. E. grandis appears to be more resistant to this disease.

E. globulus (bluegum) has been planted in Hawaii since about 1880, mainly on the islands of Hawaii and Maui. It is easily established and adapted to many sites with its best growth occurring above 2500 feet. Its wood is heavy and very hard with a large shrinkage in drying.

Bluegum wood is dense (55 lb/cu ft at 12 percent moisture) and light colored, well suited for pulp and fiber products. Its bark is thin, smooth, and regularly shed in strips from above, resulting in a thinly clad, blue-grey mottled trunk. Bluegum may grow faster and produce a denser wood than saligna at sites above 5000 feet.

All four species have the necessary attributes for this study:

- Rapid growth

  Provided they are planted in sites to which they are adapted, each has been proven to grow at rates which equal or exceed a mean annual increment of 10 BDT/acre-year. These growth rates indicate economic harvesting of wood chips on short rotations of 4 to 7 years.

- Coppicing ability

  The stumps of each of these species will produce coppice shoots after the stems have been harvested. Although actual coppice yields have not yet been adequately studied, initial reports from here and abroad indicate that coppice yields could exceed the yield of seedling stands.

- Resistance to pests

  Existing plantings of these species have thus far escaped major damage from insect, rodent, and disease pests. The only notable exception is the current problem with stem canker in E. saligna on the Island of Kauai.

- Adaptability to wide range of conditions

  These species of eucalyptus and leucaena tolerate a wide range of soil and climatic conditions, and are generally more drought resistant than the other species considered.

- Existing plantings in Hawaii

  Several exotic species were considered initially, but eucalyptus and leucaena were selected because each has been studied for its wood production in Hawaii for well over a decade.

- Suitability of wood as a fuel

  The process envisioned for the proposed plant requires that 33 percent of the total tonnage of chips be used as feedstock to fuel the plant. Each of the species selected produces good quality fuelwood (minimum specific gravity = .45, heating value of 8000 BTU/lb or more.)

o Suitability for pulpwood

E. saligna, E. grandis, and E. globulus yield fiber that is suitable for the production of high quality pulp or lumber. Therefore, there are alternate markets for the products of this project. Leucaena is also known to produce desirable pulp.

PREDICTED YIELDS

Wood yields from each of the sites were estimated in BDT/acre-year on a whole tree basis (Tables 1-2, 1-3, 1-4). These estimates include stem, bark, branches, and leaves, and are based largely on the limited data collected from E. globulus and E. saligna coppice stands growing in the Kuka'iau area. It is expected that after six years, over two-thirds of the dry weight will be from stem wood and bark, and the balance will be primarily from branches.

Subzones were defined in each area according to the following specific chracteristics:

- o Mean annual rainfall
- o Prime Forest Lands Classification
- o Elevation
- o Windfall hazard
- o Soil limitations

The subzones are described in Figures 1-1 through 1-3.

Assuming there are no serious limitations to growth, such as high winds, the most important factors influencing the growth of eucalyptus are rainfall and temperature. Subzone boundaries, therefore, were based on isohyets[1] and contour lines. Secondary consideration was given to the Prime Forest Lands Classifications, as drawn up by the State Division of Forestry. These classifications are designed to provide a means of estimating the relative suitability of lands for wood production based on environmental parameters.

[1] Map lines connecting areas of equal rainfall.

Table 1-2: Environmental Parameters Describing Yield Potential at Kapa'au, Site I

Species	Elevation	Rainfall	[1]Prime Forest Lands	Dominant soil series	[2]Predicted yield (BDT/acre-year)	Acreage	[3]Total yield (BDT)
L. leucocephala	<1000 ft	40-75 in	NS, P2	Hawi, Kohala	10	8,500	510,000
E. grandis	1000-2000 ft	40-100 in	NS, P2 P1	Ainakea Niulii	6-12	5,150	298,800
E. saligna	2000-3000 ft	75-100 in	NS, P2 P1	Ainakea Niulii	8-9	4,515	230,220
E. globulus	>3000 ft	75-100 in	NS, P2	Ainakea, Niulii Manahaa Kehena (Marginal)	8-10	2,025	121,500
TOTAL						20,190	1,160,520

[1]Not to be confused with Prime Agricultural Lands
NS = National Standard (lowest suitability class)
P2 = Prime 2
P1 = Prime 1 (highest suitability class)

[2]Mean annual increment

[3]Assuming - 6 year rotation

Note: Total yield is the summation of weighted subzone yields.

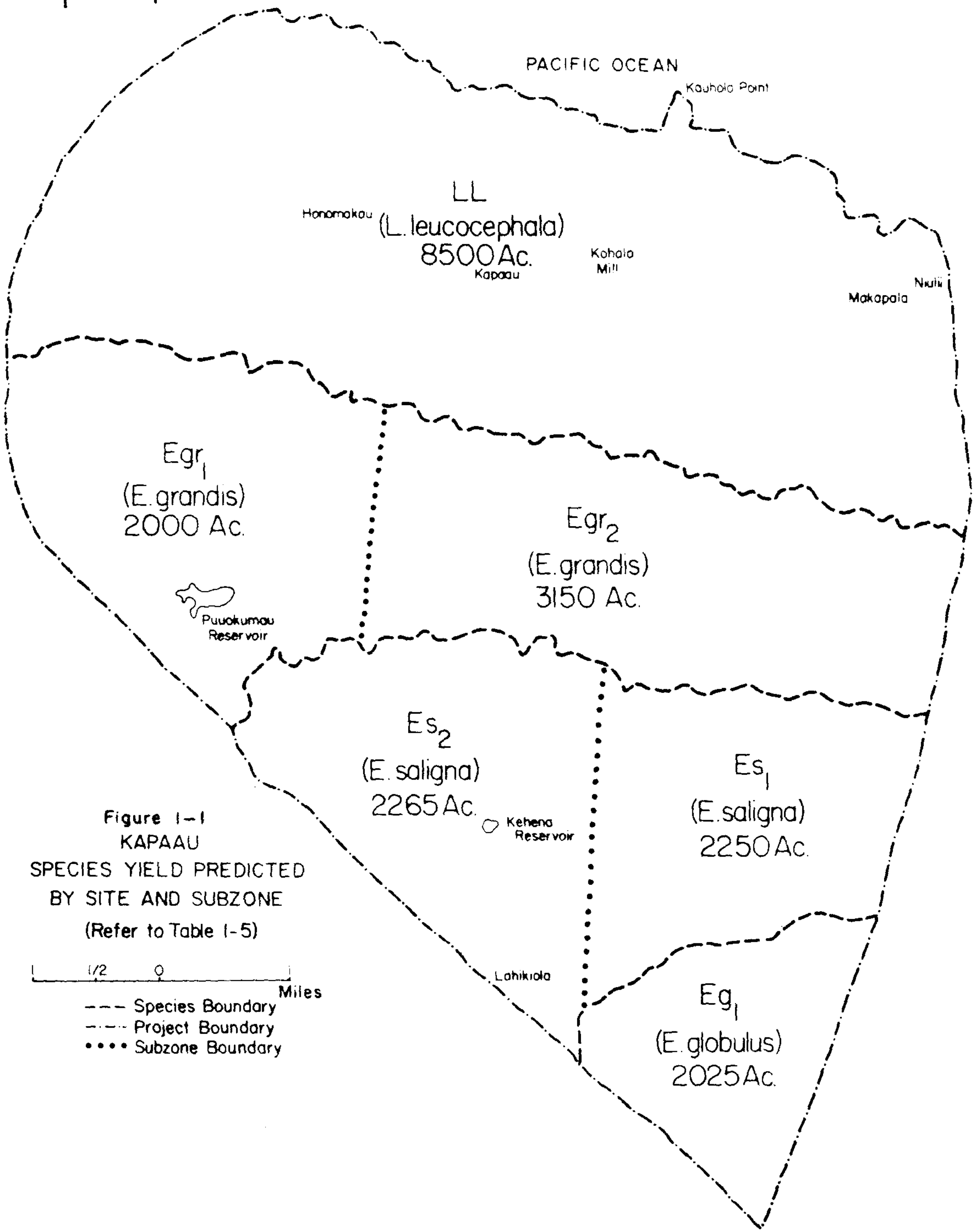


Figure 1-1
KAPAAU
SPECIES YIELD PREDICTED
BY SITE AND SUBZONE
(Refer to Table 1-5)

Table 1-3: Environmental Parameters Describing Yield Potential at Kuka'iau, Site 2

Species	Elevation	Rainfall	[1]Prime Forest Lands	Dominant soil series	[2]Predicted yield (BDT/acre-year)	Acreage	[3]Total yield (BDT)
E. saligna	3000-4000 ft	40-50 in	P2	Maile	8-12	8,060	497,040
E. globulus	4000-6000 ft	30-50 in	NS, P2	Umikoa Hanipoe	8	7,650	367,200
E. globulus	4000-6000 ft	50 + in	P2	Umikoa Hanipoe	12	4,530	326,160
TOTAL						20,240	1,190,400

[1]Not to be confused with Prime Agricultural Lands
NS = National Standard (lowest suitability class)
P2 = Prime 2
P1 = Prime 1 (highest suitability class)

[2]Mean annual increment

[3]Based on a 6 year rotation

Note: Total yield is the summation of weighted subzone yields.

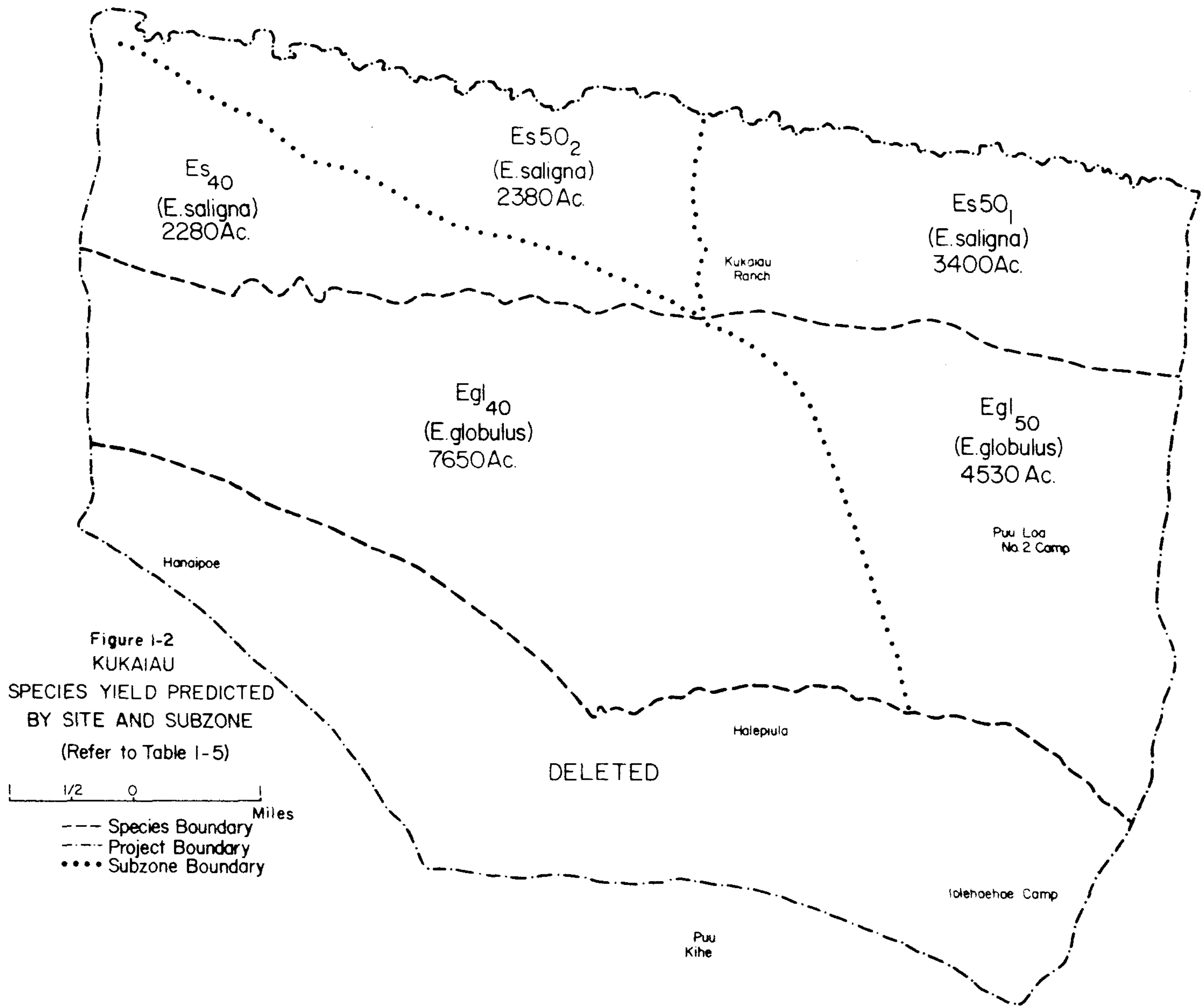


Figure 1-2
KUKAIAU
SPECIES YIELD PREDICTED
BY SITE AND SUBZONE
(Refer to Table 1-5)

Table 1-4: Environmental Parameters Describing Yield Potential at Pua'akala, Site 3

Species	Elevation	Rainfall	[1]Prime Forest Lands	Dominant soil series	[2]Predicted yield (BDT/acre-year)	Acreage	[3]Total yield (BDT)
<u>E. globulus</u>	5400-6500 ft	100-125 in	P2	Puu Oo	11	7,335	484,110
<u>E. globulus</u>	5000-6000 ft	125-150 in	P2	Piihouoa Laumia	12	6,890	496,080
TOTAL						14,225	980,190

[1]Not to be confused with Prime Agricultural Lands
NS = National Standard (lowest suitability class)
P2 = Prime 2
P1 = Prime 1 (highest suitability class)

[2]Mean annual increment

[3]Assuming - 6 year rotation

Note: Total yield is the summation of weighted subzone yields.

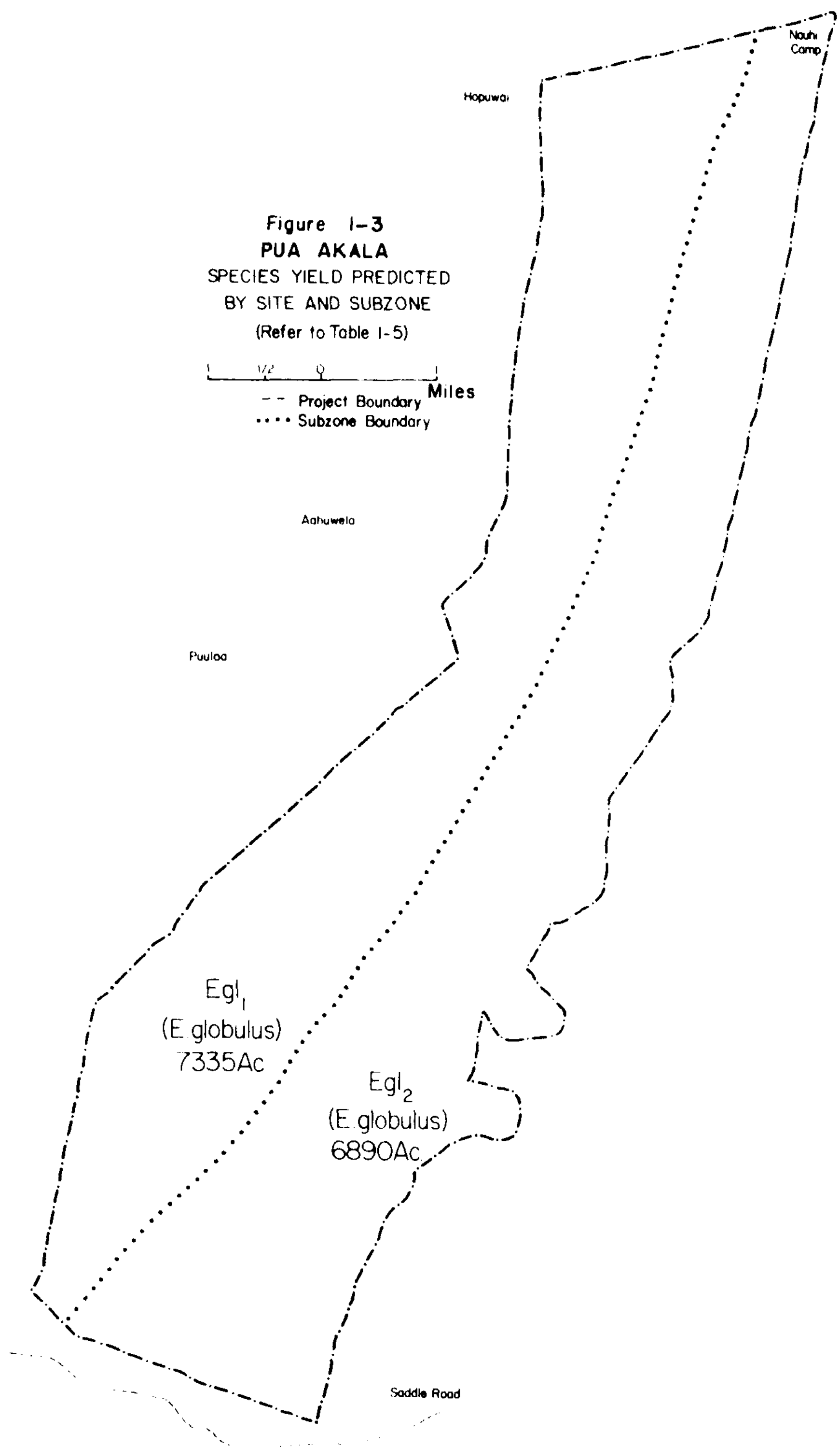


Figure 1-3
PUA AKALA
SPECIES YIELD PREDICTED
BY SITE AND SUBZONE
(Refer to Table 1-5)

Table 1-5: Species Yield Predicted by Sites and Subzones

Subzone Designation	Species	Gross acreage	Plantable acreage	Estimated annual yield/acre	Total wood yield (6-yr rotation)
			Site 1, Kapa'au		
LL	L. leucocephala	10,000	8,500	10 BDT	510,000 BDT
Egr_1	E. grandis	6,060	2,000	6 BDT	72,000 BDT
Egr_2	E. grandis		3,150	12 BDT	226,800 BDT
Es_1	E. saligna	6,020	2,250	9 BDT	121,500 BDT
Es_2	E. saligna		2,265	8 BDT	108,720 BDT
Eg_1	E. globulus	2,700	2,025	10 BDT	121,500 BDT
		24,780 acres	20,190 acres		1,160,520 BDT
			Site 2, Kuka'iau		
$Es50_1$	E. saligna	4,250	3,400	12 BDT	244,800 BDT
$Es50_2$	E. saligna	2,975	2,380	10 BDT	142,800 BDT
Es40	E. saligna	2,850	2,280	8 BDT	109,440 BDT
Egl_{40}	E. globulus	9,562	7,650	8 BDT	367,200 BDT
Egl_{50}	E. globulus	5,662	4,530	12 BDT	326,160 BDT
		25,299 acres	20,240 acres		1,190,400 BDT
			Site 3, Pua'akala		
Egl_1	E. globulus	9,842	7,335	11 BDT	484,110 BDT
Egl_1	E. globulus	10,477	6,890	12 BDT	496,080 BDT
		20,319 acres	14,225 acres		980,190 BDT
	Total area		54,655 acres		
	Total predicted yield				3,331,110 BDT

Upon delineation of subzones, gross acreages were determined and adjusted to allow for inaccessible, environmentally protected, or unusable acres. Adjustments were made by estimating the percentage of each area that would not be planted or harvested. These estimates also took into account land removed from production by access roads.

Thus, the acreages presented in Table 1-5 are the estimated net plantable acreages within the project boundaries.

Yields (Table 1-5) were estimated as ranges per species per subzone.

Section 2

SITE

Selection and Description

Arthur Seki and Gene Aguiar

This section describes the Big Island (Hawaii) sites chosen for tree plantations--abandoned sugarcane land near Kapa'au, the upper elevations of Kuka'iau, and a strip of land along Pua'akala. To meet production requirements of 1400 BDT/day, a tree farm of 46,000 to 55,000 acres is needed. Because of land availability constraints, the above three non-contiguous sites were chosen. The latter two sites currently are used for grazing, but most of the land near Kapa'au is idle. Leases on these sites vary in cost and in length, depending upon the value of the land and the time the lease was consummated. Rents at the chosen sites range from $1.71 to $14.12 per acre per year, with termination periods from 1984 to 2111. These areas are all zoned agricultural.

HAWAII COUNTY--GENERAL INFORMATION

The Island of Hawaii is the largest of the eight islands in the state (Figure 2-1). It is about 93 miles long and 76 miles wide and covers an area of 2,584,320 acres, over 50 percent of the state's total area. The island is made up of five volcanoes, two of which are considered active. The highest point on the island is Mauna Kea, 13,796 feet above sea level. The residential population was about 92,000 in 1980.

The economy of Hawaii is based on agriculture (including sugar, macadamia nut, flowers and nursery products, papayas, coffee, and cattle ranching) and a struggling tourist industry. Sugarcane takes about 114,775 acres of land while the nonplantation agriculture takes up 820,053 acres. The landowner distribution is shown in Table 2-1: the State of Hawaii owns less than 40 percent of the land, and the rest is privately owned.

Hawaii lies in the path of the northeast tradewinds and has an orographic (mountain-caused) rainfall pattern. The prevalence of the trades accounts for the high annual rainfall of 75 to more than 300 inches on the windward northeast side of the island (Figure 2-2). Heaviest annual rainfall occurs in the vicinity west of Hilo at the 2,000 to 3,000-foot elevation where it exceeds 200 inches a year. In areas where the trades predominate, the dry months of the year occur from May through September, and the wet months from October through April. Temperatures range between $8^{o}C$ and $20^{o}C$ and these differences result chiefly from variations in elevation.

The sugar companies have acquired limited data on solar insolation for the cane lands, and insolation potentials for the chosen sites can be derived from these. The low altitude areas have relatively high insolation values, and because of cloud cover, these values decrease as elevation increases (Figure 2-3). The Department of Meteorology at the University of Hawaii at Manoa also has conducted wind surveys of the island (Figure 2-4). The Kohala area has very high wind speeds, while the upper Kuka'iau and Pua'akala sites have low speed winds. Only at the Kapa'iau site is the wind considered a potential problem.

The Island of Hawaii has slightly more than 60 percent of Hawaii's commercial forest land. Most of this, however, is a mixture of native ohia and koa trees, and is not being utilized extensively for wood products. Planted eucalyptus comprise about 2 percent of the commercial forest lands in the state, and represent 23 percent of the total saw timber volume.

Care must be exercised in developing forests for commercial use; Hawaii's biologically unique native forest is extremely sensitive to disruption. For example, Ohia, the dominant native species in the forests of Hawaii, has been subjected recently to an unexplained decline.

Additionally, Hawaii's forest and watershed areas are vital to agricultural use because the state's freshwater supply is dependent on streamflow and rainfall percolating into the freshwater aquifers. Hawaii's multiple use forests are also valued for timber, recreational areas, erosion control, wildlife habitats, and visual resources. Only one of the potential and valuable uses of forest lands is as a biomass energy resource.

SITES SELECTION

The estimated acreage of the total land available was obtained through the state tax map key and by calculating the useable area in question. The majority of the land users are cattle ranchers who own, lease, or sublease the lands. The length of these leases vary as do the lease rents, because some agreements were consummated many years ago when land values were considerably lower. The lease rent worth is an estimated value of the present day cost of the lease, assuming it will cost more to sublease the land now from the present occupant than is stated in the original lease agreement.

SITE 1, KAPA'AU

The Kapa'au (Kohala) site is located northeast of the Kohala mountain road (Highway 250) from Upolu Point to about Kahua. The elevations of the area range from sea level to approximately 4,000 feet. The mean annual rainfall ranges from 30 to 150 inches.

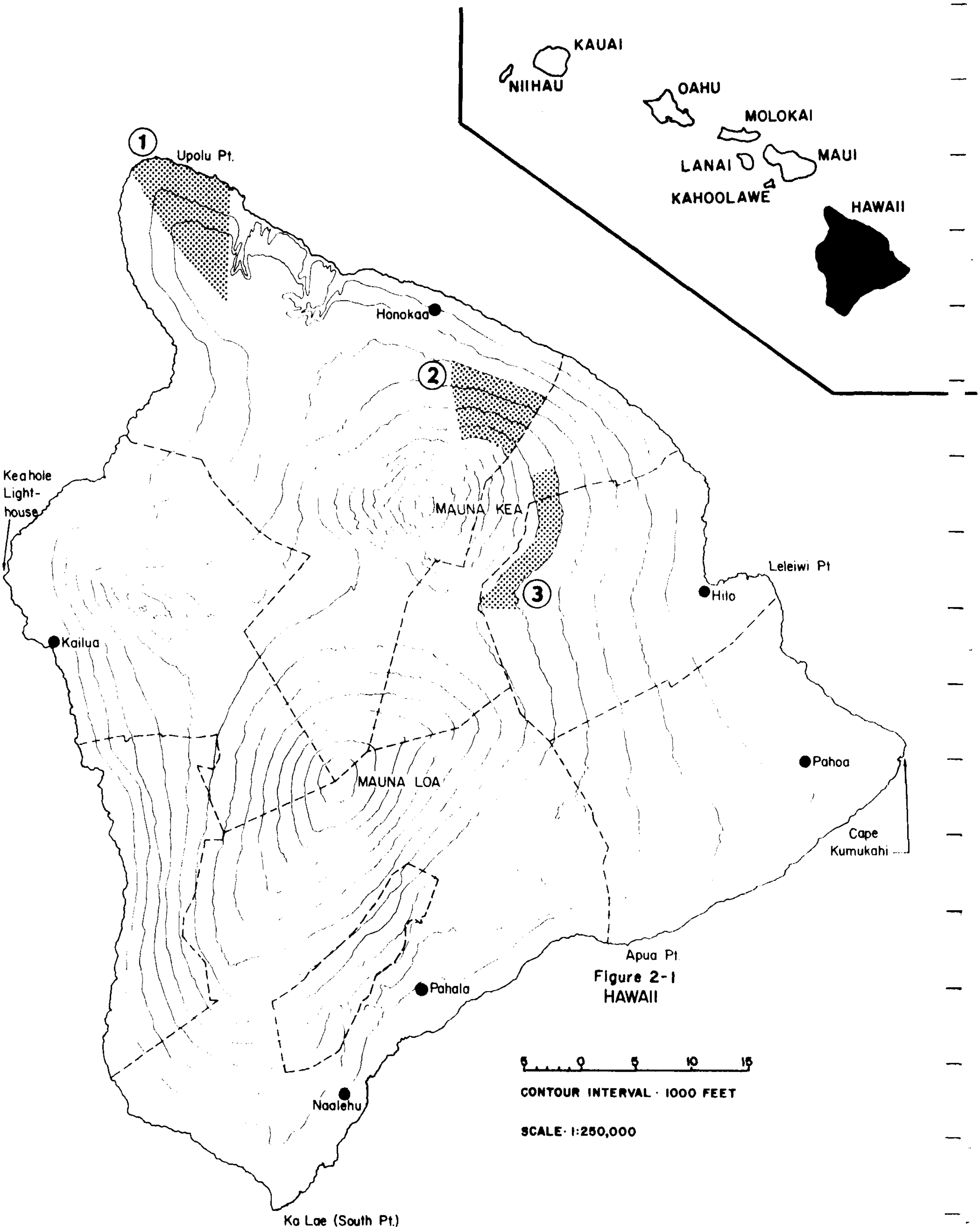


Figure 2-1
HAWAII

Table 2-1: Major Landowners, Island of Hawaii: 1964

Landowner	Acreage	Landowner	Acreage
Total Land	2,516,978	Yee Hop, Ltd.	22,270
		W. H. Shipman, Ltd.	18,525
Public Ownership:		Norman N. Inaba	15,158
Federal Government	200,995.1	Kahua Ranch, Ltd.	14,013
State of Hawaii	985,268.7	W. H. Greenwell, Ltd.	11,925
County of Hawaii	839.4	Hawaiian Ocean View Estates	10,642
		Hawaiian Paradise Park Corp.	5,502
Major Private Landowners:	1,287,595	Kapoho Land & Development Co., Ltd. ...	4,140
Parker Ranch	258,173	Queen Liliuokalani Trust	3,888
C. Brewer & Co., Ltd.	207,633	Crawford Oil Corp.	3,807
Samuel M. Damon Estate	139,510	Hawaiian Evangelical Association	3,151
Dillingham Investment Corp. ..	124,300	Elizabeth K. Booth	2,613
Theo H. Davies & Co., Ltd. ...	84,104	Mauna Loa Investment Co.	2,283
McCandless Heirs	61,277	Hawaii Mountain View Development Corp..	2,000
Signal Properties, Inc.	50,000	E. L. Wung Ranch, Ltd.	1,900
Frank R. Greenwell	35,791	Steward-Badbois Co.	1,785
World Union Industry Corp. ...	33,000	Cresent Acres, Ltd.	1,489
Thelma K. Stillman Trust	31,857	Roman Catholic Church	1,258
Bernice P. Bishop Estate	31,799	Golden State Hawaiian Corp.	1,165
Amfac, Inc.	26,515	Nanawale Estates Co.	1,064
James Campbell Estate	25,630		
Boise Cascade Properties, Inc.	25,000		
Castle & Cooke, Inc.	24,428	Small Private Landowners	43,120

Source: County of Hawaii Data Book, 1980.

Most of the commercial forest land is in grazing, and there also are many areas of non-commercial forest land—brush kiawe forest in the dry areas and native forest on very steep, rocky sites or swampy areas on the Kohala mountains. The total forest plantation land is about 500 acres, but only 280 acres are commercial types. The greater part of the commercial forests types are in the Kohala forest reserve; most of the noncommercial types are outside the reserve.

The main roads for wood chip transportation would be Highway 270 and Highway 250. The final destination would be an area outside of Waimea, roughly 25 miles from the plantation. The town of Hawi would receive some truck traffic, but it is anticipated that Waimea town will not, at least not after the new road has been completed (3 to 5 years).

The total acreage is roughly 24,780 acres for the crops of leucaena, E. grandis, E. saligna, and E. globulus. It is considered, however, that some of the land designated near the Kohala coastline is expensive agricultural land and may not be available. Assuming almost 20 percent of the area is unworkable, too expensive land, or used for roads, the workable acreage is reduced to 20,190.

Kohala Corporation (formerly Kohala Sugar Company), a subsidiary of Castle and Cooke, owns the majority of the land in question. Most of this abadoned sugar land is not now in use, but a small amount is in diversified agriculture and grazing. Richard Smart of Parker Ranch is the next largest landowner in this area. All of his land is used for grazing. Kahua Ranch owns the rest of the land under consideration, used also entirely for grazing.

Present leases in this area are from $1.75 to $13.46 per acre per year, and expire between 1984 and 2000. Some leases are longer running than others. The present worth of the leases, for the sake of the study, has been estimated at $40 per acre per year.

SITE 2, KUKA'IAU

The Kuka'iau (Honokaa) site is located along a 25-mile long section of the northeastern coast of the Island of Hawaii, from Keanakou to Hanaipoe. The elevational range within the study area is from 3,000 to about 6,000 feet. Forestry resources are greatly influenced by the annual rainfall variations across the study area. The average annual rainfall varies from 30 inches to more than 100 inches.

Forestry related resources within the site are composed of six types of vegetation including ohia-koa, commercial forest land plantations, noncommercial forest land (tree and shrub types), grassland, and herbaceous and improved pasture. A total of 4,100 acres (rounded to nearest 100) of plantation exists at the site, and 1,200 (rounded to the nearest 100) of these acres have been cutover (harvested) during the period 1975-1979. This area is from just above the sugarcane lands (about the 2,000-foot elevation) to approximately the 9,800-foot elevation, and has an annual average rainfall of 35 inches or greater.

The gross amount of land available in the Kuka'iau area is roughly 23,800 acres. An approximate 15 percent was subtracted for unworkable land and roads, leaving 20,250 acres available for planting E. saligna, E. grandis, and E. globulus.

The landowners here are the State of Hawaii, C. Notley Estate, and Theo H. Davies Company. All the land at this site has been leased or subleased to various ranchers. The termination dates of these long-term leases vary from 1990 to 2111 with a lease rent range of $4.30 to $14.12 per acre per year. The estimated present worth of these leases is $20 per acre per year.

SITE 3, PUA'AKALA

The Pua'akala area is located northwest of Hilo, mauka of the Hilo forest reserve, and stretches from beyond Nauhi Gulch to the Saddle Road. The elevational range within the study area is 5,000 to 6,000 feet on the flanks of Mauna Kea. The average annual rainfall in this area is from 75 to 150 inches. Most of the commercial forest land lies in grazing with some bushy growth near the lower elevations. The site may generally be characterized as a mixture of flat lands accompanied by rolly hills and gullies.

All of the projected truck traffic would be on the Keanakolu Mana road (which would have to be upgraded) on the upper elevations of Mauna Kea. This road also passes through the proposed Kuka'iau site. A fully weighted truck would travel approximately 35 miles downhill to an area outside of Waimea. No major towns exist en route, so problems with the community are unlikely.

The Pua'akala site has a gross acreage of about 20,300, an unworkable value of 30 percent, and therefore a workable planting area of 14,225 acres (for E. globulus). The major landowners are Liliuokalani Trust, W.H. Shipman, the State of Hawaii, and Hawaiian Homes Commission. These lands are leased or subleased to various ranchers also. Termination of these leases range from as early as 1985 to 2111. The lease rents range from $1.71 to $10.86 per acre per year. The estimated present worth of the land lease is $15 per acre per year.

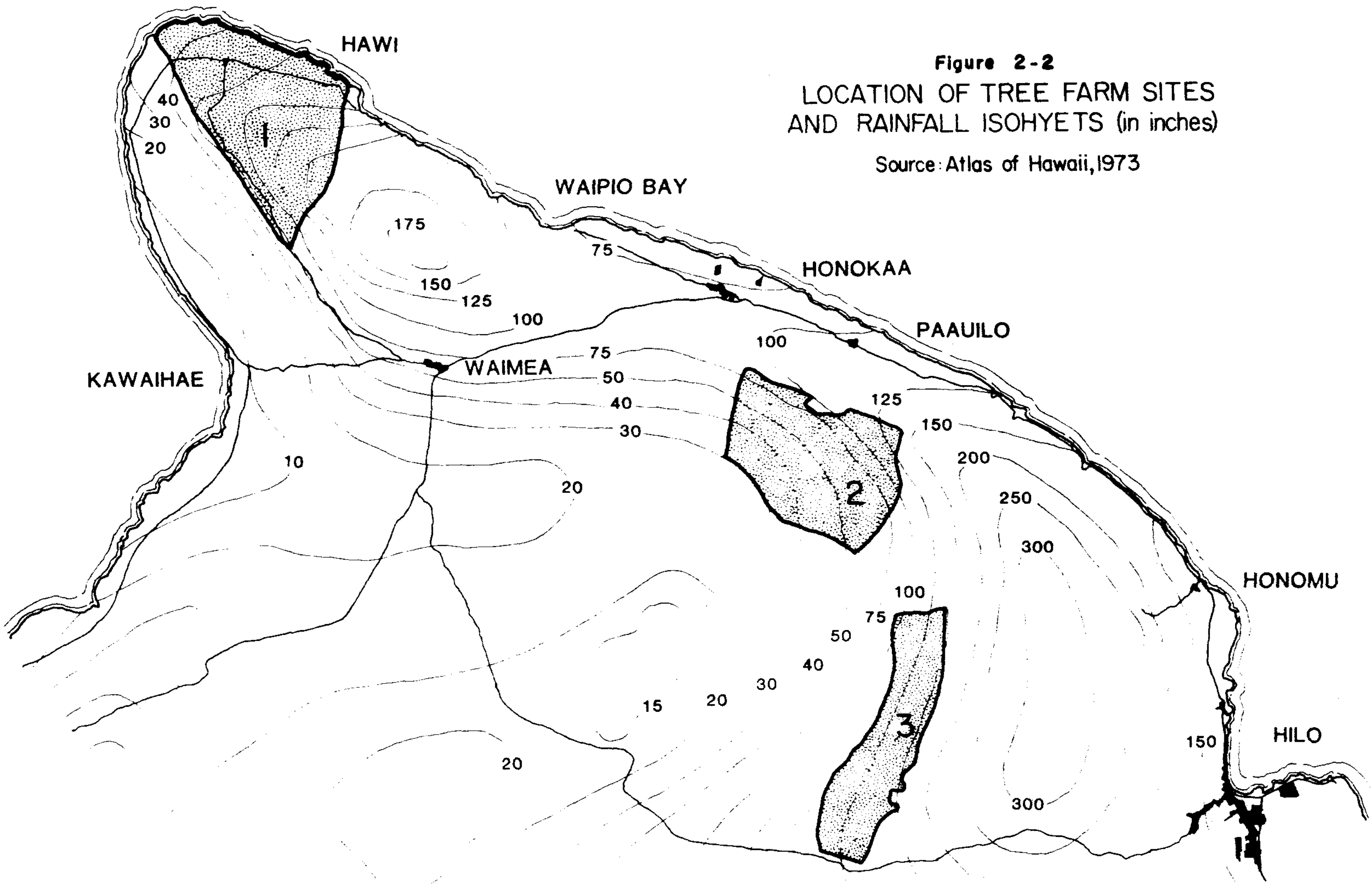


Figure 2-2
LOCATION OF TREE FARM SITES AND RAINFALL ISOHYETS (in inches)
Source: Atlas of Hawaii, 1973

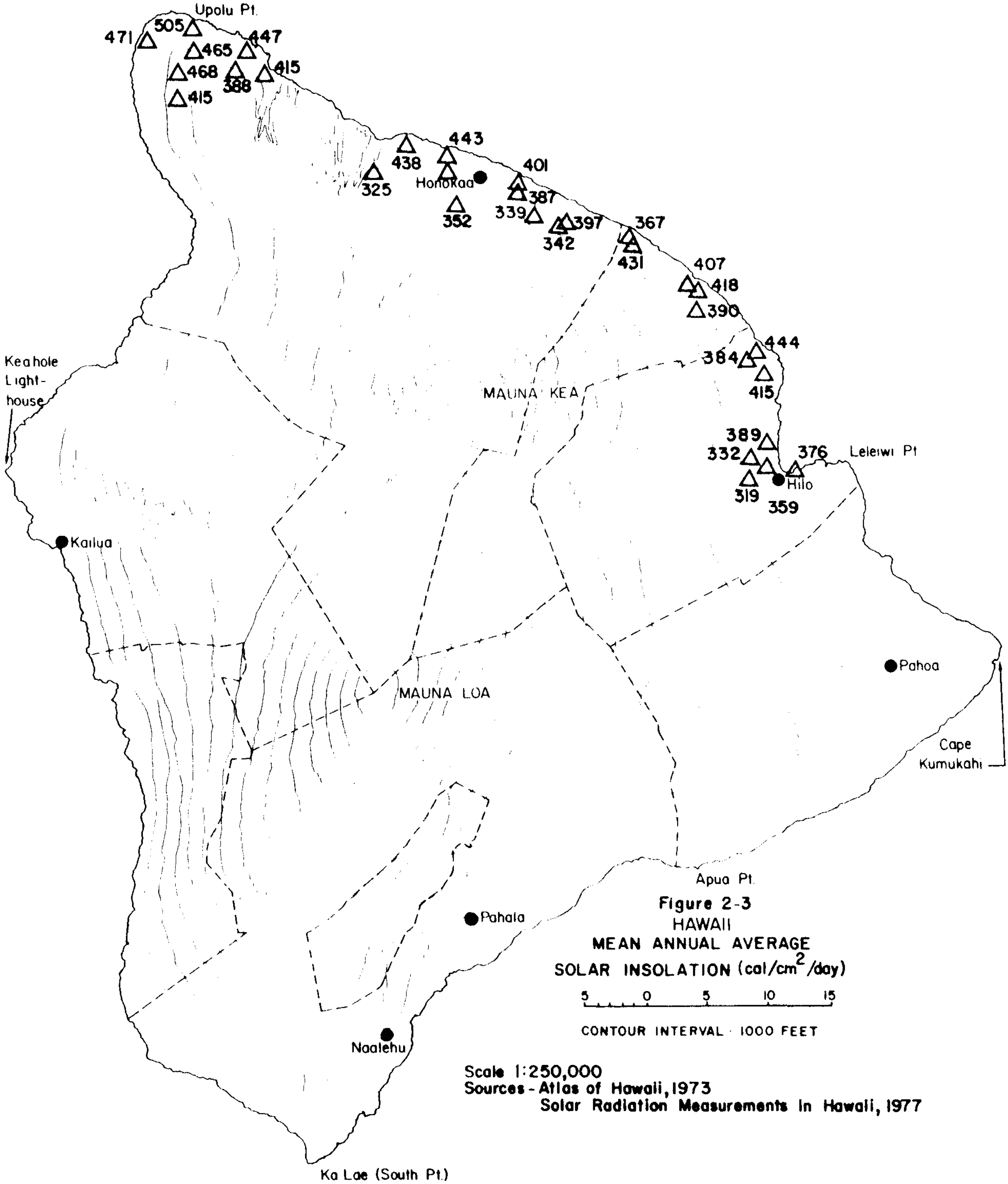


Figure 2-3
HAWAII
MEAN ANNUAL AVERAGE
SOLAR INSOLATION (cal/cm^2/day)

Scale 1:250,000
Sources - Atlas of Hawaii, 1973
Solar Radiation Measurements in Hawaii, 1977

POWER CLASS	WIND SPEED
1	9.8 mph
2	11.5
3	12.5
4	13.4
5	14.3
6	15.7
7	21.1

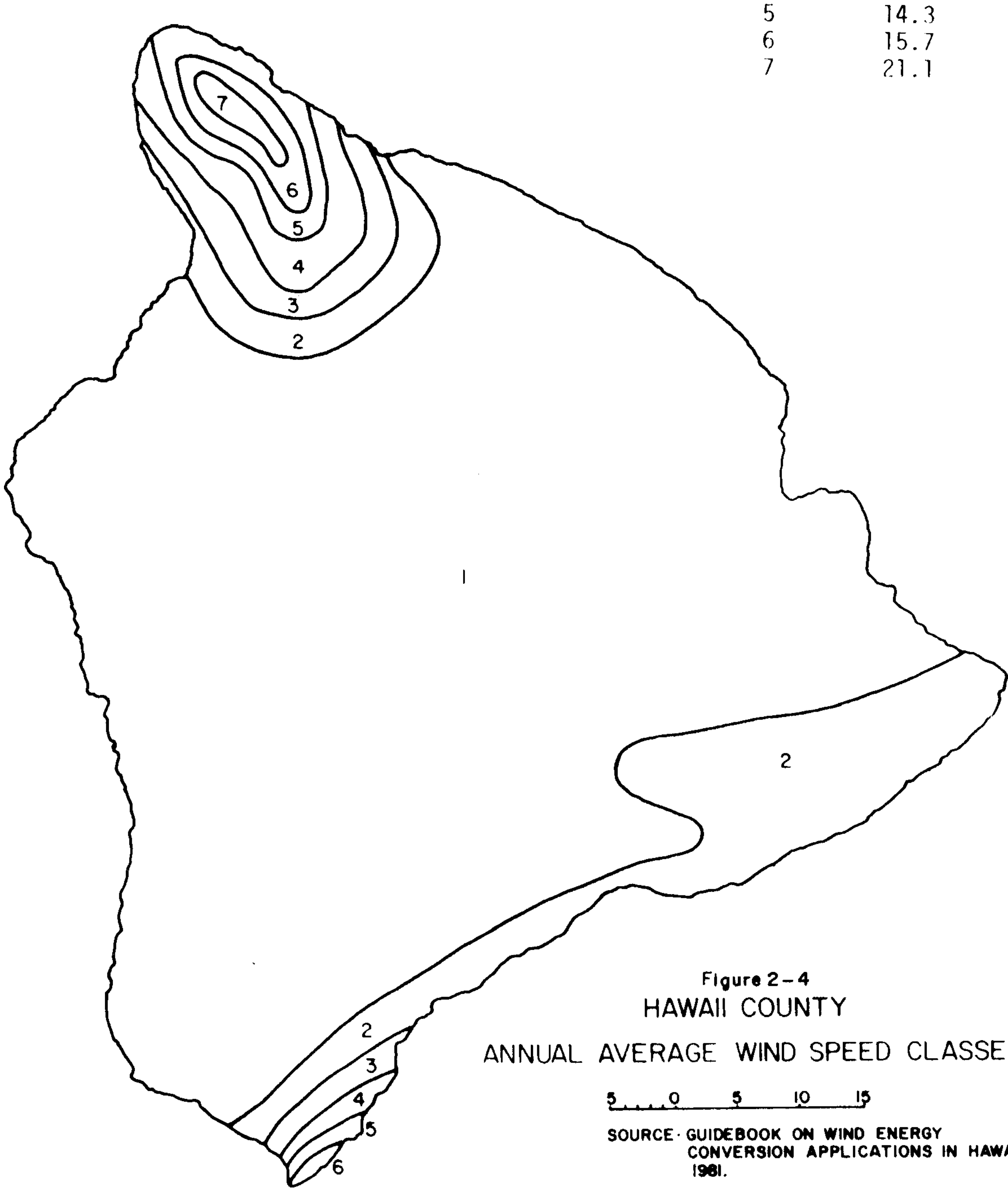


Figure 2-4
HAWAII COUNTY
ANNUAL AVERAGE WIND SPEED CLASSES

5 0 5 10 15

SOURCE · GUIDEBOOK ON WIND ENERGY CONVERSION APPLICATIONS IN HAWAII 1981.

Section 3
SOILS
Description of Soils and Their Recommended Fertilization for Leucaena and Eucalyptus Growth

H. Ikawa, Y.N. Tamimi, H.B. Wood

Three sites with a combined area of as much as 70,000 acres have been proposed for the establishment of leucaena and eucalyptus energy tree plantations on the Island of Hawaii. This section identifies the environmental and soil requirements of the species selected, describes the soils at the sites, suggests fertilization practices, and comments on the possible degradation of the land because of this use.

REQUIREMENTS OF LEUCAENA AND EUCALYPTUS

Determination of the suitability of soil or land for a crop demands some knowledge of the environmental and growth requirements of the crop, as well as the characteristics of the soil or land. For the assessment of suitability of land, performance data such as the site index, biomass yield, and volume of wood chips also are needed. The environmental and growth requirements of the leucaena and eucalyptus are presented in Table 1-1. Performance data, however, are lacking and should be added as they become available.

DESCRIPTION OF SOILS

The soils of interest in this study are classified mainly as Andepts (volcanic ash soils) or as soils having some influence of volcanic ash. Most of them are weathered to such an extent that they are acid and low in nutrients, especially those in areas of high rainfall. The classification of the soils of the study sites, according to Soil Taxonomy (SCS, 1975), is listed in Table 3-1. The approximate acreages of these soils are further tabulated in Table 3-2 and their location and distribution are shown in Figures 3-1 and 3-2.

The soils of the lower slopes (0 to approximately 2,000 ft elevation) of the Kapa'au site are mapped in high intensity, while those of the upper slopes of that area and the other sites are mapped primarily in low intensity. Thus, approximately 75 percent of the proposed sites are mapped in low intensity or reconnaissance soil survey. More soils information, however, is needed to implement the project and manage the sites, and eventually a detailed soil survey, an on-site investigation, must be made.

KAPA'AU SITE

At Site 1, Kapa'au, seven dominant soil series occur in a climosequence, where the rainfall increases up to approximately the 3,000 ft elevation and then decreases above that elevation

Table 3-1: Classification of the Soils of Kapa'au, Kuka'iau, and Pua'akala Sites[1]

Site	Soil Series	Subgroup and Family
Kapa'au	Kohala	Ustic Humitropepts, very-fine, mixed, isohyperthermic
	Ainakea	Andic Ustic Humitropepts, fine, oxidic, isohyperthermic
	Niulii	Hydric Dystrandepts, thixotropic, isothermic
	Kehena	Aeric Andaquepts, thixotropic, acid, isothermic
	Palapalai	Typic Eutrandepts, medial, isothermic
	Kahua	Typic, Placandepts, thixotropic, isomesic
	Manahaa	Hydric Dystrandepts, thixotropic, isomesic
Kuka'iau	Honokaa	Typic Hydrandepts, thicotropic, isothermic
	Maile	Hydric Dystrandepts, thixotropic, isomesic
	Umikoa	Typic Dystrandepts, medial, isomesic
	Hanipoe	Typic Dystrandepts, medial, isomesic
	Apakuie	Umbric Vitrandepts, medial, isomesic
Pua'akala	Piihonua	Typic Hydrandepts, thixotropic, isomesic
	Puu Oo	Hydric Dystrandepts, thixotropic, isomesic
	Laumaia	Typic Dystrandepts, medial, isomesic
	Lalaau	Typic Tropofolists, euic, isomesic
	Kahaluu	Lithic Tropofolists, euic, isomesic
	Mawae	Typic Tropofolists, euic, isomesic
	Kekake	Lithic Tropofolists, dysic, isomesic

[1]Adapted from Beinroth, Ikawa, and Uehara (1979).

Table 3-2: Approximate Acreage of Land in the Kapa'au, Kuka'iau, and Pua'akala Sites[1]

Site	Soil series	Intensity of survey	Soil series area	Associated rough broken land
			---------(approx. acres)---------	
Kapa'au	Kohala	high	6000	1200
	Ainakea	high	7000	2300
	Niulii	high	2800	600
	Kehena	low	3000	--
	Palapalai	low	3000	--
	Kahua	low	1800	--
	Manahaa	low	1300	--
Kuka'iau	Honokaa	low	200	--
	Maile	low	8200	--
	Umikoa	low	8400	--
	Hanipoe	low	9600	--
	Apakuile	low	4200	2600[2]
Pua'akala	Piihonua	low	6200	--
	Puu Oo	low	9300	--
	Laumaia	low	1400	--
	Mawae-Kahaluu-Lalaau association	reconnaissance	3100	--

[1]Adapted from Sato et al. (1973).

[2]Lava flows, aa.

(Figure 3-1). There is also a decrease in soil temperature with increasing elevation.

The taxonomic names (Table 3-1) show that the Kohala and Ainakea soil series are Tropets (Inceptisols other than volcanic ash soils), have an ustic moisture regime (the soils are dry for more than 90 cumulative days but less than 180 days), and have a mean annual soil temperature of 70°F or above. The Niulii, Palapalai, Kahua, and Manahaa series are Andepts (volcanic ash soils), and the Kehena series is an Aquept (Inceptisol with somewhat poor drainage and some influence of volcanic ash).

The matching of the tree crop requirements (Table 1-1) and the soil characteristics (Table 3-3) suggests that leucaena is adapted to the warm and somewhat dry Kohala series with a near-neutral pH but not adapted to the others because of either acidity, too low temperatures, or both.

Eucalyptus, on the other hand, appears to be well suited to the Ainakea, Niulii, and Manahaa series. It is moderately well suited to the Palapalai and Kehena series, even though the Palapalai series has low soil moisture content, and the Kehena series has somewhat poor drainage. It is not suited to the Kahua series because this series has a placic horizon (thin cemented iron pan) which may impede root distribution and also contribute to the poor drainage of this soil.

Compared to the other sites, many soils of the Kapa'au site are generally not as well-suited for biomass production because of their limitations mentioned above, the shallowness of soils to the bedrock, and the prevalence of strong winds in sections of Kapa'au.

KUKA'IAU SITE

Examination of the soil map for this site shows that the dominant map units belong to four series: Maile, Umikoa, Hanipoe, and Apakuie. Also included are small areas of the Honokaa soil series at the lower elevation. Information relating to the environmental and land features are listed in Table 3-4, and the location of the various soils are given in Figure 3-2.

In the Kuka'iau site, the Honokaa series and the four other soils occur in a climosequence of increasing elevation and decreasing rainfall. Because of the increase in elevation, there is also a decrease in soil temperature going from the Honokaa series at the lowest elevation to the Apakuie series at the highest elevation. The Honokaa and Maile soil series have a high moisture content and are thixotropic; they can change from a gel-like phase to an almost liquid phase with a sudden application of physical force. Thixotropic characteristics are associated with phosphate

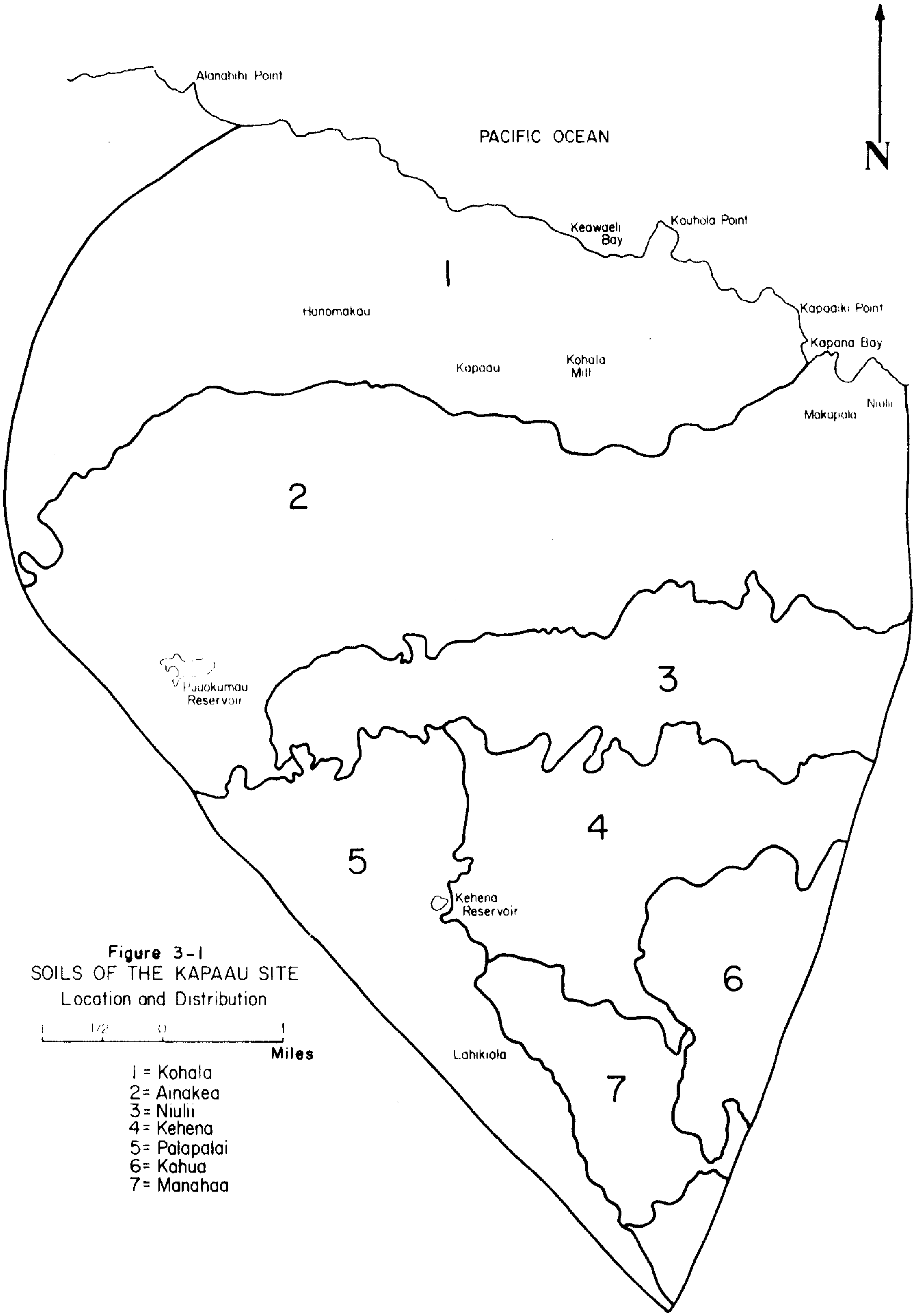


Figure 3-1
SOILS OF THE KAPAAU SITE
Location and Distribution

1 = Kohala
2= Ainakea
3= Niulii
4= Kehena
5= Palapalai
6= Kahua
7= Manahaa

Table 3-3: Environmental and Land Features of the Soils of the Kapa'au Site[1]

Soil series	Elevation (ft)	Rainfall (in)	Soil temperature (°F)	Depth to bedrock (ft)	Soil texture	Drainage	Soil pH	Slope (%)	Erosion hazard[2]
Kohala	0-1500	40-60	72-74	3½-8	silty clay	well-drained	6.1-7.3	0-3,3-12 12-20,20-35	mod.
Ainakea	0-1800	60-90	68-71	2-3½	silty clay loam	well-drained	<4.5-6.0	3-12,20-35	low
Niulii	600-2000	80-100	69-72	1½-3½	silty clay loam	well-drained	4.5-6.0	6-12,12-20 20-35	low
Kehena	1700-2500	100-150	66-68	1½-4	silty clay loam	somewhat poorly drained	4.5-5.5	6-12	low
Palapalai	3000-3500	40-90	62-65	4-6	silt loam	well-drained	6.1-7.3	6-12	mod.
Kahua	3500-4000	60-100	58	3½-5	silty clay loam	somewhat poorly drained	4.5-5.5	6-12	low
Manahaa	3500-5000	50-80	56-59	1½-3½	silt loam	well-drained	6.1-6.5	6-20	low

[1]Adapted from Sato, et al. (1973).

[2]Adapted from SCS (1981).

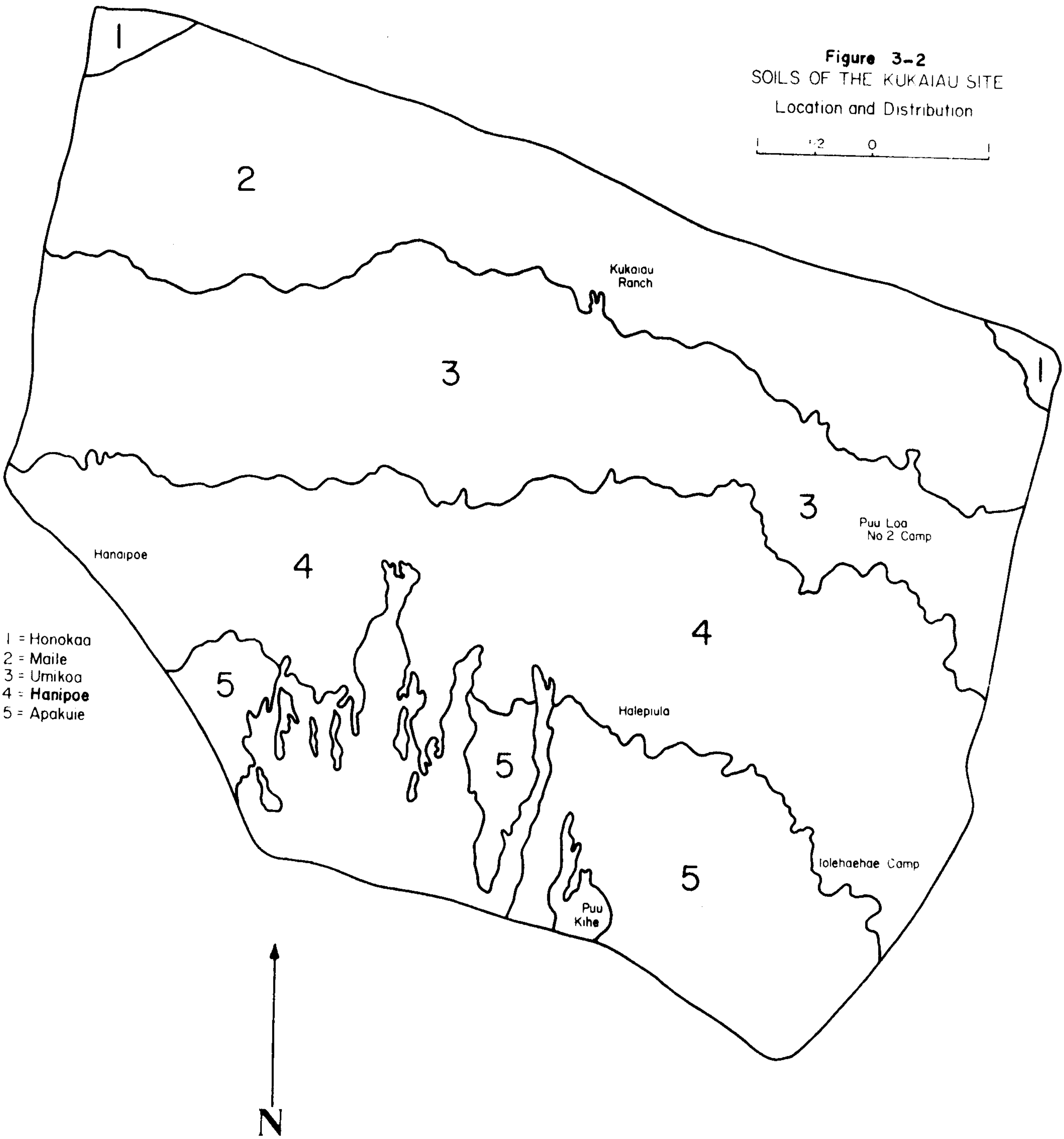


Figure 3-2
SOILS OF THE KUKAIAU SITE
Location and Distribution
1/2
0
1
2
3
4
5
Kukaiau Ranch
Puu Loa No 2 Camp
Hanaipoe
Halepiula
Iolehaehae Camp
Puu Kihe
1 = Honokaa
2 = Maile
3 = Umikoa
4 = Hanipoe
5 = Apakuie
N

Table 3-4: Environmental and Land Features of the Soils of the Kuka'iau Site[1]

Soil series	Elevation (ft)	Rainfall (in)	Soil temperature (°F)	Depth of bedrock (ft)	Soil texture	Drainage	Soil pH	Slope (%)	Erosion hazard[2]
Honokaa	1000-3000	100-150	66-69	3½-6	silty clay loam	well-drained	5.6-6.5	10-20, 20-35	low
Maile	2500-4000	60-90	57-59	5-7	silt loam	well-drained	5.6-6.5	0-3, 6-20	mod.
Umikoa	3500-5000	40-65	55-58	3½-6	silt loam	well-drained	5.6-6.5	12-20	mod.
Hanipoe	5000-6500	30-50	50-53	1½-6	silt loam	well-drained	6.1-7.3	6-20, 12-20	mod.
Apakuie	5000-8000	20-35	50-53	2½-5	very fine sandy loam	well-drained	6.6-7.3	12-20	high

[1]Adapted from Sato, et al. (1973).

[2]Adapted from SCS (1981).

retention, smeariness, and certain limitations in physical properties, particularly trafficability. The Umikoa and Hanipoe series, on the other hand, have lower moisture content and are not thixotropic. All four series have low bulk density and low or moderate base saturation.

Although the Apakuie series also has a low bulk density, is less weathered, and possesses more nutrient elements than the others, its lower soil moisture content (lower mean annual rainfall) limits good plant growth. The temperature of the Honokaa series ranges from 66^{o} to $69^{o}F$ (isothermic temperature class) while that of the others ranges from 50^{o} to $59^{o}F$ (isomesic temperature class).

When the soil and site attributes (Tables 3-1 and 3-4) are compared with the environmental and growth requirements of the four species in Table 1-1, the matching indicates that leucaena is not adapted to the Kuka'iau site.

Assuming that the requirements of E. saligna and E. grandis are fairly similar, they both are suited to all soils at the Kuka'iau site, except those of the Apakuie series with a low moisture content and/or marginal rainfall. E. globulus also is suited to most of the soils at the Kuka'iau site, especially those at higher elevations.

PUA'AKALA SITE

The dominant soils of the Pua'akala site are Andepts and Tropofolists with isomesic soil temperatures (Figure 3-3). Tropofolists are shallow Histosols, organic soils underlain by either pahoehoe or aa lava rocks. The soils at this site have slopes ranging from 6 to 12 percent normally, but can be as much as 20 percent. The soil moisture decreases in sequence from the Piihonua soil series at the lowest elevation, then to the Puu Oo, and finally to the Laumaia series at the highest elevation. Only Piihonua and Puu Oo are thixotropic.

Approximately 3,000 acres of the southernmost portion of the Pua'akala site are occupied by Tropofolists (Mawae, Kahaluu, Lalaau, and Kekake—all extremely stony or rocky muck). According to a 1973 reconnaissance soil survey, approximately 30 to 40 percent of the Tropofolists are Lithic Tropofolists (Histosols with pahoehoe substratum) and limit tree growth because of their shallow depths and poor tree footholds. The others are Typic Tropofolists (Histosols with aa substratum) and have less limitations but do not have the characteristics of the Andepts and other mineral soils. The nutrient status is generally low in these Histosols, thus rapid tree growth in these soils requires frequent application of fertilizers.

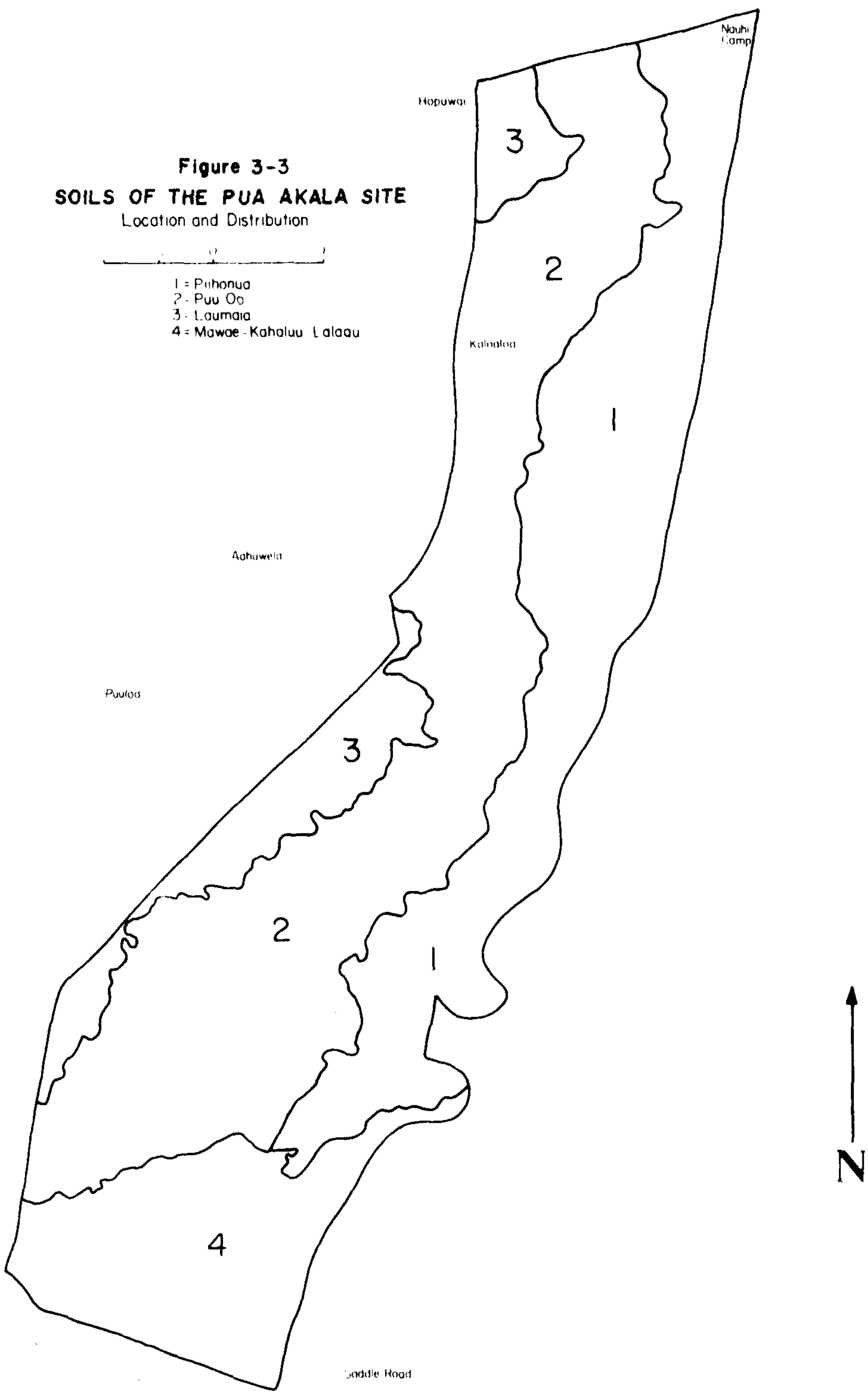


Figure 3-3
SOILS OF THE PUA AKALA SITE
Location and Distribution

Table 3-5: Environmental and Land Features of the Soils of Pua'akala Site[1]

Soil series	Elevation (ft)	Rainfall (in)	Soil temperature (°F)	Depth to bedrock (ft)	Soil texture	Drainage	Soil pH	Slope (%)	Erosion hazard[2]
Piihonua	4500-6500	90-150	55-58	3½-6	silty clay loam	well-drained	<4.5-5.5	6-20	low
Puu Oo	6000-6500	65-100	53-56	3½-6	silt loam	well-drained	<4.5-5.5	6-12	mod.
Laumaia	5500-6500	35-70	52-54	3-6	silt loam	well-drained	5.1-6.0	6-20	mod.
Lalaau	3500-7000	90-150	56-59	< 1	stony muck	well-drained	4.5-5.0	6-20	low
Kahaluu	3500-7000	90-150	55-57	< 1	rocky muck	well-drained	4.5-5.0	6-20	low
Mawae	3500-7000	50-80	53-55	< 1	stony muck	well-drained	6.6-7.3	6-20	low
Kekake	3500-7000	50-80	52-55	< 1	rocky muck	well-drained	5.1-5.5	6-20	low

[1] Adapted from Sato, et al. (1973).

[2] Adapted from SCS (1981).

According to Tables 1-1 and 3-5, leucaena is not adapted to these soils because it requires a drier and warmer soil climate and a neutral to alkaline soil pH. Eucalyptus, however, is well suited to these soils, but the extremely stony or rocky surfaces of the Andepts and the Tropofolists may present some limitations, even to it.

RECOMMENDATION FOR FERTILIZER

In general, soils that are classified as Hydrandepts and Dystrandepts (Table 3-1) require applications of lime and more fertilizer than soils such as the Eutrandepts. Lime and fertilizer recommendations, based on fertilizer trials with E. saligna in selected Hawaiian soils, are presented in Table 3-6. Time of fertilizer applications is presented through footnotes in the same table.

KAPA'AU SITE

Although there is a diversity of soils at the Kapa'au site, the general lime and fertilizer recommendations for these soils is 1 to 2 tons of $CaCO_3$/acre, 200 pounds of urea/acre/year, 150 pounds of muriate of potash/acre, and 250 pounds of treble superphosphate/acre. The phosphate and potash will be applied once, six months after planting, and once for each coppice crop. No lime is required for the Palapalai series and only 1 ton lime/acre is recommended for the Kohala series. Also, the fertilizer application in the Palapalai series is 200 pounds of urea/acre/year, with no phosphate or potash required.

At initial planting, 100 lb of 14-14-14 fertilizer/acre is recommended in a band width of about 6 inches.

KUKA'IAU

For the lower elevation soils, Honokaa and Maile, an application of 1 to 2 tons of lime (crushed coral)/acre is recommended prior to planting. In addition, 200 lb of urea/acre and 250 lb of treble superphosphate/acre are to be applied once for every rotation at the early stages of growth of the plant crop or the coppice. In most areas, application of potash may not be necessary.

For the Umikoa, Hanipoe, and Apakuie soil series, no lime is recommended. Fertilization is limited to a nitrogen fertilizer, such as urea, with applications of 200 lb/acre for Umikoa, 150 lb/acre for Hanipoe, and 100 lb/acre for Apakuie.

For all soils at this site, complete fertilizer 14-14-14 is to be applied at the initial planting in band width of about 6 inches along planting lines at a rate equivalent to 100 lb/acre.

PUA'AKALA SITE

No lime is recommended for the Laumaia series, but 1 to 2 tons of $CaCO_3$ are recommended for the Piihonua and Puu Oo series. Fertilizer recommendations call for 150 lb of urea/acre/year, 250 lb of treble superphosphate/acre, and 100 lb of muriate of potash/acre for the Laumaia series. The recommendations are 200 lb of urea/acre/year, 250 lb of treble superphosphate/acre, and 150 lb of muriate of potash/acre in the Piihonua and Puu Oo soil series.

Again, as recommended for the soils at the other sites, the initial application at planting time is 100 lb of 14-14-14 fertilizer/acre in band width of about 6 inches.

SOIL AND LAND DEGRADATION

Because most of the soils are situated on uplands with slopes ranging normally from 6 to 12 percent and as much as 20 percent, and because of the moderate to high amounts and intensities of rainfall, the removal of existing vegetation during land preparation and during the harvesting of the tree crops may lead to undesirable land degradation and erosion. Soil compaction of the sites may also be a problem and may lead to restricted root growth as well as to increased water runoff and soil erosion.

As mentioned in Section 6, however, no attempt will be made to remove the vegetation completely from the planting areas. The use of pasture grasses or residual sugarcane is further recommended. Tree production is based on staggered block planting and harvesting. Because the second and third rotations are by coppicing, it is expected that the degradation effects of land preparation will be kept to a minimum during rotation.

Proper construction and design of roads are also very important in erosion control and the recommendations presented for roads, again in Section 6, must be followed. Furthermore, the prevailing practices of the sugar plantations operating on similar lands must be consulted; for example, field operations could be suspended during periods of excessive rainfall, and the appropriate-sized-tractors or equipment with flotation tracks can be used, especially in areas with thixotropic soils. Studies have shown that when very heavy equipment is fitted with tracks rather than rubber tires, soil compaction and compressibility can be minimized, especially in thixotropic soils.

Further advice of the Soil Conservation Service, USDA, should be obtained before building structures such as terraces and diversion ditches, or initiating other soil conservation practices.

Removal of most of the above-ground biomass (stems, branches, and leaves) during harvest operation precludes the recycling of certain nutrients. Thus, after each harvest, the recommended fertilization given in Table 3-5 should be followed. Because the actual amounts of the "lost" nutrients are unknown at this time, modification to the fertilization program should be made as more research results on nutrient removal and addition are obtained.

Water repellent surface soils exist now in areas planted in eucalyptus. Studies should be pursued to determine the role of water repellent soils on water infiltration, percolation, and other physical properties of the soils.

Table 3-6: Recommended Fertilizers and Fertilization Schedule

			Fertilizer			
		Pre-Establishment	Establishment[1]	Maintenance		
Site	Soil Series	Crushed coral	14-14-14 ($N-P_2O_5-K_2O$)	Urea[2]	TSP[3]	Muriate of potash[3]
		(tons/acre)	(lb/acre)	(lb/acre/year)		
Kapa'au	Kohala	1	100	200[4]	250	150
	Ainakea	1-2	100	200	250	150
	Niulii	1-2	100	200	250	150
	Kehena	1-2	100	200	250	150
	Palapalai	0	100	200	0	0
	Kahua	1-2	100	200	250	150
	Manahaa	1-2	100	200	250	150
Kuka'iau	Honokaa	1-2	100	200	250	0
	Maile	1-2	100	200	250	0
	Umikoa	0	100	200	0	0
	Hanipoe	0	100	150	0	0
	Apakuie	0	100	100	0	0
Pua'akala	Piihonua	1-2	100	200	250	150
	Puu Oo	1-2	100	200	250	150
	Laumaia	0	100	150	250	150

[1]Fertilized in 6-inch bands.

[2]Urea (45-56 % N); first application 6 months after establishment; two additional applications at 12 months and 18 months, each application 100 lb/acre.

[3]Treble superphosphate (46% P_2O_5) and muriate of potash (60-62% K_2O), respectively; application after 6 months and at beginning of each rotation.

[4]Nitrogen fertilizer will be deleted if leucaena is planted on Kohala soil series (i.e., below 1000 ft.).

Source: Y.N. Tamimi

Section 4

SOCIAL AND BIOLOGICAL ENVIRONMENT

Impacts and Effects of a Nursery and Tree Plantations

P. Canan, S. Siegel, J. Melrose*

This section assesses the environmental (social and biological) impact of establishing and operating a tree nursery and several plantations at designated sites on the Island of Hawaii (Section 2). The creation of a nursery capable of supplying 10 million seedlings annually, and the laying out, planting, and harvesting of more than 45,000 acres of biomass plantation are the activities considered.

SOCIAL

An assessment of social effects and impacts can be made for each community by using an already developed model (Figure 4-1). Social effects will be either primary (employment and population changes), or secondary (community services and facilities, social structure, social well-being). Only primary effects are predicted here because further study and analysis are required for the other.

VALUES, INTERESTS, AND ATTITUDES

For the purposes of this preliminary study, expressions of community intent found in recent planning documents were used as indications of existing community values, interests, and attitudes. Three relevant county planning documents Hawaii County General Plan, 1971, Northeast Hawaii Community Development Plan, 1979, Honoka'a Urban Design Plan and four unadopted planning drafts—Kohala Community Development Plan, Laupahoehoe Rural Design Plan, Waimea Design Plan, Hawi-Kapa'au Design Plan—were reviewed.

The Hawaii County General Plan lists three major goals: development of an economic system that provides residents with opportunities to improve the quality of life; orderly economic development and improvement in balance with the physical and social environments; and economic stability.

Community development and urban design plans express similar desires, but address county planning issues on a regional basis, attempting to integrate County General Plan goals and objectives into more specifically defined regional/community units. Most plans list jobs and diversified agriculture as desirable, and the biomass plantation seems to fulfill both of these. There could be debate, however, about how diverse tree and sugar plantations are from one another, especially as preceived by the community.

There has been repeated expression of community concern for the preservation of existing native forests. A public survey, 1975, indicated that the residents value and wish to protect the environment in which they live. When asked to choose one priority item, 32.8 percent of the respondents indicated the need "to preserve natural beauty and control pollution." This was the number two response, following "economic development and new jobs."

Most of the plans express concern over the redistribution of housing, a circumstance closely connected with the future of the sugar industry. Honoka'a, Papa'aloa, and Laupahoehoe, for example, may have a surplus of housing units soon, but these could be filled if and when nursery and plantation operations begin for this project. Public services on the Hamakua Coast are generally adequate, and in some areas like Laupahoehoe, educational and recreational facilities can accommodate more patrons. Likewise, the Honoka'a hospital is underutilized. Emergency and fire protection services in this area are deficient, however, and pressure to supply these services may be increased by the initiation of the project.

The Waimea area, a likely location for a synthetic fuels plant (not addressed in this report), is already changing and growing. According to the design plan, the town of Waimea sees itself as a ranch town with a valued rural ambiance. It is also becoming an increasingly valuable place to own land and an attractive location for new, often wealthy, residents. Any industrial development, therefore, will probably be greeted coldly by some members of the community. An additional concern in Waimea is the availability of water for new development; any large use of water will compete with existing residential and agricultural uses.

PRIMARY SOCIAL EFFECTS

Although the site of the processing plant has not yet been determined, it has been suggested that it be located on the Mana Road, far enough away from the town of Waimea to be minimally obtrusive. The chipping machinery used in harvesting is noisy: more than 90 decibels, 1000-2000 hZ, at close range. If, however, chipping occurs in the field only during weekday daylight hours, the community will not be adversely affected by the noise. If the chips are transported to the plant on a 24-hour/day schedule, though, as is being planned, truck traffic around Waimea will be significant.

Plantation Site I, Kapa'au, is close to residential areas and the operations would be visible to the community, eventually becoming part of their daily lives. Site II (Kuka'iau) and Site III (Pua'akala), on the other hand, are located far enough from existing settlements so that the communities would suffer little from plantation activities, but would still gain in employment opportunities.

Figure 4-1:

General Social Impact Assessment And Management Model

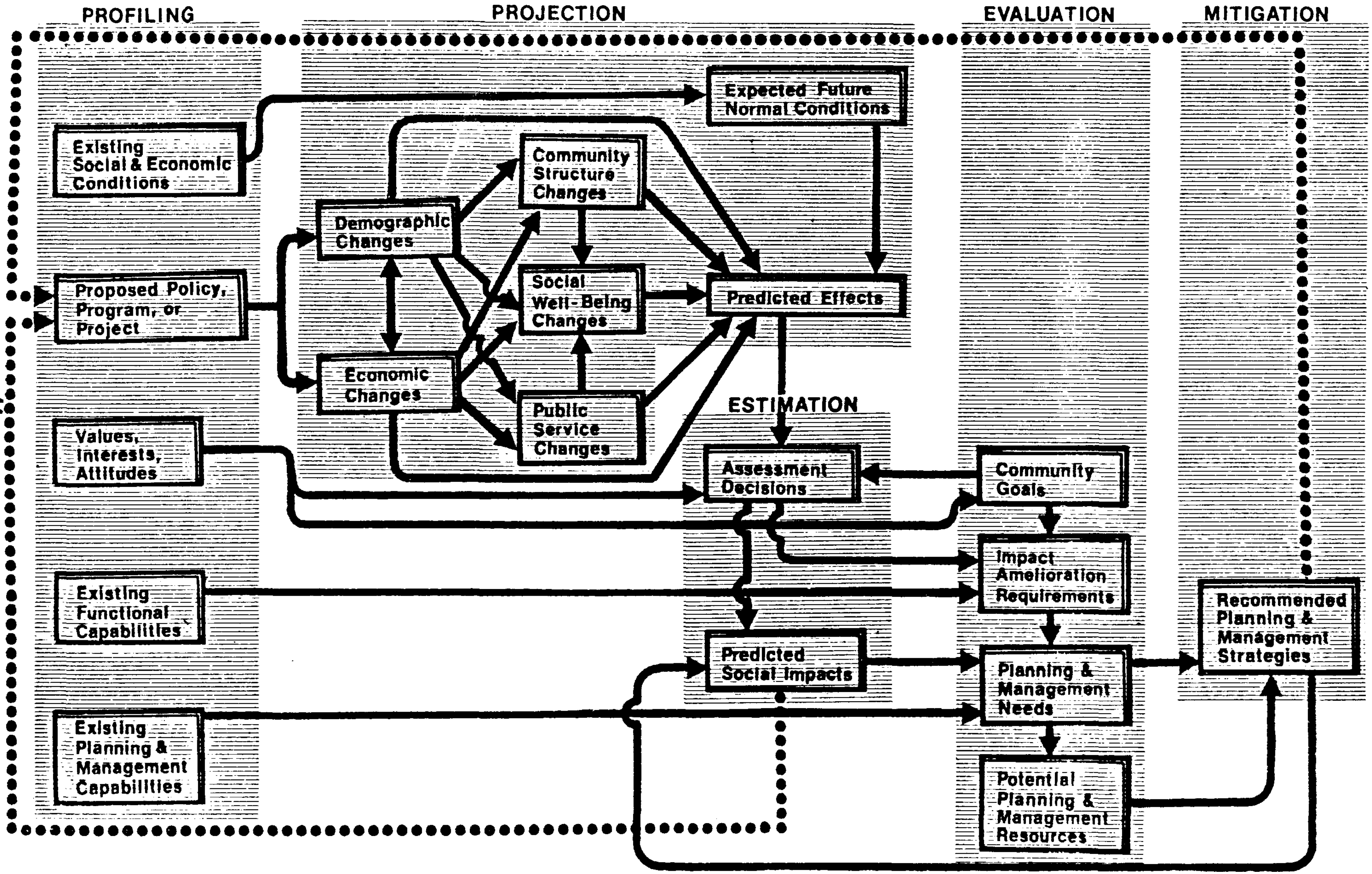


TABLE 4-1: RECENT HISTORY, LAND USE, AND SOCIAL IMPLICATIONS OF BIOMASS PRODUCTION FOR IMPACTED DISTRICTS

District	Recent History	Present Land Acreage and Use	Project Activities	Possible Social Effects
North Kohala Hawi Kapa'au Halaula Makapala Niuli (Census Tract 218)	Historically isolated sugar community Plantation closed 1975 Economic depression New jobs developing as a result of South Kohala tourist industry development Population growth from 1970 to 1980, +8.8% 1980 population: 3,620	Total acres: 79,593 Ex-sugar lands now in pasture Macadamia nuts Aquaculture Residential	Planting Maintenance Harvesting Forestry operations: planting maintenance harvesting chipping Heavy trucking	New jobs in biomass production Noise, dust, and increased traffic Loss of land for alternative agricultural/grazing purposes Daily contact with tree plantation operations Existing public services utilized
South Kohala Waimea Kawaihae (Census Tract 217)	Ranching town Developing business/commercial center of North Hawaii Hawaiian Homesteads Population growth from 1970 to 1980, 99.4% 1980 population: 4,607 Limited water availability Major resort development on west coast Deep draft harbor facility at Kawaihae underutilized	Total acres: 171,219 Cattle grazing Residential Diversified agriculture Resort development Commercial	Planting Maintenance Harvesting Heavy trucking	New jobs in biomass production and processing Increased business activity Continued population growth Increased truck traffic and noise Increased utilization of public services
Hamakua/ North Hilo Pa'auilo Kukuihaele Honokaa Laupahoehoe Papaaloa Ookala (Census Tract 219-221)	Sugar communities Decreased employment due to mechanization Cattle raising in mauka regions Intermittent forestry and macadamia nut production, operations Population growth from 1970 to 1980, 4.5% 1980 population: 6,825	Total acres: 570,185 Sugar Macadamia nuts Pasture State forests Residentia;	Nursery operations Forestry operations in remote areas i.e., planting, maintenance, harvesting, chipping, and transportation	New jobs in biomass production Increased business activities Population increase Existing public services utilized

In general, the project is expected to improve the employment situation of the island (6.7 percent unemployment, 1980) without requiring drastic shifts in occupational skills. The employment increase will be both direct and indirect and will vary in each community. Both the North and South Kohala regions, for instance, face population increases caused by tourism and related development. While a biomass plantation would probably be acceptable to local residents now, resort growth may eventually absorb the available labor, causing a shortage of workers in the area. That means that the comulative social impacts of two sources of rapid change need to be considered.

Direct Employment

As presented in Figure 4-2, approximately 90 employees will be required for the first 6 years of the project, increasing sharply to about 330 for the duration of the project, an additional 18 years. The increase will be caused by harvesting and plantation needs beginning in the 6th year.

Only nursery operations, requiring relatively few employees, will experience major cyclical variations: 50 percent of the lesser skilled workers will be laid off by the 7th year and a full complement of personnel will be required again at year 18. If opportunities for using the nursery and personnel for other purposes during this 12 year period are found, the potential problem would cease to exist.

Security guards, some repair shop personnel, and chip hauling crews probably will work in round-the-clock shifts. Most other jobs will be carried out on a regular 5-day work week. The similiarity of agricultural work in this project with that of the sugar and pineapple industry suggests pressure from organized labor to secure comparable working conditions.

Indirect Employment

Using a standard multiplier of 1.4 jobs created for each project job, there will be an additional 216 jobs available for years 1-6, and 792 for the years thereafter. The major employment stimulation in the early years, obviously will be around the nursery, and increased employment opportunities in the plantation harvesting years will probably be in the coastal communities of the Hamakua District.

Since different socio-demographic groups usually generate different economic multipliers because of differing propensities to save, varying purchasing patterns, and differing loss of transfer payment effects; a more integral approach to allocating jobs to various demographic cohorts

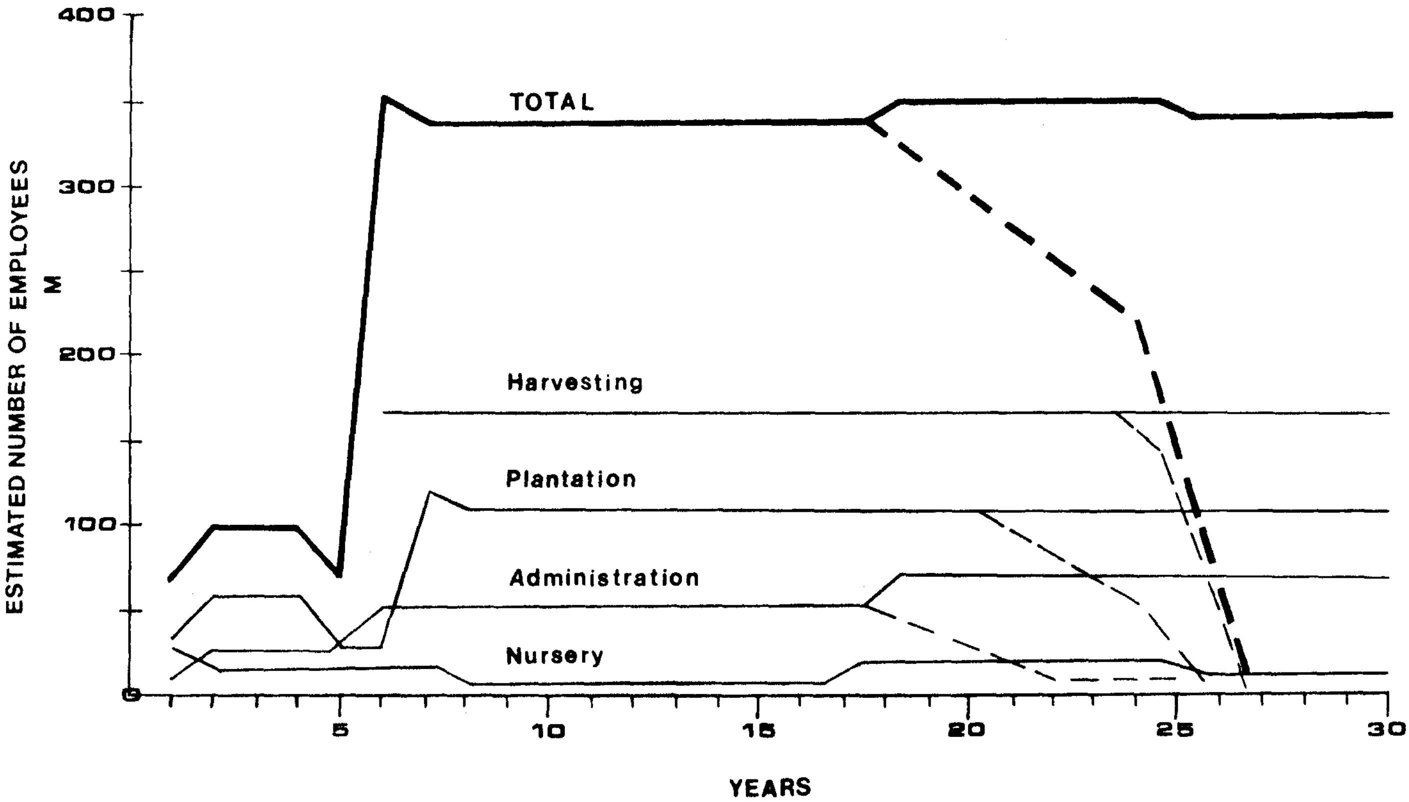
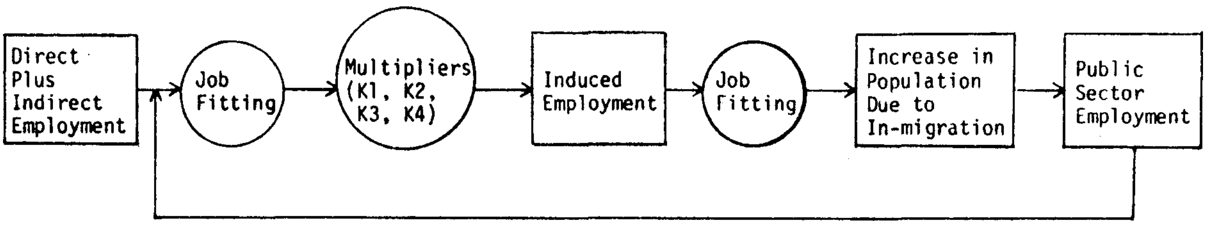


Figure 4-2 : ESTIMATED DIRECT EMPLOYMENT BY PROCESS & PHASE
(dotted line indicates potential shutdown if plantation is not replanted)

within the community is suggested. The multiplier process should be more finely tuned with an analysis of the induced employment and jobs and opportunities that subsequently develop. One such approach developed by Davis and Webster (1980) is represented in Figure 4-3.

Figure 4-3. A Compositional Approach to Socio-economic Impact Analysis



Source: H. Davis and D. Webster, "A Compositional Approach to Regional Socio-economic Impact Assessment" Socio. Econ. Plan. Sci. 15:159-163 (1981).

PRIMARY SOCIAL IMPACTS

Community Participation

Major barriers to developments often stem from outsiders' lack of knowledge of and sensitivity to local conditions combined with the developers' propensity to by-pass residents during the planning stage. Therefore, assessment of local conditions and residents' opinions of the project are essential. In fact, the social impacts, the subjective evaluations of the consequences, require public input by definition. Evaluation by the residents themselves will assist in the development of a mediation strategy for addressing community concerns.

We may suggest that positive recruitment and training programs become part of this project, thereby avoiding the inequitable stratification of laborers along ethnic lines that has characterized plantation work in the past. Recruitment and training programs would also insure that workers in the area have opportunities for employment, thus lessening the need to bring in outsiders. The "boom-bust" syndrome, experienced in the Kohala area when sugar plantations shut down, is a possibility with this endeavor as well. Frankness about this possibility is essential so that residents may plan for their economic livelihood should one project be discontinued after one generation. Additionally, a tree plantation would represent the substitition of a single economic base for another and may not be the diversification residents desire.

Summary

In spite of some increases in noise, traffic, and population, it is predicted that the social effects will be mainly positive, especially if the community is involved with the planning. A summary of the social implications of biomass production for the region is presented in Table 4-2.

Table 4-2: Significant Primary Social Effects

1. Increase in labor demands compatible with local skills.

2. Opportunity to pursue active training programs such that past inequitable ethnic stratification of plantation labor need not be repeated.

3. Additional jobs created by indirect and induced employment.

4. Increase in heavy truck traffic.

5. Population increases requiring planning for pace and style of community development in harmony with residents' values.

6. Opportunity to enhance nearby residents' ability to fulfill labor requirements, reducing the need to import labor.

7. Opportunity to plan ahead for possible biomass plantation shutdown.

8. Opportunity to involve residents and community organizations in development planning and mitigation of undesirable social effects.

PHYSICAL

This assessment of physical impacts and effects on the environment of a tree nursery and plantation includes evaluations of air, soil, and water quality. No adverse impacts are anticipated during any phase of the project, but careful and continued monitoring are recommended as protective measures.

NURSERY

One reason nursery establishment and operation can be considered environmentally benign is that all activities are done on a small scale. Even potential problems caused by this smallness are easily avoided. Over-shooting during spraying, for example, can be controlled by establishing a safe zone around the nursery that is either kept clear of vegetation through mechanical means or planted with herbicide resistant ground cover. Throughout nursery operations, pesticide applications should be highly site specific. If any concern about pesticides entering the ground water system and changing the water chemistry exists, a run off collection system could be developed to prevent any hazard whatsoever.

One other possible problem of the nursery operation is that elevated nutrient levels in the substratum (ground water and soil) caused by the use of fertilizers could stimulate the growth of certain weeds as well as the growth of trees in the area. Slow-release fertilizer, however, could mitigate such concerns by keeping nutrient levels at low concentrations.

A possible bio-ecological risk of the nursery operation is the upset of plant, bird, and wildlife habitats. Care must be taken to insure that there are no endangered species in the area.

Containment also can be a concern during nursery operations. No matter what plant is grown, if it is closely related to native species in the surrounding areas, gene flow can be a threat. A barren or sterile zone is indicated as a solution.

PLANTATION

During plantation site preparation, air problems caused by turbidity may arise as a result of dust or burning rubble. Turbidity caused by dust in the air is a possible problem during plantation operation also. The amount of dust can be minimized, however, through standard wetting down practices, and the period of rubbish burning can be kept short to eliminate any significant problems.

Erosion problems, possible at the Pua'akala site if at all, can be eliminated by shallow terracing.

During site preparation, no contamination of water quality is anticipated, but the introduction of pesticides into ground water may present a hazard during plantation maintenance. If readily bio-degradable products such as Sevin and Glyphosate are used, this hazard will be eliminated.

As with the nursery, fertilization may stimulate the growth of weeds and exotic plants which could eventually escape the plantation and cause problems in more sensitive surrounding areas. Fertilizer, then, should be spread with care to avoid an increased need for herbicides to control the resulting weed growth.

If there is a chance that endangered species of plants and animals can be harmed during nursery construction, there is even more of a chance of this during plantation site preparation and road building. Careful assessments of the areas will have to be made before site preparation.

HARVESTING

Major environmental impacts during harvesting will be created by the noise and dust of chipping and transporting. Dust can be abated by hosing or spraying, though, and the noise is primarily a workplace problem, likely to affect the local community per se only at the Kapa'au site, if at all. The noise level, however, should be monitored.

SPECIAL CONCERNS

Baseline

Open areas with a history of use as cane fields or pastures with some existing stands of eucalyptus, require no special attention. Ohi'a forest areas, however, should be left untouched and examined for rare, threatened, or endangered species. Gullies and small ravines often harbor native, relict forests, and are wetter, shadier, and quieter to some degree than patches on high ground. Therefore, they are the last habitates for rare birds, animals, and plants; they should be surveyed and inventoried prior to any operation in the vicinity.

Monitoring

The ground water monitoring program for pesticides and fertilizer contamination can be phased down to yearly testing after the first complete test series proves negative. If the results are positive, though, more careful surveillance is required. Any wells not drawing upon basal water should be tested for nitrate and pesticide organic chlorine.

Biomass Waste Disposal

Biomass waste should be recycled into the land to reduce somewhat the depletion of soil nutrients in nursery and plantation areas.

Possible Eucalyptus Problems

Drs. Otto and Isa Degener have called our attention recently to some aspects of eucalyptus tree farms which require attention. Fire resistance, the ability of eucalyptus to regenerate quickly after disasters, their flammable and toxic oils content, and frequent eucalyptus forest fires in Australia, New Zealand, and Tasmania were listed by the Degeners as being the undesirable aspects of wide-scale eucalyptus plantings.

Whether or not these concerns apply to the Big Island, and whether or not they should affect any decisions to plant eucalyptus tree farms have yet to be determined. Based on preliminary information, however, it is recommended that additional study be done, including research into the Big Island's eucalyptus fire history, provided large enough stands can be located.

*The authors would like especially to thank Mr. John Gilbert, East-West Center Resource Systems Institute, for his contribution.

Section 5
NURSERY
Establishment and Operation

R.G. Skolmen, T.D. King, H.H. Horiuchi

This section outlines the location, design, operation, and financial requirements of a nursery capable of supplying the seedlings needed to stock 7,800 acres of plantation per year at a rate of 1,210 trees per acre. This nursery would have to be in operation 5 to 6 months before tree planting could begin. During the first 6 years, the proposed energy tree planting will require over 10 million mixed tree seedlings per year. The nursery needed is about three times as large as the largest one existing in the state now.

LOCATION

The most important requirement of a large tree nursery is a constant, assured supply of water. The location near the lands to be planted that appears most suitable is in the vicinity of Honokaa. A well can be drilled there at reasonable cost and, in addition, seedlings will grow rapidly because of the warmer average temperature of the lower elevation. At the proposed nursery site, Ahualoa (elevation about 1,500 feet), it is currently possible to purchase suitable land at a reasonable cost.

DESIGN

It has been determined by numerous tests that the tube container nursery system is best for the tree species selected. The particular tube container system chosen governs the design and size of the entire nursery. Two possible tube systems, both in use now in Hawaii, were compared to determine their cost differences before selecting one.

The systems compared were the Leach Pine Cell and Leach Tray used by the BioEnergy Development Corporation and the Hawaii Dibbling Tube used by the Hawaii Division of Forestry and Wildlife. It has not been proven at this time, but it appears that the Dibbling Tube system produces eucalyptus seedlings that have a slightly higher survival potential than the Leach Cell system. This is largely because the seedlings are spaced more precisely to accommodate eucalyptus leaf area and the tube is larger, permitting a larger root mass.

Despite this, the Leach Pine Cell was chosen because of the considerably higher cost of using the Dibbling Tube system. Use of the Dibbling Tube system would require an additional acre of land, one additional greenhouse, higher priced pallets, and a larger irrigation system, resulting in a cost increase of about $95,000.

The nursery has been planned to have the capacity to produce 10.4 million ssedlings per year, more than enough to plant 7,800 acres per year at a rate of 1,210 trees per acre (6 ft x 6 ft spacing). It will be possible to hold seedlings in the nursery for up to 4 months in the event drought prevents planting.

The species grown will be Leucaena leucocephala, E. grandis, E. saligna, and E. globulus. The three eucalypts will be grown on the same schedule. The leucaena will have slightly shorter greenhouse and growth period requirements and will also require a modified seeding device. These are minor concerns that will not significantly affect the costs or procedures outlined here.

The physical plant will consist of a 7-acre, nearly level, rectangular land area containing the buildings and growing area. This fenced area will contain a 3-bedroom caretaker's home, an office/storage/lunchroom building, a headhouse used for container loading equipment and for storage, eight 40 ft x 120 ft steel-pipe framed greenhouses, a small pumphouse, a 4-acre paved, irrigated seedling growing/hardening space, and surrounding unpaved storage space. The fenceline area will be pleasantly landscaped and will have a dense windbreak of trees and shrubs on its windward sides. Water will be supplied by a well drilled on site, or alternatively by the County Water Board if a constant supply can be guaranteed.

There will be two 4 x 4 pickup trucks, one 2-1/2 ton flat-bed truck, one large tractor truck with a 9 ft x 9 ft x 30 ft van trailer, and two small forklifts.

The staff will consist of a manager, a supervisor, a nurseryman, a technician, a truck driver, an electrician/plumber, a clerk-typist, 2 forklift operators, 7 laborers, a caretaker who will live on site, and a night watchman. Employees will work normal 40-hour weeks except the electrician/plumber, who will work 6-hour days, and the caretaker, who will work weekends with days off during the week. Salaries and wages are based on those current for similar jobs in the Hilo area.

OPERATION

Seedlings will be grown in polyethylene tubes of rooting medium for periods of 4 to 5-1/2 months and then transported to the field for planting. This operation involves several steps: placing tubes in plastic trays (racks) for support, filling tubes with rooting medium, seeding the filled tubes, placing gravel on top of the seeds, placing the tubes in greenhouses for germination and early growth for 6 weeks, moving the tubes to an outdoor growing space for 3 to 4 months, hardening the seedlings for planting by withholding fertilizer, loading the seedlings with tubes and trays into a van, hauling to the field, and returning the empty tubes and trays to the nursery where they are sterilized and readied for the next crop. More specific details follow.

Seeds will be purchased from commercial sources at these approximate prices: Leucaena (8,000 seed/lb) $50/lb, E. saligna and E. grandis (1,000,000 seed/lb after cleaning and pelletizing) $110/lb, and E. globulus (300,000 clean seed/lb) $50/lb. E. saligna and E. grandis seed will be purchased in lots of 120 lb of uncleaned seed. They will be cleaned at the nursery and shipped to a pelletizing company. E. globulus will be purchased in one lot of 360 lb, and, because the seeds are large enough for mechanical seeding, they will be cleaned but not pelletized. A 6-year supply of seed will be stored in the refrigerator in sealed containers. The leucaena seeds will be scarified with sulfuric acid before sowing and the media for leucaena will be inoculated with rhizobia. Procedures for these processes are outlined in the HNEI publication, Giant Leucaena Energy Tree Farm, 1980.

A specially constructed flat filler and precision seeder, already manufactured by a few contractors, will be used for mixing planting medium, filling and compacting medium in the tubes, sowing seed, and covering the tubes in the trays with gravel. The medium used will be 2:1 vermiculite: peat. The filling and loading machine and its auxiliary equipment will be operated by 7 employees.

The Leach Pine Cells and Trays last about 3 years, so they will be completely replaced once during the first 6 years of operation. The tubes, including shipping, will cost $0.04 each and the trays $5.00. These prices are very nearly the same for the Hawaii Dibbling Tubes.

After loading and seeding, the trays of tubes will be placed on 4 ft x 4 ft wooden pallets (8 per pallet) and set out in the greenhouse by forklift trucks. The pallets will be supported on concrete blocks both in the greenhouse and later in the outdoor growing area and arranged in rows with 2 ft wide access aisles between them. An overhead irrigation system in the greenhouse will be used for both water and liquid fertilizer as needed. The greenhouses will be steel-pipe construction, roofed with "clear" Tedlar-coated polyester roofing, a material which transmits about 50 percent of ambient light. The seedlings will germinate and be kept in the greenhouse for 6 weeks.

After 6 weeks, the pallets of seedlings will be moved to the 4-acre seedling growing/hardening area where they will be set out in rows on concrete blocks as in the greenhouses. Irrigation and liquid fertilizer will be supplied by overhead sprinklers. Species will be separated so that they may receive different watering and fertilizing regimes. Solenoid valves and several fertilizer injection stations will be used to control the varying water and fertilizer requirements.

If tests now underway at the BioEnergy Development Corporation so indicate, it may be possible to mix fertilizer directly into the rooting medium in the amounts required for hardening-off; the fertilizer will be used up at the end of the growing period. Because growth in the outdoor area will vary throughout the year with ambient light, temperature, and rainfall, however, it is now safer to plan on the liquid fertilizer system which provides more effective control.

After approximately 4 months, hardened seedlings will be ready for planting. The pallets of seedlings will be carried by forklift to the van truck which will carry the seedlings to the field. The trailer will be a 9 ft x 9 ft x 30 ft van, specially constructed to hold up to 600 trays on shelves with space for 1 ft tall seedlings. Seedlings will be loaded (still in trays) by two men with the aid of the forklifts and will be removed by two men at the planting site.

Seedlings will be removed from the tubes by a crew at the planting site. It is hoped that a mechanical device can be developed to perform this time-consuming chore. Once the seedlings are removed, the tubes will be returned to the trays, and then to the van.

It is suggested that the seedlings be carried to the planting machine on polyethelene sheets in manageable size lots. When hand planting is done, the tubes can be kept on the roots until just before planting and later returned by the tree planters to a central location.

After they are returned to the nursery, the tubes, still in the trays, will be washed in a vat of 10 percent clorox, rinsed off with a hose, and returned to the headhouse for re-use in the next crop.

SCHEDULING

It is suggested that the nursery be started about 6-1/2 years before the synfuels plant so that planting can begin about 6 years before the plant requires a constant supply of biomass.

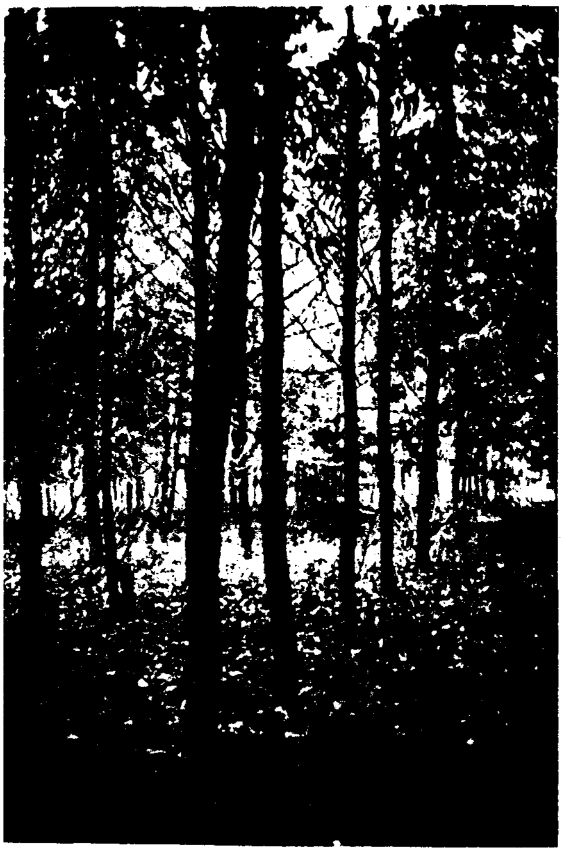
The nursery is intended to run at full capacity for 6 years. Early in the 7th year, after a sufficient amount of harvesting of the first crop has been done to indicate how much re-planting will be required to replace noncoppicing stumps, the size of the nursery will be reduced. It is estimated that the nursery will operate at between 20 to 50 percent of capacity for the remainder of the project term.

If 20 percent of the stumps don't coppice, 2,100,000 seedlings per year will be required to replace them. During the second coppice rotation, a larger percentage of stumps will not coppice, so nursery capacity will have to be increased to maintain the necessary production. If a third coppice rotation is sought, the nursery will have to be brought back to about 70 percent of original capacity at the end of 18 years. This will allow replanting of the many dead stumps.

Therefore, the nursery would be simply scaled back, but kept well maintained during the slack period. It may be possible to remain at nearly full production by supplying trees to other outlets or producing ornamentals. For financial planning, we suggest a 50 percent reduction in material and labor costs from year 7 to year 18.

VEGETATIVE PROPAGATION

Recent work in Brazil, Australia, and Florida has indicated that many eucalypts can be grown from rooted cuttings, thus permitting mass propagation of superior clones. So far this has not been done in Hawaii, but if it proves possible, the nursery system presented here can be modified to carry out vegetative propagation rather than raising seedlings.



Above, eucalyptus plantings, and below seedlings at C. Brewer and Co.'s eucalyptus nursery, both on the Big Island.

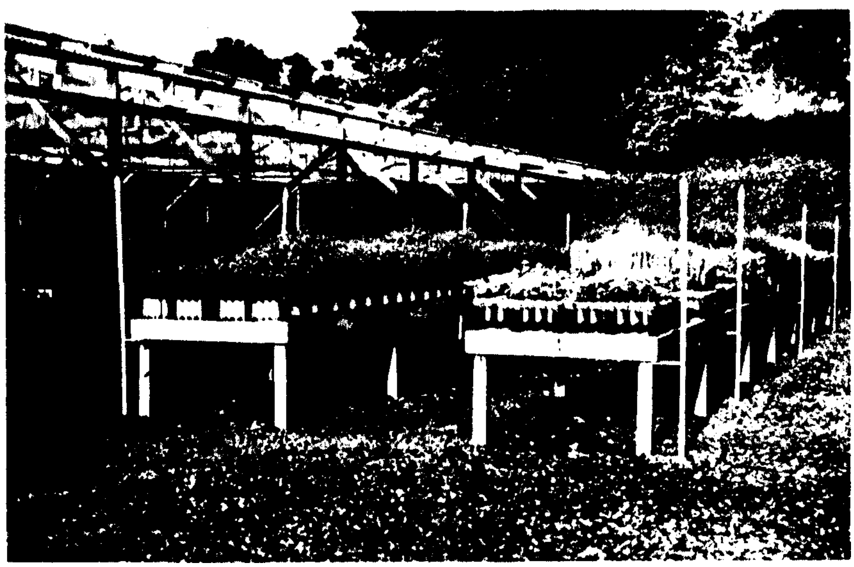


Table 5-1: Nursery Establishment Costs

	Cost (Dollars)	Life (Yr)
I. Site Preparation:		
A. Paving 5 acres	1,089,000	20
B. Landscaping 2 acres	1,000	20
C. Fencing	7,200	12
D. Windbreak	2,000	20+
E. Land cost of 7 acres @ $18,000/ac	126,000	
II. Building and Structures:		
A. Caretaker residence (3 bedroom w/1-1/2 bath)	60,000	20
B. Operations building, 30' x 100'	100,000	20
C. Headhouse, 40' x 100'	150,000	20
D. Eight greenhouses, 40' x 120' (prestanding metal structure with fiberglass roofing)	200,000	20
Fiberglass roofing replacement at the end of 10 years	50,000	10
III. Fleet Equipment and Vehicles:		
A. Two 3/4-ton 4-wheel drive trucks @ $11,500	23,000	5
B. 2 1/2-ton flatbed truck	35,000	5
C. Truck tractor with trailer 9' x 9' x 30' trailer	100,000	10
D. Two forklifts, $20,000 each, 2000-lb capacity	40,000	12
IV. Irrigation:		
Total well development cost at $200/ft well depth 1500 ft (Alternately county water--see Annual Material Cost)	300,000	
B. Greenhouse irrigation		
1. Installation and materials for 8 units	20,000	10
2. Irrigation control unit, minimum 20-station unit	1,000	10
3. Fertilizer injector (small unit)	1,200	10
C. Growing and hardening area		
1. Irrigation and materials for 8mm seedlings	28,400	10
2. Irrigation control unit, minimum 30-station unit	1,800	10
3. Fertilizer injector (large unit)	1,800	10

Table 5-1: Nursery Establishment Costs (con't.)

	Cost (Dollars)	Life (Yr)
V. Nursery Equipment:		
Flat filler, seeder, grit coverer	100,000	10
Vacuum seed cleaner	1,000	10
Tables and roller conveyor system, 100-ft	4,500	10
Balance (scale)	1,200	10
Refrigerator	1200	10
Hollow tile blocks (40,000 tile @ $.75)	30,000	10
Pallets (10,250 pallets @ $25.00)	256,250	5
Calculators	500	10
Desks (3 desks @ $400.00)	1,200	20
Reference material	4,000	20
Sterilization equipment	3,000	10
Miscellaneous equipment ($1,670/yr)	10,020	6
Container cells and trays		
Leach Pine Cells (8,200,000) @ $.04 1st year 328,000 and 4th year another 328,000	656,000	6
Leach TRays (82,000) @ $5.00 1st year $410,000 and 4th year another $410,000	820,000	6
Typewriter	650	10

Table 5-2: Annual Nursery Material and Labor Costs

	Dollars/Year
I. Annual Material Costs:	
Seed requirement	
1. E. Saligna	2,200
2. E. Grandis	2,200
3. E. Globulus	2,400
4. Leucaena spp.	10,700
Pelletized seeds ($600 per lot)	
1. E. Saligna	100
2. E. Grandis	100
Seed cover (gravel)	2,000
Peat moss and vermiculite	75,000
Insecticide/Fungicide	1,200
Sterilant	1,000
Fertilizer	5,000
Herbicide	1,500
Office equipment rental	
Telephone and charges	800
Xerox machine	1,800
Electricity	10,000
Motor vehicle maintenance	45,000
Oil and gas	25,000
Water, alternative to well on property @ $.50/1000 gal	22,550
Maintenance:	
Building	500
Grounds	500
II. Labor costs:	
1 Manager	30,000
1 Operation supervisor	24,000
1 Nurseryman	20,000
1 Technician	20,000
1 Electrician/Plumber ($15/hr for 6 hr/day)	22,500
1 Truck driver ($7.50/hr)	15,000
1 Clerk/typist	8,500
2 Forklift operators ($4.00/hr)	16,000
7 General laborers ($3.50/hr)	49,000
1 Watchman	10,000
1 Caretaker (housing provided)	10,000

Section 6

PLANTATION

Land Preparation, Planting, and Management

R.J. Van Den Beldt, V.C. Aguiar, S.C. Miyasaka, E.J. Sprague

This section discusses tree spacing, preparation, and planting for the 55,000 acres of land recommended by this study. Labor and machinery expenses for land preparation and planting are estimated for the Kapa'au, Kuka'iau, and Pua'akala sites at $65, $79, and $81 per acre respectively. Fertilizer costs are projected to be $58 to $134 per acre for the 6-year rotation, depending upon soil type. Road systems, coppice management, plantation protection, and maintenance and labor are treated in detail.

GENERAL CONSIDERATIONS

The total acreage suitable for tree plantations is broken by natural boundaries into three noncontiguous sites. About 15 percent of this land will be set aside because of environmental reasons, steep slopes, or unfavorable growing conditions. The remaining total planting area is 46,458 acres. Cropping is based on an 11-month per year factory operation. Farm activities will be carried out on an 8-hour, 40-hour week basis, and labor costs are estimated at $10 per hour.[1] With a 6-year average crop rotation, it is expected that about 7,800 acres will be planted and harvested per year, or about 33 acres per day. Cost figures for this section are based largely on operating figures for a highly mechanized 35,000-acre sugar plantation in the vicinity of the Kuka'iau site.

Production schedules and requirements are based on a strip-planting and harvesting concept with alternate areas being harvested in alternate years to help control erosion and to minimize wind throw of developing coppice stems.

Road construction operations will start one year in advance of land preparation. Once heavy earth moving for roadways is performed, some machinery will be transferred to the field operations. The land preparation schedules will vary with the least difficult sites being prepared first. A site such as Pua'akala will take longer because it is wetter; it will be prepared later. Planting will closely follow land preparation in most cases.

[1]Union scale (ILWU) through January 31, 1982 was $6.09 per hour, Grade I, and $8.25 per hour, Grade II.

PREPARATION AND PLANTING

It is expected that site preparation costs will be low overall. This is partly because no attempt will be made to completely remove vegetation from planting areas for economic and soil conservation reasons. Pasture grasses and residual cane will be flattened, planting lines cut, and areas between rows treated with suitable herbicide, fertilizer, and liming rates.

Preparation costs at the different sites are highly dependent on parameters such as vegetation, slope, presence of rocks, and rainfall. Costs range from about $56/acre in the Kapa'au region to over $90/acre at the Pua'akala site. These costs could be partially offset by commercially harvesting existing woody vegetation (mostly koa, ohia, and eucalyptus), estimated at approximately 40 green-tons per acre in certain areas. Presumably, the timber could be felled by subcontractors for veneer (as in the case of koa) or woodchips for either energy or pulp (as with eucalyptus and ohia). No reliable estimates exist, however, for this residual tree cover, so no effort will be made to incorporate such figures into the calculations here.

The time required for land preparation also will vary. Wet sites such as Pua'akala will be cleared with flotation track DC-6s, and will require a month of advance time for preplanting operations.

Equipment needs for the different sites also are variable, as shown in Table 6-3. Total equipment costs for land preparation are found in Table 6-1. About 33 acres will be prepared each day during the 6-year establishment period to keep ahead of efficient planting machines. Hourly operating costs for machines are presented in Table 6-2.

Land preparations will require a D6 or D9 track-type tractor for leveling and removing large obstructions, and for performing necessary soil erosion berm construction. A wheel tractor will be used to broadcast herbicides. On the Kapa'au leucaena site, wheel tractors will broadcast lime shortly before planting. On the Kapa'au, Kaka'iau, and Pua'akala eucalyptus sites, a D7 tractor will be used to line the fields and to apply fertilizers in the lines. A 4-line planter will follow, planting trees on a 6 ft x 6 ft spacing, roughly 1,210 trees per acre. An inter-row high-and-wide tractor will apply herbicides when the trees are 5 to 6 ft high. Approximately 20 men will be employed year round on land preparation and planting operations after the start of the second year.

The 4-line tree planters will be modeled after existing cane-piece planters used by the local sugar companies. Two of these machines will be able to plant 33 acres per day.

Table 6-1 Estimated Equipment Requirements and Costs

	EQUIPMENT	COSTS
2	D7 Track-type Tractors, Rippers w/Fertilizer attachment @ $205,000	$ 410,000
2	D6 Track-type Tractors w/disc harrow @ $155,000	310,000
2	Wheel Tractors to broadcast Herbicide @ $45,000	90,000
2	Wheel Tractors to apply fertilizer @ $60,000	120,000
2	Wheel Tractors for in-row Herbicide @ $45,000	90,000
3	Four-row tree planters - fabricated @ $300,000	900,000
4	D9 Track-type Tractors w/dozers @ $425,000	1,700,000
5	D6 Track-type Tractors w/dozer flotation track @ $135,000	675,000
10	Labor and utility trucks @ $16,000	160,000
25	Pickups @ $9,000	225,000
2	Front-end Loaders @ $60,000	120,000
3	Lowboy trailers and tractors @ $110,000	330,000
		$5,130,000

Table 6-2 Estimated Operating Costs for Equipment

EQUIPMENT	COST PER HOUR
D4 Tractor	$11.00
D5 Tractor	$15.00
D6 Tractor	$14.50
D7 Tractor	$25.90
D8 Tractor	$24.00
D9 Tractor	$24.00
High and Wide (herbicide application)	$15.50
Planter (4-line)	$14.50
Wheel tractor	$ 9.00

Table 6-3 Estimated Land Preparation and Planting Costs

Site	Species	Acreage		Machinery Needed	Costs ($/day) Machinery	Labor	Total Cost/Acre
Kapa'au	L. Leucocephala	7,225	Land preparation:	1 D6 w/disk harrow	$ 116	$ 80	$ 5.94
				2 4-line planters	232	900	34.30
				3 wheel tractors	216	240	13.82
				Support machinery[2]	104	80	5.57
				Total	$ 668	$1300	
				Cost per acre[3]	$ 20.24	$ 39.39	$59.63
	Eucalyptus	9,937	Land preparation:	1 D9	$ 192	$ 80	$ 8.24
				- rest same as above -	668	1200	56.61
				Total	$ 860	$1280	
				Cost per acre	$ 26.06	$ 38.79	$64.85
Kūka'iau	E. saligna	17,204	Land preparation:	3 D9 tractors	$ 576	$ 240	$24.73
	E. globulus			1 D7 tractor w/ripper	207	80	8.70
				2 4-line planters	232	800	31.27
				2 wheel tractors	144	160	9.21
				Support machinery[2]	104	80	5.57
				Total	$1263	$1360	
				Cost per acre[3]	$ 38.27	$ 41.21	$79.48
Pua akala	Eucalyptus globulus	12,092	Land preparation:	4 D6 tractors, w/flotation tracks	$ 464	$ 320	$23.76
				1 D7 tractor w/ripper	207	80	8.70
				Support machinery[2]	104	80	5.57
				Total	$ 775	$ 480	
				Cost per acre[3]	$ 23.48	$ 14.55	$38.03
			Planting:	2 4-line planters	$ 232	$ 800	$31.27
				2 wheel tractors	216	160	11.40
				Total	$ 448	$ 960	
				Cost per acre	$ 13.58	$ 29.09	$42.67
				Cost per acre land preparation and planting			$80.70

[1]This chart assumes that the 12,092 acres will take 575 days for land preparation and 365 days to plant.
[2]Consists of 2 flatbed trucks, 1 semi-truck, and 1 966-Caterpillar Trucksalator.
[3]Assumes 33 acres prepared and planted per day.

A summary of land preparation and planting costs are presented in Table 6-3.

MANAGEMENT

FERTILIZER

Fertilizer requirements per soil type are presented in Section 3. The assumption is made that lime (up to 2 tons/acre) and a complete mixed fertilizer (100 lb/acre) will be incorporated in the soil at the time of planting. Other fertilizer may be added at recommended rates by air at a cost of $3/100 lb. Table 6-4 is a summary of fertilizer rates and costs for the three areas.

HERBICIDES

Herbicides will be broadcast prior to planting by a wheel tractor. Roundup at a 1 percent solution (.5 gal/acre) will be the principal herbicide used. A high-and-wide tractor fitted with shields will pass over the seedlings when they are 4 to 5 ft in height and spray an additional 1/2 lb per acre betweeen rows. No other herbicide treatment is expected, except for manual application of herbicides for eradication of banana poka should it become a problem later on. Cost of herbicides, including both applications and banana poka treatment, is predicted to be $70.00 per acre for all sites.

COPPICE MANAGEMENT

It has been decided that no coppice shoot pruning will be done.

Also, it is probably not economical to replant after harvesting unless the number of dead stumps exceeds 10 percent of the total. Neighboring trees will usually compensate for the missing or dead stumps. If replanting is done, however, a 4-man crew is needed and the cost will be $65.00 per acre.

PROTECTION

Fire

Firebreaks are ruled out as an option because they will probably occupy too much space if constructed to be truly effective. Reliance will be placed on the road system to provide some firebreak activity, and to allow rapid transport of the water tanker (from road building crew) and fire fighting teams to a fire site. Also, stockpiles of DAP slurry will be placed near airplane landing sites and will be used to control potential fires there.

Table 6-4 Estimated Fertilizer Costs

Site	Species	Elevation	Acreage	Fertilizer Application At planting	Fertilizer Application Aerial	
Kūka'iau	E. saligna	3000 to 4000 ft.	6,851	2 tons lime $14.50 100 lb complete $15.00	300 lb urea Appl. cost 250 lb P Appl. cost	$48.00 9.00 40.00 8.00
				Total: $134.50/acre		
	E. globulus	4000 to 6000 ft.	6,503	100 lb complete $15.00	300 lb urea Appl. cost	$48.00 9.00
				Total: $72.00/acre		
	E. globulus	4000 to 6000 ft.	3,850	100 lb complete $15.00	225 lb urea Appl. cost	$36.00 7.50
				Total: $58.50/acre		
Kapa'au	Leucaena leucocephala		7,225	1 ton lime $7.25	250 lb P Appl. cost 150 lb K Appl. cost	$40.00 7.50 20.00 4.50
				Total: $79.25/acre		
Kapa'au	Eucalyptus, sp.		9,937	1 to 2 tons lime $12.00 100 lb complete $15.00	300 lb N Appl. cost P, K Appl. cost	$48.00 9.00 60.00 12.00
				Total: $156.00/acre		
Pua'akala	E. globulus	5400 to 6500 ft.	6,235	2 tons lime $15.00 100 lb complete $15.00	250 lb P Appl. cost 150 lb K Appl. cost 300 lb N Appl. cost	$40.00 7.50 20.00 4.50 48.00 9.00
				Total: $159.00/acre		
	E. globulus	5000 to 6000 ft.	5,857	2 tons lime $15.00 100 lb complete $15.00	258 lb P Appl. cost K 100 lb Appl. cost N 150 lb. Appl. cost	$40.00 7.50 15.00 3.00 24.00 4.50
				Total: $124.00/acre		

Pests and Diseases

This problem can be solved in advance by the selection of disease and pest resistant cultivars or species. Continued genetic selection also will help.

Fencing

Invasion of the plantations by wild pigs or range cattle may pose a problem. In places where this is thought to be an issue, electric fencing can be erected to protect young seedlings. Sufficient fencing to enclose ten 640-acre areas can be purchased at a cost of $96,000.

Plantation Laboratory

Soil and tissue nutrient analysis are necessary for an intensively cultivated forest plantation. Information gained can be used in making fertilization decisions. The plantation laboratory may also be used as a tool in monitoring the health of the forest, especially pests and disease problems. The lab will be housed at the nursery, and will cost $155,000 for the building and all equipment. An additional $5,000 will be needed for annual maintenance. The crops control staff will consist of a field crew of 3 persons for the first 3 years after planting, at a cost of $62,400 per year, and 6 persons for all succeeding years, at a cost of $124,000 per year. Three people will be needed as supervisory and lab staff, for an additional $90,000 per year.

ROADS

Plantation roads will consist of 3 types–a 40 ft wide main private transport road linking plantation sites 2 and 3 with Waimea, 20 ft wide main access roads linking all plantation sites with the main road, and 15 ft feeder field roads. Other than the main road, 70 percent of all roads will be feeder type and 30 percent will be main access roads. Costs are estimated here for roads built within good soil conservation standards–i.e., crowning, terracing, etc. Roads will be built before land preparation begins, with a 1-year interim between commencement of road construction and land preparation. Expensive equipment, then, may be shared by both operations. The main road to Waimea, 40 ft wide, 35 miles long, will be 185,000 linear feet (LF) @ $30/LF, for a cost of $5,550,000. The access roads, 20 ft wide, will comprise 30 percent of all field roads. Of this, 1/2 will be paved and 1/2 will be gravel. Paved roads cost $25/LF, and gravel roads cost $13/LF. The average, then, is $19/LF and at 511,500 LF, access roads will cost approximately $9,718,500. Feeder roads, assuming 70 percent are 15 ft wide gravel laterals, will cost $6/LF. At 1,193,500 LF, the cost of feeder roads will be $7,161,000.

The total road cost is:

Main roads	$ 5,550,000
20-ft roads (1/2 paved)	9,718,500
15-ft roads	7,161,000
	$22,429,500

Parts of the main and access roads will be widened to accommodate the landing of aircraft for the purposes of aerial fertilizing and firefighting. Four sites are believed necessary to serve this purpose. Accordingly, tanks of diammonium phosphate (DAP) slurry and fertilizer stocks will be positioned at these landing sites.

Road construction will require about 40 men. Twenty of those will be phased into the planting and clearing operations after year 2, and the remaining will stay on road maintenance.

A list of equipment needed for road construction follows: Note that several items will be used also for clearing and planting. It is presumed that these machines will be transferred for use in clearing or planting after some initial road building activities are completed.

All heavy equipment in the road and plantation motorpool will be new and under full warranty for 1 year. After that time, the plantation will have to operate a maintenance and repair shop, costing about $2,000,000. Shop labor will be phased in, with 15 men hired the first year, 30 for the next 4 years, and 60 for each succeeding year; the repair crew, from year 6 on, will consist of 105 men. The rate of pay will be $21,000/man-year, or $315,000 for the first year, $630,000 for the next four, and $1,260,000 for each succeeding year.

Table 6-5 Plantation Road Equipment

Item		Total Cost
4	D9 tractors	(1)
3	D8 tractors	$945,000
1	D6 tractor	(1)
1	D4 tractor	80,000
5	Motor graders	400,000
12	Dump trucks	960,000
4	Front end loaders	240,000
1	Scraper	75,000
2	Packers	25,000
1	3000-gal semi trailer (water)	20,000
2	Lowboys (trailer)	(1)
4	6x6 service trucks	440,000

[1] Costs Already Included in Clearing and Planting Section.

Section 7

HARVESTING AND UTILIZATION

Methods, Equipment, and Costs

A. Seki, D. L. Sirois, T. Kamen

This section explains the harvesting system selected, based upon topography, soil condition, and tree size. It is a highly mechanized, capital intensive system which includes tracked feller-bunchers to cut and bunch the trees, and tracked forwarders to transport the bunched trees to a whole tree chipper. The chips will be loaded into vans and transported to a designated site. The total capital cost, including support equipment, will be $14,104,000 and the annual operating expenditure will be $6,764,837.

PLANTATION AND TREE CHARACTERISTICS

The proposed energy plantation will consist of 46,750 acres divided among three locations planted in equcalyptus and leucaena. Spacing will be 6 ft x 6 ft for 1,210 trees per acre; the rotation age of the plantation stands may vary from 5 to 8 years; and the average tree size at harvest will be at least 6 inches dbh. Trees of this size are estimated to have a volume of 4.75/ft^3 and to contain 333 lb of biomass, green weight, based on a density of 70 lb/ft^3 before chipping, and 21 lb/ft^3 after chipping. Moisture content of the green chips is 50 percent on a wet basis.

During the second and third rotations, the individual tree stems will be somewhat smaller, about 5 inches dbh, but multiple stems will sprout from the original stumps. Surviving sprouts per stump will vary, but should be near these percentages of the original size—1 stem/60 percent stump, 2 stems/30 percent stump, 3 stems/10 percent stump.

The foliage portion of harvested trees along with most of the dirt will be separated at the chipper. No attempt will be made to recover it, other than possibly spreading this foliage over the area near the chipper.

ENERGY PRODUCTION AND EFFICIENCY

The planned plantation of 46,750 acres with an estimated growth of 20 green tons of harvestable biomass per acre per year will yield 10 bone dry tons per acre per year over the rotation period of 5 to 7 years. With a requirement of approximately 467,500 bone dry tons (935,000 green tons) per year it will be necessary to harvest about 7,790 acres of plantation per year starting with the sixth year after start of plantation establishment. The daily harvesting rate (based on 240 work days per year) will have to be 3,896 green tons per day to meet this need. The selected harvesting system will produce this quantity of chips and deliver them to the plant.

The harvesting system, including transportation of chips to the plant 35 miles away, will require approximately 1,180,000 gallons of fuel and other petroleum products per year. By equating the above values to equivalents of barrels of oil (42 gallons per barrel), calculations can be made.

Harvesting needs:

$$\frac{1{,}180{,}000 \text{ gal.}}{42 \text{ gal/bbl.}} = 28{,}100 \text{ barrels of oil}$$

Equivalent energy (gross) produced:

935,000 green ton wood chips x 1 bbl/bT = 935,000/barrels of oil

Energy efficiency ratio:

$$\frac{935{,}000}{28{,}100} = 33.3:1$$

This ratio appears favorable and indicates the feasibility of plantation harvesting using the proposed highly mechanized system.

HARVESTING SYSTEMS CONSIDERATIONS

A broad range of harvesting system alternatives were available for consideration at the beginning of this study. The alternatives ranged from highly labor intensive systems based on manual felling with chainsaws and inwoods transport by rubber-tired cable skidders to the portable chipper at the landing or chipping deck, to highly mechanized systems such as mobile chippers that fell, chip, and transport the chipped material to the landing. The mobile chipping systems are the least labor intensive but are very capital intensive. They are also the least highly developed at this time and therefore the least reliable. As criteria were developed for tree species, sites (including acreage limitations), plantation yields, social factors, and plant requirements, the choice of alternatives was narrowed.

Based primarily on the major factors of total daily production requirements of 3,896 green tons per day for 240 days per year, small tree sizes of 6 inches dbh at the end of rotation, given site conditions (slopes, rocks, low bearing strength soils), high level of rainfall, and limited labor force for woods work; four mechanical systems appeared feasible:

- o The machinery used in this system are rubber-tired drive-to-tree feller-bunchers, rubber-tired grapple skidders, and portable whole tree chippers. Similar systems have been proven capable of high production at reasonable costs. Generally, rubber-tired machines are faster and less costly (fixed and variable) than tracked machines performing the same functions. This system becomes sensitive to tree size, however, as tree size decreases below 6 inches dbh. Stand densities also influence the production capacities of the feller-bunchers. The major drawbacks to this system arise from the plantation environment. A high percentage of plantation sites contain slopes over 10 percent, and drive-to-tree feller-bunchers operate better on flatter lands. Also, during wet weather, soils have low bearing strengths, and excessive soil compaction could result. Another problem is that drive-to-tree feller-bunchers could run over the stumps, possibly damaging them and the vehicle tires.

o Machinery used here are limited area feller-bunchers, cable skyline yarder, rubber-tired or tracked grapple skidders (at landing), and a portable whole tree chipper. This system can operate under the most adverse conditions of slopes, soils, and weather, but problems with it are higher costs and required additional harvesting/planning skills. Also, the cable yarding system needs slopes of 10 percent or greater to provide suitable cable deflection for fully or partly suspended log loads for high speed yarding without damage to the plantation; some plantation areas considered have slopes less than 10 percent.

o Machinery used in this system are mobile chip harvesters and forwarders. Mobile chip harvesters appear to be the least sensitive to small stem diameters (tree volumes) and have the potential for high production rates with reduced labor requirements. Presently, all machines of this type are only in the prototype stage of development, and are restricted to relatively rock free sites with slopes less than 20 percent. Also, the present design would have to be modified to accept trees of 30 ft and greater in height, growing in dense stands of 1,200 trees or more per acre, if it were to be used for this project.

o Limited-area accumulating feller-bunchers, tracked clam bunk skidders, and a portable whole tree chipper comprise the next system considered. For the conditions of this study—biomass volume requirements, sites, and plantation size—this system is the most flexible. It is capable of working under adverse terrain and weather conditions while maintaining good production potential. It also causes little site/stand disturbance. The system is highly mechanized, keeping labor requirements low and placing a relatively moderate cost on high production. THIS IS THE SYSTEM SELECTED.

SELECTED SYSTEM AND PRODUCTION RATES

The selected system is made up of two limited-area feller-bunchers (also known as swing-to-tree feller-bunchers), two steel tracked clam bunk skidders with knuckle boom loaders, and one portable whole tree chipper. Transportation of chips will be by standard highway truck tractors pulling vans.

The feller-buncher selected is modified from a standard commercial hydraulic excavator. The changes have been made to the outer or stick boom and additional adaptations of the accumulating feller-buncher shear or other cutting device may be required to reduce damage to the stump or butt log. The use of an accumulating shear head will help to increase production when harvesting small trees. Use of the swing machines and boom mounted shear will permit cutting a 50-ft wide swath as the machine progresses across the plantation. Production increases and site impact reduction will result from not having to drive to each tree. The tracked carrier will operate on slopes of up to 30 percent. Ground pressures will be within the 6 to 7 psi range, so the unit will be capable of working under poor soil conditions. Bunches of up to 21 trees (6 ft x 6 ft tree spacing) will be made with minimum travel. Representative machines of this type are the Drott 40 LC and John Deer 693 B.

The selection of a steel tracked clam bunk skidder was based on specific requirements dictated by the operating conditions. The skidder must be able to operate on wet poor bearing strength soils, withstand abrasive soils, and self-load bunches into full payloads without excessive, stump-damaging travel. The selected machine has high travel rates for good production. It will work also on slopes up to 40 percent, making it compatible with the feller-buncher. The basic machine is represented by the FMC 180 log skidder and will be modified by adding the clam bunk and loader similar to the FMC 200 BG skidder.

The portable whole tree chipper is to be a standard disk chipper with a conveying system and a boom loader. It will discharge chips directly into chip vans. The chipper is represented by a Morbark model 550 or Trelan DL-18.

HARVESTING EQUIPMENT AND COSTS

The total output of a chipping operation depends upon the organization of the work. The most common practice is to fell the trees, transport them to an open area, chip into a vehicle, and transport. One line production varies according to the chipper, climate, chip van availability, and other factors; including preparation of work at the harvesting site, movement of the chipper within and between harvesting sites, and servicing and repairs. Table 7-1 shows the amount of equipment necessary for the total harvesting job based on a production goal of 467,500 BDT/year of wood chips. This production goal will require 14 operational systems, each comprised of two feller-bunchers, one bunk grapple skidder and one whole tree chipper. For some items, spare machines have been included and are planned as replacements only in cases of major equipment failures requiring more than one day to repair. Each system will have the services of a full time on-site mechanic. Two additional mechanics will work in the central shop to handle major repairs and to provide assistance to the field mechanics. An adequate inventory of spare parts should be kept in stock to reduce repair down times.

The 14 systems are to be in operation each work period. Because each system is based on one whole tree chipper, 3 spares will be purchased as insurance. The total capital cost of a chipper is about $128,000 and the total capital investment, including spares, is $2,176,000.

Each system will operate with two feller-bunchers, therefore twenty-eight operational feller-bunchers will be used during each work period. Three spares will be used as backups in case of major failures and major maintenance needs that could take an operational feller-buncher out of service for more than a day. This is less critical, however, than having replacements for chippers or skidders, because half of the system production could be maintained with only one operational feller-buncher. If necessary, then, the three spare feller-bunchers could be deleted to reduce the capital investment. Each unit costs approximately $140,000, so omitting the spares would reduce the initial cost by $420,000, bringing the total investment from $4,340,000 to $3,920,000.

Only one tracked clam bunk skidder is required for each system. This piece of machinery, though, could be the most sensitive to weather and terrain factors (with little opportunity to correct for adverse conditions--except by shortening skid distance) and to down times caused by mechanical failures. Plans are made here for the minimum number of machines, one for each of the 14 systems plus three spare units, to be purchased at an estimated cost of $140,000 per unit, bringing the total capital investment to $2,380,000. More of these machines may be needed, however, requiring more capital investment.

Transportation of the wood chips to the loading site will require an approximate 70 mile round trip. Six 50 ft chip vans will be located at each chipping site and an equivalent 8 chip vans will be located at each site per 8-hour day. Wood chip transportation will be conducted on a 24-hour basis, about 3 round trips per 8-hour day. Therefore, 17 truck tractors (14 operational, 3 spares) and 84 chip vans are required. The estimated capital cost of these units are $986,000 and $2,352,000 respectively. The total capital cost will be $3,338,000.

Finally, at the destination of the loaded chip vans will be 2 chip van unloaders (total cost $220,000) that lift the entire truck and van to a 45^{o} angle to unload the wood chips. This completes the total cycle of a woodchipping operation--cutting trees with feller-bunchers, forwarding the trees to the chipper, chipping the whole trees, transporting the woodchips to a destination, and unloading.

Other equipment, though, is necessary to support this type of operation. For example, 7 pickup trucks ($70,000 total) will be needed by the supervisors. Each supervisor will manage 2 of the 14 woodchipping operations to make sure that the high cost system is running as smoothly as possible. To move the work crew from various locations, 14 vans also are needed, for a total of $140,000. Each chipping site will have a maintenance truck fully equipped with a mechanic and the necessary tools for on site repairs. Two other maintenance vehicles and mechanics will be stationed at a central repair shop for major servicing. Therefore, 16 maintenance units are needed, for a total cost of $252,000. Three fuel trucks will service the whole operation (1 at each site). They will travel to each chipping operation and fill the existing fuel tanks. The three fuel trucks will cost $45,000 and 14 fuel tanks, about $56,000. A D-4 dozer type, needed at each site for preparation and maintenance of the landing, will complete the support group. Each D-4 dozer will cost $917,000.

At the central repair shop, an 8 unit chipper knife sharpener, about $128,000 will be operating continuously. Each chipper requires 15 sets of chipper blades, for a total of 210 sets, costing $42,000.

TOTAL COST

A summary of all these costs is presented in Table 7-1. The total, including 2 percent for inventory and 15 percent for contingency, is $16,501,680. The depreciated value per year is about $2,385,000 and the annual operating cost will reach $6,764,837. As expected, the high cost items in the harvesting system are the woodchippers, feller-bunchers, forwarders, and truck transportation.

A Clam Bunk Skidder in operation.

TABLE 7-1: SUMMARY OF HARVESTING COST

Equipment	Labor	Life	Units	Unit Capital Cost	Unit Salvage Values	Total Capital Cost	Annual[3] Operating	Percentage of Annual Operating Costs For Labor
Chipper	28[1,4]	5	17[2]	128,000	25,200	2,176,000	1,184,064	43.1
Fellerbuncher	28[4]	4	31[2]	140,000	28,000	4,340,000	1,758,883	29.1
Forwarder	14[4]	4	17[2]	140,000	28,000	2,380,000	1,092,609	23.4
Truck Tractor	42[4]	3	17[2]	58,000	11,000	986,000	970,662	48.5
Chip Vans	--	8	84	28,000	5,600	2,352,000	460,992	--
Pickup Trucks	7	3	7	10,000	2,000	70,000	70,630	0.0
Crew Vans	--	3	14	10,000	2,000	140,000	141,260	--
Maintenance Trucks with Tools	16[5]	5	16	18,000	3,600	252,000	497,400	62.8
Fuel Trucks	3[6]	5	3	15,000	2,400	40,000	51,056	79.0
Fuel Tanks	--	5	14	4,000	720	56,000	9,408	--
Chip Van Unloaders	2[6]	10	2	120,000	24,000	220,000	165,481	48.4
Dozer (D-4)	14[4]	5	14	65,000	13,000	917,000	229,768	28.9
Knife Grinder	8[6]	8	8	16,000	3,200	128,000	132,682	80.9
Knives	--	1	210 sets	200	--	42,000	--	--
Subtotal	162					14,104,000	6,764,837	
Inventory (2% of Capital)						282,080		
Contingency (15% of Capital)						2,115,600		
TOTAL						16,501,680		

[1]includes landhand

[2]includes 3 spare units

[3]includes interest , insurance, taxes, maintenance, repairs, fuel, lubricants, and labor (units in field)

[4]labor cost $9.50/hr

[5]labor cost $10.00/hr

[6]labor cost $7.00/hr

Section 8

FINANCIAL RESULTS

Economic Feasibility of Tree Farms for Energy

J.S. Denyes, C.T.K. Ching, P. Leung

Producing 467,500 bone dry tons of chips per year to be used in a synthetic liquid fuel plant can be done at an average after-tax cash cost of $29.47 per ton. The cash outflow during the first six years of the project, before any chips are produced, will be $62.2 million (excluding interest charges and inflation). The average cost per year after production commences (again excluding interest and inflation) will be $5.8 million.

A rate of return also was calculated, based upon the assumption that the chips will be sold directly as fuel, at a price related to the market price of bunker fuel. This return will be 12 percent excluding inflation. In this situation, the original net outflow of $62.2 million will be recovered by the end of Year 11; the average (positive) cash flow after harvesting begins will be $11.7 million.

METHODS OF ANALYSIS

The "average after-tax cash cost" per ton of chips was obtained by a discounted cash flow calculation which assumed that the net present value (NPV) of chips sold at a breakeven price would equal the NPV of the costs incurred in this project. This breakeven price will thus be equivalent to an average cost which includes the time value of the money invested in the project. The calculation can be expressed symbolically:

$T(1)$ = tons of chips sold in year 1
P = breakeven price of chips per ton
$R(1)$ = $PT(1)$ = total revenue, year 1
$C(1)$ = total cost (cash outflows) in year 1
$f(1)$ = discount factor in year 1

$$f(1)\,C(1) + f(2)\,C(2) + \ldots + f(n)\,C(n) = f(1)\,R(1) + f(2)\,R(2) + \ldots + f(n)\,R(n)$$

$$f(1)\,C(1) + f(2)\,C(1) + \ldots + f(n)\,C(n) = f(1)\,PT(1) + f(2)\,PT(2) + \ldots + f(n)\,PT(n)$$

$$P = \frac{f(1)\,C(1) + f(2)\,C(2) + \ldots + f(n)\,C(n)}{f(1)\,T(1) + f(2)\,T(2) + \ldots + f(n)\,T(n)}$$

The NPV of a time series (one year) of chips is calculated by multiplying the amount of chips (tons) by the price of the chips. In other words, the tons of chips produced in one year multiplied by the price per ton ($29.47) equals the present value of the revenue.

The discount rate used in this calculation is 8 percent. At first glance this appears unrealistically low, especially at a time when actual rates are in the 15 to 20 percent range. It must be remembered, however, that the cost projections used in this report are in constant dollars including no allowance for inflation. Since a real-world investor will be repaid in inflated dollars, he must charge an interest rate which allows for this. In an environment with a 10 percent inflation rate, the assumed 8 percent rate (3 percent for the real cost of money and 5 percent for profits) would then become an actual interest cost of 18 percent.

The calculation of cash flow must include the effects of income taxes. For the purpose of this analysis, it is assumed that the project is operating as part of a larger profit-making entity. Consequently, tax benefits resulting from operating losses and investment tax credits need not be carried into other years but can be credited in the year they occur normally.

Much of the capital investment required to implement the project is eligible for investment tax credits; these credits are summarized in Table 8-7. Current tax regulations allow an additional 10 percent Energy Tax Credit for equipment used to produce synthetic fuels. As this is the intended purpose of the chips produced by this project, the Energy Tax Credit should be available. Under present law the Energy Tax Credit expires at the end of 1985. The analysis of this project, however, assumes that Energy Tax Credit provisions will be extended at least through the initial 6-year installation phase. Considering the prevailing legislative climate of encouragement to business expansion in general and oil-substitution projects in particular, this assumption is defensible. In the event that Energy Tax Credits are allowed to expire and the commencement of this project is delayed beyond the expiration date, or if the expenditures are not eligible for the credit, the cost per ton of chips would increase from $29.47 to $29.91.

Depreciation costs under new tax regulations will be calculated differently depending on the year depreciation begins. Three different tables are to be used: one for investments made in 1981 through 1984, one for investments in 1985, and one for investments in 1986 and thereafter. Consequently, the implementation of this project must be associated with specific years. For calculation purposes, Year 1 will be defined as 1982.

COSTS

Prior chapters have enumerated the costs expected in implementing this project. Those costs will be stated in summarized form in this section, and the source section will be cited. If further calculations or detail are required, however, they will supplied here.

ESTABLISHMENT

NURSERY

Section 5 gives the costs of establishing a 7-acre nursery capable of producing 10.4 million seedlings per year for the first 6 years of the project's operation. The costs required to establish this facility are $3,130,620 (including a land purchase) in Year 1, $739,670 in Year 4, and $1,670 in Years 2, 3, 5, and 6. Tax regulations state that the portion of these expenditures that would normally be capitalized and depreciated can alternatively be accumulated to the point where the trees are producing a revenue, and then amortized against the production cycle. This latter method was chosen, and costs are amortized over a six-year period. The land purchase is recovered after Year 18. Details of timing of these expenditures and estimated tax credits are shown in Table 8-3.

PLANTATION

Section 6 details costs incurred in the initial clearing and planting phase of the project. The list of equipment for construction of roads and clearing land is contained in that section, and summarized here.

1. Clearing, Planting, and Cultivation Equipment	
Tractor, loader, heavy trucks	$4,905,000
Pickup trucks	225,000
subtotal	5,130,000
2. Road Construction Equipment	3,185,000
Total	$8,315,000

The above equipment cost is in addition to the labor and other costs incurred in clearing, planting, constructing roads, etc. Also, there will be a need for a crop log laboratory, a repair and maintenance shop, and four airstrips. Costs for these items are as follows:

1. Crop Lab	
building	$ 55,000
equipment	100,000
subtotal	155,000 (Year 1)

2. Shop Facility

building	$1,000,000
equipment and working capital	1,000,000
subtotal	2,000,000

3. Roads

Main Road (35 miles x $30/ft)	5,550,000

This cost will be incurred in Years 4-6 at $1,850,000 per year

Field Roads

20 ft roads; 511,500 ft @ $19.00	9,718,500
15 ft roads; 1,193,500 ft @ $6.00	7,161,000

These costs will be incurred evenly over the initial 6 year establishment period at a rate of $2,813,250 per year.

4. Clearing, Planting, Fertilizing

Included in Section 6 is a tabulation of the cost per acre of planting and growing trees at the different potential plantation sites. The table below shows the calculation of total clearing costs:

Table 8-1: Clearing Costs

Site		Gross Acres Leased	Net Acres Planted	Cost per Acre Preparation	Fertilizer	Herbicide	Total Cost
Kuka'iau	A	8,060	6,851	79.48	134.50	70.00	$ 1,946,000
	B	7,650	6,503	79.48	72.00	70.00	1,440,000
	C	4,530	3,850	79.48	58.50	70.00	801,000
Subtotal		20,240	17,204				4,187,000
Kapa'au							
Leucaena		8,500	7,225	59.63	79.25	70.000	1,509,000
Eucalyptus		11,690	9,937	64.85	156.00	70.00	2,890,000
Subtotal		20,190	17,161				4,399,000
Pua'akala	A	8,908	6,235	80.70	159.00	70.00	1,931,000
	B	8,367	5,857	80.70	124.00	70.00	1,609,000
Subtotal		17,275	12,092				3,540,000
Total		57,505	46,458				$12,126,000

The cost of preparing and planting will be spread evenly over the first six years of the project at a rate of $2,021,000 per year.

5. Fencing

A moderate amount of fencing is proposed to protect the newly planted seedlings from pigs or cattle. The amount estimated for fences is $96,000 and will be spent in the first six years at a rate of $16,000 per year.

Total costs of plantation establishment and tax credits are shown in Table 8-4.

HARVESTING AND CHIPPING

The capital required for harvesting, chipping, and hauling equipment is given in Table 7-1. As shown, the total cost of equipment required to begin operations is $16,501,680. This investment will be made in Year 6.

Table 8-5 (in this chapter) shows the initial purchase and replacement schedules for harvesting/chipping/hauling equipment, and the expected tax credits. Table 8-4 shows the resulting depreciation.

OPERATING COSTS

NURSERY

The operating costs of the nursery are enumerated in Section 5, Table 5-2. They amount to $209,550 per year for materials and $225,000 per year for labor for the first six years of operation. This cost of $434,550 per year is estimated to decrease 50 percent after Year 6; it will be $217,275 per year until Year 19. Because the last harvesting cycle is expected to begin in Year 19, there will be no nursery costs after Year 18.

PLANTATION

Land Lease

Different lease rents for the different parcels of land were assumed in Section 2, Table 2. These rates and the total resulting costs are shown below:

	Acres Leased	Cost Per Acre	Total Cost
Kuka'iau	20,240	$20	$ 405,000
Kapa'au	20,190	$40	808,000
Pua'akala	17,275	$15	259,000
	57,505		$ 1,472,000

This annual lease rent will build up to the final $1,472,000 for year 6 and thereafter; it will increase gradually for years 1-5 as follows:

Year	Lease Rent
1	$ 245,000
2	491,000
3	736,000
4	981,000
5	1,227,000
6 & thereafter	1,472,000

Similarly, as land is taken out of production in the termination phase of the project (Years 19-24) the lease rent will follow the above pattern, but in reverse order. During the final 6 years, lease costs will be charged to the harvesting operations.

Laboratory

Section 6 discusses the need for a crop log laboratory, and projects the costs of operation as follows:

Annual Maintenance	$ 5,000/year
Supervisory/Lab Personnel	90,000/year
Crop Control Field Crew	
First 3 years after planting	62,400/year
Thereafter	124,800/year
Total Years 1 through 9	157,400/year
Total Years 10 and after	219,800/year

Shop Labor

As discussed in Section 6, a maintenance and repair facility will be required for servicing of the mobile equipment. Costs projected for this operation are:

Year 1	$ 315,000
Year 2	630,000
Year 3	1,260,000/year

HARVESTING, HAULING, AND CHIPPING

The cost of manning and operating the mechanized harvesting operation is given in Table 1, Section 7, as $6,806,875. To this must be added the depreciation shown in Table 8-6; the resulting total is shown as Harvesting Operation Expenses in Table 8-8 and 8-9.

Table 8-2: Annual Coordination and Management Costs

Project Manager/Controller Group

Average annual plant operating cost	11,230,000
4% of plant operating cost	449,000
Annual cost of plant manager & controller group	449,000

Management Group

	Number	Cost/Supvsr	Total
Field Manager	1	$48,000	$ 48,000
Maintenance/Garage	4	36,000	144,000
Nursery	2	27,000	54,000*
Harvest	7	36,000	252,000
Road	4	36,000	144,000
Cultivation	3	36,000	108,000
Subtotal			$ 696,000*
Total Annual Management & Coordination Cost			$1,145,000

*Nursery supervision has been included in the costs for that operation, and is excluded from totals here.

Table 8-3: Nursery Establishment Costs

	YEAR												
	1	2	3	4	5	6	7-9	10	11	12	13	14-18	19
I. Nursery - General													
A. Site preparation													
5 acres paving	1,089,000						None					None	
2 acres landscaping	1,000												
B. Fencing	7,200										7,200		
C. Windbreak	2,000												
D. Land purchase	126,000												(126,000)
II. Building and Structures													
A. Caretaker residence	60,000												
B. Headhouse	150,000												
C. Operations building	100,000												
D. 8 greenhouses	200,000							50,000					
III. Fleet Equipment and Vehicles													
A. 2 forklifts	40,000										40,000		
B. 2 - 3/4-ton truck	23,000												
C. 2 - 1/2-ton flatbeds	35,000												
D. Truck-tractor and trailer	100,000												
IV. Irrigation													
A. Greenhouse													
1. Inst'n/Materials - 8 Un.	20,000												
2. Control Unit - 20 Un.	1,000								1,000				
3. Fertilizer injector	1,200								1,200				
B. Growing/hardening area													
1. Units for 8mm seedlings	28,400								28,400				
2. Control unit	1,800								1,800				
3. Fertilizer injector	1,800								1,800				
V. Nursery Equipment													
A. Flat filler, seeder	100,000												
B. Vacuum cleaner	1,000												
C. Tables and conveyor	4,500												
D. Balance	1,200												
E. Refrigerator	1,200												
F. Hollow tile blocks	30,000												
G. Pallets (13,000)	256,250												
H. Calculators	550												
I. Desks	1,200												
J. Reference material	4,000												
K. Sterilizers	3,000							3,000					
L. Cells	328,000			328,000									
M. Trays	410,000			410,000									
N. Typewriter	650												
O. Miscellaneous	1,670	1,670	1,670	1,670	1,670	1,670							
Total	3,130,620	1,670	1,670	739,670	1,670	1,670	-	53,000	34,200	-	47,200	-	(126,000)
Tax Credit													
Regular							298,142	5,300	3,420		4,720		
Energy							300,462						

Table 8-4: Plantation Establishment Costs

Item	Year 1	2	3	4	5	6	7
Plantation Equipment							
Tractors, loaders, heavy trucks	$ 4,905,000						
Pickup trucks	225,000						
Road Building Equipment	3,185,000						
Subtotal	8,315,000						
Crop Lab Building	55,000						
" " Equipment	100,000						
Subtotal	155,000						
Shop Facility Building	1,000,000						
" " Equipment	1,000,000						
Subtotal	2,000,000						
Roads							
Main road				1,850,000	1,850,000	1,850,000	
Field roads	2,813,250	2,813,250	2,813,250	2,813,250	2,813,250	2,813,250	
Clearing/planting	2,021,000	2,021,000	2,021,000	2,021,000	2,021,000	2,021,000	
Fencing	16,000	16,000	16,000	16,000	16,000	16,000	
TOTAL	$15,320,250	$4,850,250	$4,850,250	$6,700,250	$6,700,250	$6,700,250	
Tax Credits - Regular							$4,503,150
- Energy							4,512,150

Table 8-5: Harvesting Equipment Costs and Tax Credits

	1-6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
17 Chippers		2,176,000					2,176,000					2,176,000					2,176,000			
31 Feller-Bunchers		4,340,000				4,340,000				4,340,000				4,340,000				4,340,000		
17 Forwarders		2,380,000				2,380,000				2,380,000				2,380,000				2,380,000		
17 Truck-tractors		986,000			986,000			986,000			986,000			986,000			986,000			
84 Chip Vans		2,352,000								2,352,000								2,352,000		
7 Pickup Trucks		70,000			70,000			70,000			70,000			70,000			70,000			
14 Crew Vans		140,000			140,000			140,000			140,000			140,000			140,000			
16 Maintenance Trucks		252,000					252,000					252,000					252,000			
3 Fuel Trucks		40,000					40,000					40,000					40,000			
14 Fuel Tanks		56,000					56,000					56,000					56,000			
2 Chip Unloaders		220,000										220,000								
14 D-4's		917,000					917,000					917,000					917,000			
8 Knife Grinders		128,000								128,000								128,000		
Contingency (15%)		2,109,000			179,000	1,008,000	516,000	179,000		1,380,000	179,000	549,000		1,187,000			696,000	1,380,000		
Inventory (2%)		281,000																		
TOTAL	None	16,452,000			1,375,000	7,728,000	3,957,000	1,375,000		10,580,000	1,375,000	4,210,000		9,103,000			5,333,000	10,580,000		
Tax Credits																				
Regular		1,594,000			128,000	773,000	382,000	128,000		1,058,000	128,000	408,000		901,000			510,000	1,058,000		
Energy		1,617,000																		

Table 8-6: Harvesting Equipment Depreciation

	Years 1-6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15
Chippers	$ --	$ 435,200	$ 696,320	$ 522,240	$ 348,160	$ 174,080	$ 435,200	$ 696,320	$ 522,240	$ 348,160
Feller-Bunchers	--	868,000	1,388,800	1,041,600	694,400	1,215,200	1,388,800	1,041,600	694,400	1,215,200
Forwarders	--	476,000	761,600	571,200	380,800	666,400	761,600	571,200	380,800	666,400
Truck-Tractors	--	197,200	315,520	236,640	354,960	394,400	236,640	354,960	394,400	236,640
Chip Vans	--	470,400	752,640	564,480	376,320	188,160	--	--	--	470,400
Pickup Trucks	--	23,100	31,500	15,400	23,100	31,500	15,400	23,100	31,500	15,400
Crew Vans	--	46,200	63,000	30,800	46,200	63,000	30,800	46,200	63,000	30,800
Maintenance Trucks	--	83,160	113,400	55,440	--	--	83,160	113,400	55,440	--
Fuel Trucks	--	13,200	18,000	8,800	--	--	13,200	18,000	8,800	--
Fuel Tanks	--	11,200	17,920	13,440	8,960	4,480	11,200	17,920	13,440	8,960
Chip Unloaders	--	44,000	70,400	52,800	35,200	17,600	--	--	--	--
D-4 Dozers	--	183,400	293,440	220,080	146,720	73,360	183,400	293,440	220,080	146,720
Knife Grinders	--	25,600	40,960	30,720	20,480	10,240	--	--	--	25,600
Contingency	--	431,550	684,630	504,660	365,600	426,080	474,040	447,000	310,480	468,800
Total	--	$3,308,210	$5,248,130	$3,868,300	$2,800,900	$3,264,500	$3,633,440	$3,623,140	$2,694,580	$3,633,080

	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23	Year 24
Chippers	$ 174,080	$ 435,200	$ 696,320	$ 522,240	$ 348,160	$ 174,080	$ 435,200	$ 696,320	$ 522,240
Feller-Bunchers	1,388,800	1,041,600	694,400	1,215,200	1,388,800	1,041,600	694,400	1,215,200	1,388,800
Forwarders	761,600	571,200	380,800	666,400	761,600	571,200	380,800	666,400	761,600
Truck-Tractors	354,960	394,400	236,640	354,960	394,400	236,640	354,960	394,400	236,640
Chip Vans	752,640	564,480	376,320	188,160	--	--	--	470,400	752,640
Pickup Trucks	23,100	31,500	15,400	23,100	31,500	15,400	23,100	31,500	15,400
Crew Vans	46,200	63,000	30,800	46,200	63,000	30,800	46,200	63,000	30,800
Maintenance Trucks	--	83,160	113,400	55,440	--	--	83,160	113,400	55,440
Fuel Trucks	--	13,200	18,000	8,800	--	--	13,200	18,000	8,800
Fuel Tanks	4,480	11,200	17,920	13,440	8,960	4,480	11,200	17,920	13,440
Chip Unloaders	--	44,000	70,400	52,800	35,200	17,600	--	--	--
D-4 Dozers	73,360	183,400	293,440	220,080	146,720	73,360	183,400	293,440	220,080
Knife Grinders	40,960	30,720	20,480	10,240	--	--	--	25,600	40,960
Contingency	537,280	496,640	432,920	494,680	493,800	372,000	369,270	624,550	618,980
Total	$4,157,460	$3,963,700	$3,397,240	$3,871,740	$3,672,140	$2,537,160	$2,594,890	$4,630,130	$4,665,820

Table 8-7: Summary of Tax Credits

	Years 1-6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14
Nursery									
Regular		298,142			5,300	3,420		4,720	
Energy		300,462			--	--		--	
Total		598,604			5,300	3,420		4,720	
Plantation									
Regular		4,503,150							
Energy		4,512,150							
Total		9,015,300							
Total Plantation Operations									
Regular		4,801,292			5,300	3,420		4,720	
Energy		4,812,612			--	--		--	
Total	None	9,613,904			5,300	3,420		4,720	
Harvesting, Chipping & Hauling									
Regular		1,594,000			128,000	773,000	382,000	128,000	
Energy		1,617,000			--	--	--	--	
Total	None	3,211,000			128,000	773,000	382,000	128,000	

	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20	Year 21	Year 22	Year 23
Nursery									
Regular									
Energy									
Total									
Plantation									
Regular									
Energy									
Total									
Total Plantation Operations									
Regular									
Energy									
Total									
Harvesting, Chipping & Hauling									
Regular	1,058,000	128,000	408,000		901,000			510,000	1,058,000
Energy	--	--	--		--			--	--
Total	1,058,000	128,000	408,000		901,000			510,000	1,058,000

Table 8-8: Energy Tree Farm Net Cash Outflow
($000)

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10	YEAR 11	YEAR 12	YEAR 13
TREE FARMING OPERATIONS													
COSTS													
ESTABLISHMENT COSTS													
NURSERY LAND PURCHASE	$ 126	-	-	-	-	-	-	-	-	-	-	-	-
NURSERY	3,005	2	2	740	2	2	-	-	-	53	34	-	47
LABORATORY	155	-	-	-	-	-	-	-	-	-	-	-	-
SHOPS	2,000	-	-	-	-	-	-	-	-	-	-	-	-
PLANTATION AND ROADS	4,850	4,850	4,850	6,700	6,700	6,700	-	-	-	-	-	-	-
SUBTOTAL	10,136	4,852	4,852	7,440	6,702	6,702	-	-	-	53	34	-	47
OPERATING COSTS													
LAND LEASE COSTS	245	491	736	981	1,227	1,472	1,472	1,472	1,472	1,472	1,472	1,472	1,472
MANAGEMENT & CONTROL	1,145	1,145	1,145	1,145	1,145	1,145	435	435	435	435	435	435	435
NURSERY	435	435	435	435	435	435	217	217	217	217	217	217	217
LABORATORY	157	157	157	157	157	157	157	157	157	220	220	220	220
SHOPS	315	630	1,260	1,260	1,260	1,260	1,260	1,260	1,260	1,260	1,260	1,260	1,260
SUBTOTAL	2,297	2,858	3,733	3,978	4,224	4,469	3,542	3,542	3,542	3,604	3,604	3,604	3,604
TOTAL COSTS	12,433	7,710	8,585	11,418	10,926	11,171	3,542	3,542	3,542	3,657	3,638	3,604	3,651
LESS COST OF LAND	126	-	-	-	-	-	-	-	-	-	-	-	-
NET COSTS TO BE DEFERRED	12,307	7,710	8,585	11,418	10,926	11,171	3,542	3,542	3,542	3,657	3,638	3,604	3,651
AMORTIZATION OF DEFERRED COSTS	-	-	-	-	-	-	10,353	10,353	10,353	10,353	10,353	10,353	3,587
INCOME BEFORE TAX	-	-	-	-	-	-	(10,353)	(10,353)	(10,353)	(10,353)	(10,353)	(10,353)	(3,587)
CAPITAL GAINS TAXES	-	-	-	-	-	-	(3,106)	(3,106)	(3,106)	(3,106)	(3,106)	(3,106)	(1,076)
INCOME AFTER TAX	-	-	-	-	-	-	(7,247)	(7,247)	(7,247)	(7,247)	(7,247)	(7,247)	(2,511)
PLUS AMORTIZATION OF COSTS	-	-	-	-	-	-	10,353	10,353	10,353	10,353	10,353	10,353	3,587
LESS DEFERRED COSTS	12,307	7,710	8,585	11,418	10,926	11,171	3,542	3,542	3,542	3,657	3,638	3,604	3,651
LESS COST OF LAND	126	-	-	-	-	-	-	-	-	-	-	-	-
PLUS TAX CREDITS	-	-	-	-	-	-	9,614	-	-	5	3	-	5
NET CASH FLOW	(12,433)	(7,710)	(8,585)	(11,418)	(10,926)	(11,171)	9,178	(436)	(436)	(546)	(529)	(498)	(2,570)
HARVESTING, CHIPPING, & HAULING													
OPERATING EXPENSES	-	-	-	-	-	-	10,825	12,765	11,385	10,318	10,781	11,150	11,140
INCOME BEFORE TAX	-	-	-	-	-	-	(10,825)	(12,765)	(11,385)	(10,318)	(10,781)	(11,150)	(11,140)
INCOME TAXES	-	-	-	-	-	-	(5,332)	(6,288)	(5,608)	(5,083)	(5,311)	(5,492)	(5,488)
INCOME AFTER TAX	-	-	-	-	-	-	(5,493)	(6,477)	(5,777)	(5,235)	(5,470)	(5,658)	(5,652)
PLUS DEPRECIATION	-	-	-	-	-	-	3,308	5,248	3,868	2,801	3,265	3,633	3,623
LESS CAPITAL EXPENDITURES	-	-	-	-	-	-	16,452	-	-	1,375	7,728	3,957	1,375
PLUS TAX CREDITS	-	-	-	-	-	-	3,212	-	-	128	773	382	128
NET CASH FLOW	-	-	-	-	-	-	(15,425)	(1,229)	(1,909)	(3,681)	(9,161)	(5,599)	(3,276)
TOTAL PROJECT CASH FLOW	(12,433)	[illegible]	(8,585)	(11,418)	(10,926)	(11,171)	(6,247)	(1,665)	(2,344)	(4,227)	(9,690)	(6,097)	(5,847)

Table 8-9: Energy Tree Farm Net Cash Outflow
($000)

	YEAR 14	YEAR 15	YEAR 16	YEAR 17	YEAR 18	YEAR 19	YEAR 20	YEAR 21	YEAR 22	YEAR 23	YEAR 24
TREE FARMING OPERATIONS											
COSTS											
ESTABLISHMENT COSTS											
NURSERY LAND PURCHASE	-	-	-	-	-	($ 126)	-	-	-	-	-
NURSERY	-	-	-	-	-	-	-	-	-	-	-
LABORATORY	-	-	-	-	-	-	-	-	-	-	-
SHOPS	-	-	-	-	-	-	-	-	-	-	-
PLANTATION AND ROADS	-	-	-	-	-	-	-	-	-	-	-
SUBTOTAL	-	-	-	-	-	(126)	-	-	-	-	-
OPERATING COSTS											
LAND LEASE COSTS	1,472	1,472	1,472	1,472	1,472	-	-	-	-	-	-
MANAGEMENT & CONTROL	435	435	435	435	435	-	-	-	-	-	-
NURSERY	217	217	217	217	217	-	-	-	-	-	-
LABORATORY	220	220	220	220	220	-	-	-	-	-	-
SHOPS	1,260	1,260	1,260	1,260	1,260	-	-	-	-	-	-
SUBTOTAL	3,604	3,604	3,604	3,604	3,604	-	-	-	-	-	-
TOTAL COSTS	3,604	3,604	3,604	3,604	3,604	(126)	-	-	-	-	-
LESS COST OF LAND	-	-	-	-	-	(126)	-	-	-	-	-
NET COSTS TO BE DEFERRED	3,604	3,604	3,604	3,604	3,604	-	-	-	-	-	-
AMORTIZATION OF DEFERRED COSTS	3,587	3,587	3,587	3,587	3,587	3,612	3,612	3,612	3,612	3,612	3,612
INCOME BEFORE TAX	(3,587)	(3,587)	(3,587)	(3,587)	(3,587)	(3,612)	(3,612)	(3,612)	(3,612)	(3,612)	(3,612)
CAPITAL GAINS TAXES	(1,076)	(1,076)	(1,076)	(1,076)	(1,076)	(1,084)	(1,084)	(1,084)	(1,084)	(1,084)	(1,084)
INCOME AFTER TAX	(2,511)	(2,511)	(2,511)	(2,511)	(2,511)	(2,528)	(2,528)	(2,528)	(2,528)	(2,528)	(2,528)
PLUS AMORTIZATION OF COSTS	3,587	3,587	3,587	3,587	3,587	3,612	3,612	3,612	3,612	3,612	3,612
LESS DEFERRED COSTS	3,604	3,604	3,604	3,604	3,604	-	-	-	-	-	-
LESS COST OF LAND	-	-	-	-	-	(126)	-	-	-	-	-
PLUS TAX CREDITS	-	-	-	-	-	-	-	-	-	-	-
NET CASH FLOW	(2,528)	(2,528)	(2,528)	(2,528)	(2,528)	1,210	1,084	1,084	1,084	1,084	1,084
HARVESTING, CHIPPING, & HAULING											
OPERATING EXPENSES	10,211	11,150	11,674	11,481	10,914	12,861	12,416	11,035	10,848	12,638	12,428
INCOME BEFORE TAX	(10,211)	(11,150)	(11,674)	(11,481)	(10,914)	(12,861)	(12,416)	(11,035)	(10,848)	(12,638)	(12,4[illegible])
INCOME TAXES	(5,030)	(5,492)	(5,751)	(5,655)	(5,376)	(6,335)	(6,116)	(5,436)	(5,344)	(6,225)	(6,122)
INCOME AFTER TAX	(5,181)	(5,657)	(5,924)	(5,825)	(5,538)	(6,525)	(6,300)	(5,599)	(5,504)	(6,413)	(6,306)
PLUS DEPRECIATION	2,695	3,633	4,157	3,964	3,397	3,872	3,672	2,537	2,595	4,630	4,666
LESS CAPITAL EXPENDITURES	-	10,580	1,375	4,210	-	9,103	-	-	5,333	10,580	-
PLUS TAX CREDITS	-	1,058	128	408	-	901	-	-	510	1,058	-
NET CASH FLOW	(2,487)	(11,546)	(3,013)	(5,664)	(2,141)	(10,856)	(2,628)	(3,062)	(7,732)	(11,304)	(1,640)
TOTAL PROJECT CASH FLOW	(5,015)	(14,074)	(5,541)	(8,191)	(4,668)	(9,646)	(1,544)	(1,978)	(6,649)	(10,221)	(556)

Table 8-10: Energy Tree Farm Profit & Loss and Cash Flow
($000)

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	YEAR 6	YEAR 7	YEAR 8	YEAR 9	YEAR 10	YEAR 11	YEAR 12	YEAR 13
TREE FARMING OPERATIONS													
REVENUE	-	-	-	-	-	-	$ 16,933	$ 16,933	$ 16,933	$ 16,933	$ 16,933	$ 16,933	$ 16,933
COSTS													
ESTABLISHMENT COSTS													
NURSERY LAND PURCHASE	$ 126	-	-	-	-	-	-	-	-	-	-	-	-
NURSERY	3,005	2	2	740	2	2	-	-	-	53	34	-	47
LABORATORY	155	-	-	-	-	-	-	-	-	-	-	-	-
SHOPS	2,000	-	-	-	-	-	-	-	-	-	-	-	-
PLANTATION AND ROADS	4,850	4,850	4,850	6,700	6,700	6,700	-	-	-	-	-	-	-
SUBTOTAL	10,136	4,852	4,852	7,440	6,702	6,702	-	-	-	53	34	-	47
OPERATING COSTS													
LAND LEASE COSTS	245	491	736	981	1,227	1,472	1,472	1,472	1,472	1,472	1,472	1,472	1,472
MANAGEMENT & CONTROL	1,145	1,145	1,145	1,145	1,145	1,145	435	435	435	435	435	435	435
NURSERY	435	435	435	435	435	435	217	217	217	217	217	217	217
LABORATORY	157	157	157	157	157	157	157	157	157	220	220	220	220
SHOPS	315	630	1,260	1,260	1,260	1,260	1,260	1,260	1,260	1,260	1,260	1,260	1,260
SUBTOTAL	2,297	2,858	3,733	3,978	4,224	4,469	3,542	3,542	3,542	3,604	3,604	3,604	3,604
TOTAL COSTS	12,433	7,710	8,585	11,418	10,926	11,171	3,542	3,542	3,542	3,657	3,638	3,604	3,651
LESS COST OF LAND	126	-	-	-	-	-	-	-	-	-	-	-	-
NET COSTS TO BE DEFERRED	12,307	7,710	8,585	11,418	10,926	11,171	3,542	3,542	3,542	3,657	3,638	3,604	3,651
AMORTIZATION OF DEFERRED COSTS	-	-	-	-	-	-	10,353	10,353	10,353	10,353	10,353	10,353	3,587
INCOME BEFORE TAX	-	-	-	-	-	-	6,580	6,580	6,580	6,580	6,580	6,580	13,346
CAPITAL GAINS TAXES	-	-	-	-	-	-	1,974	1,974	1,974	1,974	1,974	1,974	4,004
INCOME AFTER TAX	-	-	-	-	-	-	4,606	4,606	4,606	4,606	4,606	4,606	9,342
PLUS AMORTIZATION OF COSTS	-	-	-	-	-	-	10,353	10,353	10,353	10,353	10,353	10,353	3,587
LESS DEFERRED COSTS	12,307	7,710	8,585	11,418	10,926	11,171	3,542	3,542	3,542	3,657	3,638	3,604	3,651
LESS COST OF LAND	126	-	-	-	-	-	-	-	-	-	-	-	-
PLUS TAX CREDITS	-	-	-	-	-	-	3,614	-	-	5	3	-	5
NET CASH FLOW	(12,433)	(7,710)	(8,585)	(11,418)	(10,926)	(11,171)	21,031	11,417	11,417	11,307	11,324	11,355	9,283
HARVESTING, CHIPPING, & HAULING													
REVENUE	-	-	-	-	-	-	11,117	11,117	11,117	11,117	11,117	11,117	11,117
OPERATING EXPENSES	-	-	-	-	-	-	10,825	12,765	11,385	10,318	10,781	11,150	11,140
INCOME BEFORE TAX	-	-	-	-	-	-	292	(1,648)	(268)	799	336	(33)	(23)
INCOME TAXES	-	-	-	-	-	-	144	(312)	(132)	294	165	(16)	(11)
INCOME AFTER TAX	-	-	-	-	-	-	148	(336)	(136)	406	170	(17)	(12)
PLUS DEPRECIATION	-	-	-	-	-	-	3,308	5,248	3,868	2,801	3,265	3,684	3,623
LESS CAPITAL EXPENDITURES	-	-	-	-	-	-	16,452	-	-	1,375	7,728	3,957	1,375
PLUS TAX CREDITS	-	-	-	-	-	-	3,211	-	-	128	773	332	128
NET CASH FLOW	-	-	-	-	-	-	(9,785)	4,412	3,732	1,959	(3,520)	42	2,364
TOTAL PROJECT CASH FLOW	(12,433)	(7,710)	(8,585)	(11,418)	(10,926)	(11,171)	11,246	15,829	15,149	13,267	7,804	11,396	11,647

Table 8-11: Energy Tree Farm Profit & Loss and Cash Flow
($000)

	YEAR 14	YEAR 15	YEAR 16	YEAR 17	YEAR 18	YEAR 19	YEAR 20	YEAR 21	YEAR 22	YEAR 23	YEAR 24
TREE FARMING OPERATIONS											
REVENUE	$ 16,933	$ 16,933	$ 16,933	$ 16,933	$ 16,933	$ 16,933	$ 16,933	$ 16,933	$ 16,933	$ 16,933	$ 16,933
COSTS											
ESTABLISHMENT COSTS											
NURSERY LAND PURCHASE	-	-	-	-	-	($ 126)	-	-	-	-	-
NURSERY	-	-	-	-	-	-	-	-	-	-	-
LABORATORY	-	-	-	-	-	-	-	-	-	-	-
SHOPS	-	-	-	-	-	-	-	-	-	-	-
PLANTATION AND ROADS											
SUBTOTAL	-	-	-	-	-	(126)	-	-	-	-	
OPERATING COSTS											
LAND LEASE COSTS	1,472	1,472	1,472	1,472	1,472	-	-	-	-	-	-
MANAGEMENT & CONTROL	435	435	435	435	435	-	-	-	-	-	-
NURSERY	217	217	217	217	217	-	-	-	-	-	-
LABORATORY	220	220	220	220	220	-	-	-	-	-	-
SHOPS	1,260	1,260	1,260	1,260	1,260						
SUBTOTAL	3,604	3,604	3,604	3,604	3,604						
TOTAL COSTS	3,604	3,604	3,604	3,604	3,604	(126)					
LESS COST OF LAND						(126)					
NET COSTS TO BE DEFERRED	3,604	3,604	3,604	3,604	3,604	-	-	-	-	-	-
AMORTIZATION OF DEFERRED COSTS	3,587	3,587	3,587	3,587	3,587	3,612	3,612	3,612	3,612	3,612	3,612
INCOME BEFORE TAX	13,346	13,346	13,346	13,346	13,346	13,321	13,321	13,321	13,321	13,321	13,321
CAPITAL GAINS TAXES	4,004	4,004	4,004	4,004	4,004	3,996	3,996	3,996	3,996	3,996	3,996
INCOME AFTER TAX	9,342	9,342	9,342	9,342	9,342	9,325	9,325	9,325	9,325	9,325	9,325
PLUS AMORTIZATION OF COSTS	3,587	3,587	3,587	3,587	3,587	3,612	3,612	3,612	3,612	3,612	3,612
LESS DEFERRED COSTS	3,604	3,604	3,604	3,604	3,604	-	-	-	-	-	-
LESS COST OF LAND	-	-	-	-	-	(126)	-	-	-	-	-
PLUS TAX CREDITS											
NET CASH FLOW	9,325	9,325	9,325	9,325	9,325	13,063	12,937	12,937	12,937	12,937	12,937
HARVESTING, CHIPPING, & HAULING											
REVENUE	11,117	11,117	11,117	11,117	11,117	11,117	11,117	11,117	11,117	11,117	11,117
OPERATING EXPENSES	10,211	11,150	11,674	11,481	10,914	12,861	12,416	11,035	10,848	12,638	12,428
INCOME BEFORE TAX	906	(33)	(557)	(364)	203	(1,744)	(1,299)	82	269	(1,521)	(1,311)
INCOME TAXES	446	(16)	(275)	(179)	100	(859)	(640)	40	133	(749)	(646)
INCOME AFTER TAX	459	(17)	(283)	(184)	103	(885)	(659)	42	137	(772)	(665)
PLUS DEPRECIATION	2,695	3,633	4,157	3,964	3,397	3,872	3,672	2,537	2,595	4,630	4,666
LESS CAPITAL EXPENDITURES	-	10,580	1,375	4,210	-	9,103	-	-	5,333	10,580	-
PLUS TAX CREDITS		1,058	128	408		201			510	1,058	
NET CASH FLOW	3,154	(5,906)	2,623	(23)	3,500	(5,215)	3,013	2,579	(2,092)	(5,664)	4,001
TOTAL PROJECT CASH FLOW	12,479	3,420	11,953	9,302	12,825	7,848	15,950	15,515	10,845	7,273	16,937

COORDINATION AND MANAGEMENT

Cost estimates considered so far are for specific tree plantation operations, including nursery, cultivation, hearvesting, etc. The size of this venture suggests that the costs of coordinating and managing the tree plantation must also be considered.

An organization chart showing the management of the plantation is shown in Figure 8-3. The number of supervisory personnel identified is consistent with other operations of this size in the area. Even though the chart has not been formulated in great detail, it should suffice to indicate the cost involved in the management and coordination of the tree plantation. The numbers in each component of the chart represent the number of supervisory personnel required. It is assumed that certain operations, such as chip hauling and road maintenance, will function on a two shift basis.

To project the cost of coordination and management, the supervisory personnel depicted in Figure 8-1 are placed into two groups: the project manager and controller group, and the field manager group. The cost of the first group is estimated as four percent of the total operating cost of the tree plantation (the cost of specific operations developed previously). This will be \$449,000 per year. The cost of the field manager group is estimated based on the number of supervisory personnel and annual cost of different classes of supervisors. It is estimated at \$696,000. Of the \$1,145,000 total coordination and management cost, \$710,000 should be allocated to the harvesting/chipping/hauling operations (70 percent of \$449,000, plus the salaries of the harvesting and road construction supervisors); the remaining \$435,000 should be charged to the farming operations. (During the initial six-year planting period, however, there are no harvesting operations and all management expenses must be charged to the agriculture function.)

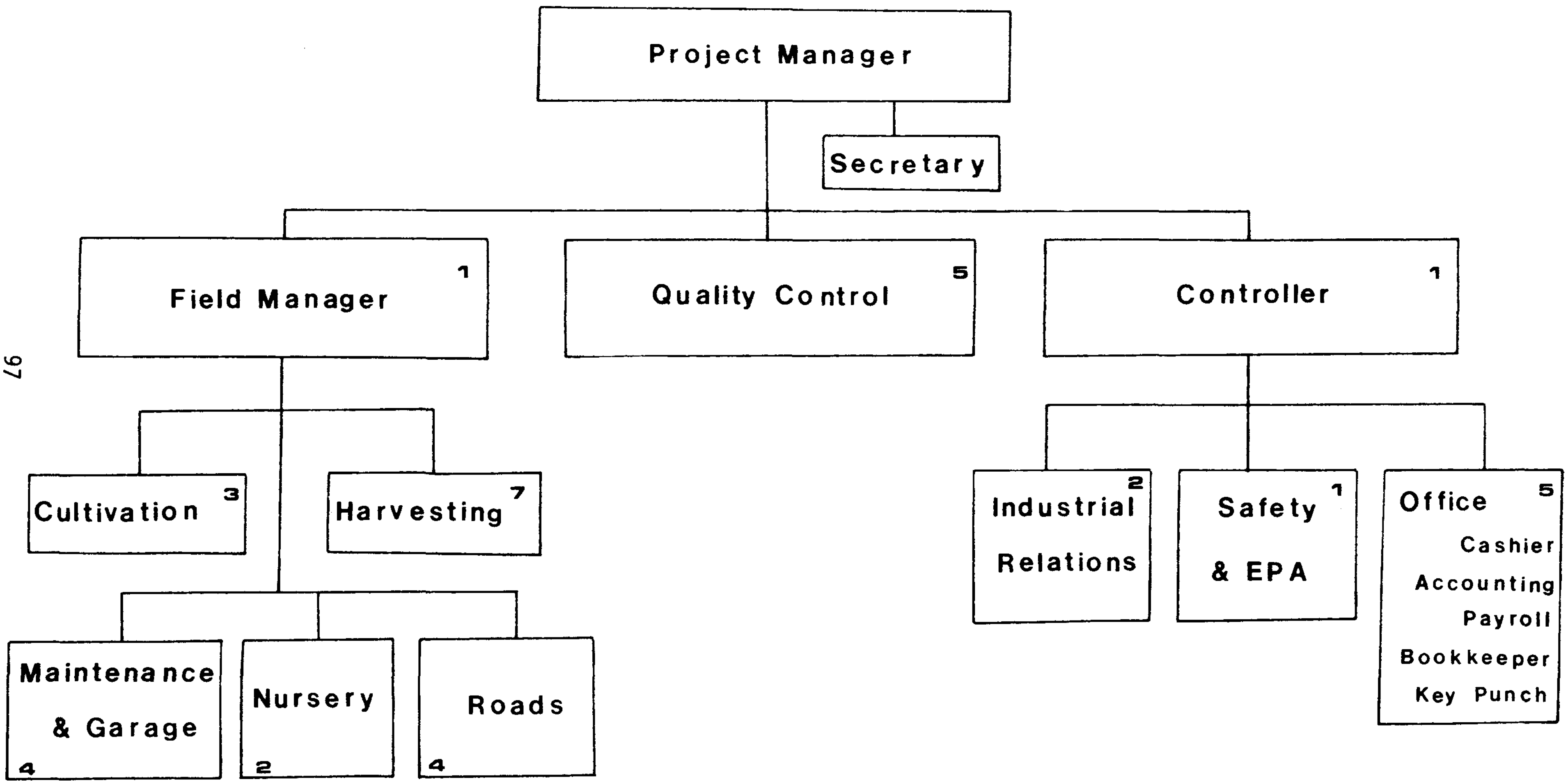
TOTAL CASH FLOW

A financial overview of the proposed project is presented in two alternative ways:

- o Table 8-8 gives the average cost of chips, as if used as feedstock in a subsequent processing operation. Revenues are assumed to be zero; costs and production are adjusted for time values, as previously discussed.

- o Table 8-9 shows the Profit and Loss Statement and cash flow used to derive the 12 percent rate of return if a revenue is assigned to the chips produced. The assigned revenue is based on the assumption that each ton of chips (green weight) is approximately equal to one barrel of boiler fuel; at 935,000 tons of chips per year and $30 per barrel for oil, this results in a total revenue assumption of $28,050,000 per year. Of this total revenue, $11,117,000 is allocated to harvesting (representing the $6,800,000 approximate cash cost per year, plus $4,310,000 for recovery of the initial capital investment, plus an 8 percent cost of money/profit factor).

Figure 8-1



Project Manager
Secretary
Field Manager 1
Quality Control 5
Controller 1
Cultivation 3
Harvesting 7
Maintenance & Garage 4
Nursery 2
Roads 4
Industrial Relations 2
Safety & EPA 1
Office 5
Cashier
Accounting
Payroll
Bookkeeper
Key Punch

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Appendix A

RESUMES

AGUIAR, GENE

Education:	BA, 1966, University of Portland, Political Science.
Experience:	1981 to present: Davies Hamakua Sugar Company Land Coordinator – land sales, exchanges, development, etc. 1971-81: Theo H. Davies & Co., Ltd. (Laupahoehoe Sugar Company & Davies Hamakua Sugar Company) Industrial Relations Director, Industrial Relations Activities & Housing Management & Development. 1969-71: Hamakua Mill Company, Irrigation Supervisor Development and installation of irrigation system.

CANAN, PENELOPE

Education and Memberships:	Ph.D., 1976, M.A. 1972 University of Denver, Sociology, A.B. 1969 University of North Carolina-Chapel Hill. Member, American Sociological Association, American Planning Association, Pacific Sociological Association, Sociologists for Women in Society.
Experience:	1978 to present: University of Hawaii, teaching policy analysis, community development, social impact assessment, community services, and facilities planning; 1977-78, Univ. Virginia, Director Federal Presence in Middletown, USA; 1976-77 East-West Center Research Participant; 1975-76, American Bar Foundation, Research Associate.
Contributions and Awards:	Published Moloka'i Data Book: Community Values and Energy Development, 1981; published Overview of Socio-Economic Issues in Geothermal Energy Development in Hawaii, 1980. Much research on social change related to alternate energy development.

CHING, CHAUNCEY T.K.

Education: Ph.D. 1967 University of California-Davis (Agricultural Economics), M.S. 1965 University of California-Davis (Agricultural Economics), B.A. 1962 University of California-Berkeley (Economics).

Experience: 1980 to present: Professor of Agricultural Economics, University of Hawaii at Manoa – production economics research, teaching in computer application to economic analyses; 1972-80: University of Nevada-Reno, production economics research teaching in production economics and operations research; 1968-72: University of New Hampshire, resource economics research, teaching in regional economics and statistics.

DENYES, JOHN S.

Education and Memberships: M.B.A. 1965 Harvard, B.S. 1963 University of California-Berkeley, Mechanical Engineering; Member of Pi Tau Sigma, Tau Beta Pi, Hawaiian Sugar Technologists, Hawaii Society of Corporate Planners, part member of California Institute of Technology.

Experience: 1981 to present: Director of Corporate Development, Alexander & Baldwin, Inc., planning, capital budgeting, acquisition analysis; 1975-81: Hawaiian Commercial & Sugar Company, Maui, Planning & Budget Department Head; 1969-75: HC&S, Planning Superintendent/Planning Manager; 1968-69: Alexander & Baldwin, Inc., Planning Analyst; 1965-68: C. Brewer & Company, Hilo and Honolulu, Industrial Engineering/Planning Department.

Contributions: Analysis of koa haole fuel wood farm on Molokai; formulation and application of computerized financial forecasting/planning model for sugar plantation; analysis of irrigation system selection and expansion program for largest plantation in Hawaii; feasibility study of expansion and alternative cropping program for 9000-acre potato/wheat farm in Washington; evaluation of possible acquisitions of two sugar plantations, meat packing firm, agricultural equipment suppliers, etc.

FUJITA, ROBERT K.

Education and Memberships:	B.S. 1948 Chemistry, University of Hawaii; Member of American Chemical Society (AC) and American Society for Testing and Materials (ASTM).
Experience:	Present: Manager, Technical Liaison, Pacific Resource, Inc.; 1949-present: Honolulu Gas Co., predecessor of PRI, Inc., Chief Chemist, quality control and research to improve gas plant operation. Developed patented process for gas purification and process for benzene purification.

HOLDERNESS, JAMES S.

Education and Memberships:	M.S. in Agriculture, Cornell University; B.S. University of Idaho; Member American Agricultural Economics Association and Agricultural Communicators in Education.
Experience:	Present: Associate Professor, Agricultural & Resource Economics, University of Hawaii at Manoa; 1977-present: teaching agribusiness management and agricultural finance at Manoa with research in the production economics of sugarcane among independent growers on the Hilo Coast; sabbatical year at Texas A&M University, lecturer in agribusiness management (1977); 1969-76: Science Editor, College of Tropical Agriculture, University of Hawaii at Manoa; 1966-69: national level agricultural development officer (AID), Vietnam; 1963-66: Agricultural Editor, University of Idaho, Moscow.
Contributions and Awards:	Several publications dealing with the viability of small farmers and indendent sugarcane growers; Editor of Hawaii Farm Science. Agricultural medal, Government of South Vietnam.

HORIUCHI, HOWARD H.

Education:	B.S. 1967 Oregon State University.
Experience:	1967 to present: Forest management in Hawaii.

IKAWA, HARUYOSHI

Education and Memberships: Ph.D. 1968 Penn State University, M.S. 1956 University of Hawaii at Manoa; member of American Society of Agronomy, Soil Science Society of America, International Soil Science Society.

Experience: 1955 to present: University of Hawaii at Manoa, soil characterization and classification, teaching introductory soil science, soil formation, and classification. Sabbatical leaves with Soil Correlation Unit of USDA Soil Conservation Service, Texas, and Agricultural University at Wageningen, the Netherlands.

Contributions: Published papers on the classification of soils of Hawaii.

KAMEN, TERRY P.

Education: B.A. 1972 University of New York, Queens College Division, Communications and Engineering.

Experience: Present: Owner and President of Woodfuels, Inc. Operator of wood chips for energy production on Kauai, supplying Lihue Plantation's bagasse boiler.

Contributions: Created first wood chip business solely for energy production in Hawaii. Many previous experiments had been with waste material from other logging operations.

KING, TERI D.

Education and Membership: A.S. 1976, Hawaii Community College; member of Young Farmer's Organization.

Experience: 1981 to present: BioEnergy Development Corp., Operations Supervisor, oversees total project operation; 1979-81: BioEnergy Development Corp., Forest Technician; 1978-79: Hawaii Community College, Farm Assistant.

LEUNG, PATRICK C. H.

Education and
Memberships: M.B.A. candidate, University of Hawaii at Manoa, B.B.A. 1977 University of Hawaii at Manoa; member of American Institute of Certified Public Accountants, Hawaii Society of Certified Public Accountants, Hawaii Society of Corporate Planners, National Association of Accountants.

Experience: 1979 to present: Pacific Resources, Inc., Financial Reporting and Control Coordinator; 1977-79: Ernst and Whinney, Accountant.

MacDICKEN, KENNETH G.

Education and
Memberships: M.S. program in Agronomy, University of Hawaii at Manoa, 1981-present; Fifth year program in Gen. Agriculture (Forestry), Washington State University, 1980; B.A. Washington State University, Political Science – Natural Resources Policy Administration, 1980; member: International Society of Tropical Foresters, Soil Conservation Society of America, American Society of Agronomy.

MELROSE, JEFFREY

Education: M.A. 1981 University of Hawaii at Manoa (Urban and Regional Planning); Certificate, 1976 Stanford University, Mass Media Institute; B.A. 1974 Western Washington University.

Experience: 1979 to present: Participant East-West Center Open Grants; 1981: University of the South Pacific, Associate, Institute for Pacific Studies; 1976-78: Project LEARN, Kohala Center for Continuing Education; 1975-76: Lapakahi State Historical Park, Historic Park Specialist.

Awards: Co-produced Moloka'i Data Book: Community Values and Energy Development, 1981; co-produced Kohala Keia: Collected Expressions of a Community, 1978; Makana Award for Individual Contribution to the East-West Center 1981.

MIYASAKA, SUSAN

Education and Memberships: M.S. 1979 University of Hawaii at Manoa, B.S. 1976 University of California-Berkeley.

Experience: 1980 to present: BioEnergy Development Corporation, Agronomist/Soil Scientist, responsible for all cooperative research efforts with the U.S. Forest Service; 1977-79: University of Hawaii Cooperative Extension Service, Lab Technician.

Contributions: Co-authored paper on calcium nutrition of Taro, 1979. Research experience in experimental design.

SEKI, ARTHUR

Education and Membership: M.S. 1976 University of Hawaii at Manoa, Sanitary Engineering; B.S. 1974 Arizona State University, Chemical Engineering; member of American Institute of Chemical Engineers.

Experience: 1976 to present: Hawaii Natural Energy Institute, field work and data analysis with Hawaii Geothermal Project, energy self-sufficiency research analysis for Maui County, Kauai County, and Molokai; solar researcher on Wilcox Hospital photovoltaic project and rooftop photovoltaic project; biomass resource analysis on synthetic fuel project.

Contributions: Published numerous papers on geothermal engineering and well-test analysis, and energy self-sufficiency for various counties and islands.

SIEGEL, SANFORD M.

Education and Memberships: Ph.D. 1953, M.S. 1950 University of Chicago; member of American Chemical Society, Scandinavian Society of Plant Physiologists, Phi Beta Kappa, Sigma Xi; 1979-82: Secretary, Life Sciences Commission of the ICSU Committee on Space Research (COSPAR); 1970-present: member of Environmental Health Committee, Hawaii Chapter, American Lung Association; 1972-74: Environmental Advisory Committee, National Aeronautics and Space Administration.

Experience: 1980 to present: Chairman, Department of Botany, University of Hawaii at Manoa; 1967-present: Professor of Botany, UHM; 1958-67: Head, Physical Biochemistry Group, Union Carbide Research Institute, N.Y.; 1955-58: Assistant Professor of Biology, University of Rochester.

Contribution and Awards: Over 200 technical papers and reviews published, also 10 chapters in books and symposium volumes and 1 monograph; 45 publications on toxic metals. 1974 Senior Fellow, Weizmann Institute, Israel; 1970 NASA Fellowship, Iceland-Surtsey Expedition; 1957 Guggenheim Fellow, University of Rochester; 1953 Research Fellow, Cal Tech.

SIROIS, DONALD L.

Education and Memberships: B.S. 1959, Bucknell University. Adjunct Associate Professor, Department of Forestry, Auburn University; member of Society of Automotive Engineers Sub. Comm. 28 Forestry and Logging Equipment; Advisory member to Sub. Comm. PM 55 Forestry Equipment of American Society of Agricultural Engineers; member of Technical Advisory Group (TAG) in U.S. for the International Standards Organization (ISO) Sub. Comm. 15 for Forestry Machinery; Member Alabama Forestry Council.

Experience: 1976 to present: Southern Forest Experiment Station, forest engineering research related to forest management specializing in timber harvesting; 1970-75: Equipment Development Staff Engineer, U.S. Forest Service National Office, Washington, D.C.; 1960-69: Equipment Development Project Engineer, U.S.F.S. Equipment Development Center, San Dimas, CA.; 1959: Research Engineer, Curtiss Wright, Corp.

Contributions and Awards: Published 15 scientific papers and reports and 20 Forest Service national equipment specifications.

SKOLMEN, ROGER G.

Education and Memberships: Ph.D. 1977, University of Hawaii at Manoa, Agronomy and Soil Science, Tissue Culture, M.S. University of California, Silviculture, B.S. 1957, University of California. Member: Society of American Foresters, Tissue Culture Association, International Association of Plant Tissue Culture, Forest Products Research Society. Registered Professional Forester, State of California No. 490. Published 36 papers on various forestry research subjects outlined above.

Experience: 1960 to present: U.S. Forest Service research on forestry and forest products utilization in Hawaii, including forest survey, mensurational studies, studies of natural and artificial regeneration (tree planting); physical and mechanical properties, durability and uses of Eucalyptus saligna, robusta, globulus, Acacia koa, etc.; Growth of plantation species, tissue culture and other vegetative propagation techniques for koa, coppice management of E. globulus and E. saligna, management of koa, silviculture of E. saligna, globulus, robusta, Grevillea robusta, etc. 1958-60: Soil Scientist mapping soils and vegetation in Northern coastal California. 1979-present: member United Nations North American Forestry Commission Silviculture Study Group.

SPRAGUE, JOHN E.

Education and Memberships: M.S. 1958, B.S. 1954, Montana State University. Member, National Association Conservation Districts, past member, Soil Conservation Society of America.

Experience: 1960-81: District Conservationist with experience in small grain and livestock operations and tropical agriculture; 1958-60: soil conservationist; 1954-56: teacher of Vocational Agriculture; 1946-49: small grain farmer; 1944-46: U.S. Navy.

TAMIMI, YUSUF NIMR

Education and Memberships: Ph.D. 1963, University of Hawaii (Soil Chemistry); M.S. 1959, N. Mexico State University (Soil Chemistry); B.S. 1957, Purdue University (Agriculture); membership in American Society of Agronomy, American Society of Soil Science, International Society of Soil Science, Gamma Sigma Delta, Sigma Xi; member of an International Panel on Tropical Legumes called for by the National Academy of Sciences (1979).

Experience: 1959 to present: Professor of Soil Science, University of Hawaii at Manoa Forest tree nutrition, forest soils, soil fertility/chemistry/plant nutrition, pasture fertilization and management, field and vegetable crops, sugarcane. Investigation of forest soil in Indonesia (1972), sabbatical leave 1970-71: visiting Scientist Purdue University, sabbatical leave 1978-79: Professor and Head Department of Soils and Irrigation, University of Jordan; several consultantships on land utilization, pasture, and crop management.

Contributions and Awards: Published over 60 scientific papers, received several grants for research on pasture management and soil/plant relationships.

TROY, MARY D.

Education: B.A. 1970, University of Missouri, English and Education.

Experience: Present: Researcher, Writer/Editor, College of Engineering, University of Hawaii at Manoa; 1978-81: Writer/Editor, Hawaii Natural Energy Institute, writing and editing technical and general informarion reports, preparing public information publications; 1977-78: News Reporter, Advertising Copywriter; 1970-77: English and Composition teacher.

Contributions: Edited and wrote numerous papers and reports on biomass, geothermal, ocean, solar, and wind energy.

VAN DEN BELDT, RICK

Education and Memberships:	M.S. 1981, University of Hawaii at Manoa (Agronomy), B.S. 1973, Michigan State University (Forestry); member: Gamma Sigma Delta, Xi Sigma Pi.
Experience:	1978 to present: Degree participant, Resource Systems Institute, East-West Center, and research on biomass production of woody species for energy, University of Hawaii at Manoa. Consulting work in Hawaii and abroad for aboreal biomass production; 1973-77: U.S. Forest Service (surveying).
Contributions:	Published 7 articles and papers, including 3 delivered at international conferences.

WAKIDA, CHARLES K.

Education:	B.S. 1962, Oregon State University, Forest Management.
Experience:	1962 to present: District Forester, Hawaii District, Division of Forestry and Wildlife, Department of Land and Natural Resources. Various levels of responsibility in forest management on the island of Hawaii, including reforestation, forest product sales, wildlife fire protection, land use matters pertaining to Conservation Districts, and forest land and resource conservation and protection.

APPENDIX II

INSTITUTE OF GAS TECHNOLOGY
IIT CENTER
CHICAGO, ILLINOIS 60616

HYDROPYROLYSIS OF BIOMASS TO PRODUCE LIQUID HYDROCARBON FUELS

FINAL REPORT

Project 65045

for

PACIFIC RESOURCES, INCORPORATED

June 1982

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EXECUTIVE SUMMARY

This report describes work performed by the Institute of Gas Technology (IGT) as part of a study to investigate the feasibility of producing oils and other fuels from Hawaiian biomass. IGT's work has consisted of providing process designs and estimates of investment and operating costs using IGT's HYFLEX® process.

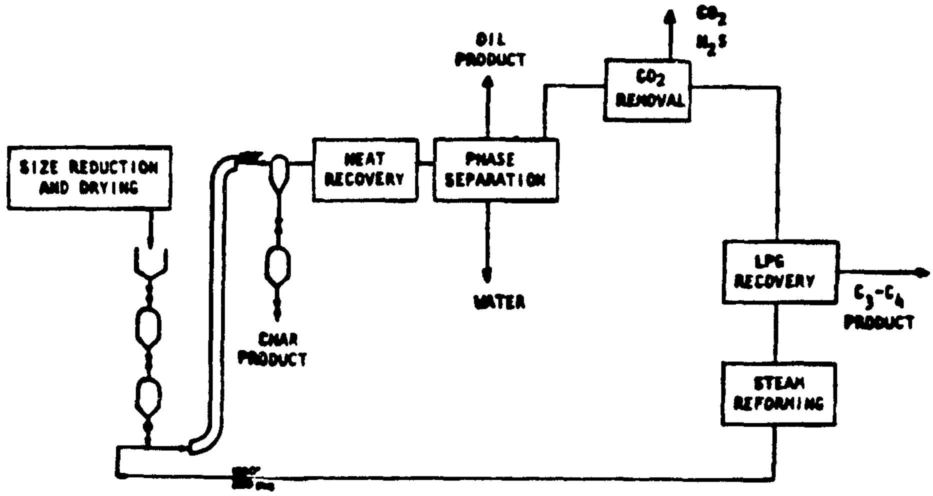
The HYFLEX process features a short residence time hydropyrolysis. Extensive design data had been previously developed in IGT laboratories on application of HYFLEX to lignites and a significant amount on application to peat. It was contemplated that this data base on lignite and peat conversion would be sufficient for preliminary screening designs, which would then be confirmed by tests on a Hawaiian biomass to be selected during the course of the project.

Early work consisted of establishing a Base Case Process Design and, simultaneously screening various candidate feedstocks by elemental chemical analysis and Fischer Assay analysis. At the beginning of March 1981, a decision was made by PRI that the preferred feedstock would be eucalyptus wood. This decision was taken on the basis that eucalyptus would be preferred because of availability. Following this all work, including the tests made to confirm the Base Case Process Design, were confined to eucalyptus.

This study is based on a system to pyrolyze 1000 tons/day (dry basis) of eucalyptus tree wood. Two separate events have been considered. In one case (Base Case A) it is considered that whole logs will be delivered to the plant. That being the case, an additional 678 tons/day (dry basis) of wood is required to produce steam, electric power, process heat, and heat to dry moist wood. Alternately, it is considered that wood chips may be delivered to the plant. In the latter case (Base Case B), reduction of utilities required for chipping and grinding wood, lowers the additional wood required to 464 tons/day (a total of 1464 tons/day instead of a total of 1678 tons/day).

The Base Case processing is depicted in the process flow diagram and described below.

Wood logs are brought to the plant and chipped (Base Case A) or alternately (Base Case B), wood, chipped in the field and air-dried to approximately



30% moisture, is brought to the plant by trucks. Wood chips are fed through size-reduction and drying equipment, where they are ground to about 20-mesh particle size and dried to a moisture content of 5% to 10%. Chips are then mixed with recycle gas and fed to the pyrolysis reactor. Following reaction at about 1100°F and 200 psig, char and liquids are separated from the reactor outlet gas. LPG and CO_2 are removed and, since fuel gas is not a desirable product at the location contemplated, the remaining gas is reformed with steam for production of a high hydrogen content gas that is recycled to the HYFLEX reactor.

Costs of all major equipment for the Base Case designs have been determined and factored estimates of the total erected plant investment made. The total capital required for completed facilities and estimates of annual operating costs (exclusive of investment) are shown in the following tables.

CAPITAL REQUIREMENT
(1st Quarter 1981 Dollars)

		Case A		Case B*
		$ million		
Total Plant Investment		47.549		38.169
Initial Charge of Catalyst and Chemicals		0.100		0.100
Spare Parts		0.250		0.250
Interest During Construction (Plant Investment Cost x Average Spending Period of 1.5 years x 10%)		7.132		5.725
Start-Up Cost (20% of Gross Annual Operating Cost)		3.337		2.901
Working Capital				
Raw Materials Cost for 1 Month	1.234		1.076	
Payroll Burden for 1 Month	0.119	1.353	0.119	1.195
Total Capital Requirements		59.721		48.340

* Revised costs for delivery of wood chips and fines to plant instead of logs and for hot carbonate gas cleanup instead of amine.

TABLE OF ANNUAL OPERATING COST*
(1st Quarter 1981 Dollars)

	Case A	Case B***
	$ million	
Wood – 69.9 or 61.0 tons/hr (dry basis) at $24.51/ton of dry wood**	13.507	11.807
Water – 65 gpm at $1.00/1000 gallons	0.031	0.022
Catalysts and Chemicals	0.050	0.050
Process Operating Labor – 20 men at $20K (average)	0.400	0.400
Supervision at 20% of Process Operating Labor	0.080	0.080
Administration and General Overhead at 60% of Process Operating Labor	0.240	0.240
Maintenance at 3% of Plant Investment Cost (50% Labor plus 50% Material)	1.426	1.146
Taxes and Insurance at 2% of Plant Investment Cost	0.951	0.763
Total	16.685	14.508

* Based on 90% plant service factor

** At $1.50/10^6 Btu based on higher heating value.

*** Revised costs for delivery of wood chips and fines to plant instead of logs and for hot carbonate gas cleanup instead of amine.

Until the decision was made that eucalyptus wood would be the preferred feedstock on the basis of availability, preliminary screening analyses were conducted on a variety of candidate feedstocks. Materials tested included the following:

- Eucalyptus limbs
- Leucaena limbs
- Pineapple waste
- Sugar cane waste
- Bagasse
- Sugar cane stalk
- Ohio wood
- Albizzia wood
- Guinea grass

Proximate and Ultimate analyses show that the main distinguishing feature from one feedstock to another is the ash content. Leucaena and eucalyptus have very similar analyses and very low ash contents of around 1.5 weight percent. Their sulfur and nitrogen content is also low. Bagasse has higher ash content than the woods, at 3.4 weight percent, but is otherwise quite similar. So also, the pineapple waste, but the sulfur and nitrogen content is significantly higher for this feedstock. The sugar cane waste analysis shows a very high ash content (21.9 wt % on the proximate analysis). Sugar cane stalk had a very high water content (68.9%) as would be expected. Also, its hydrogen-to-carbon ratio (H/C) of 1.75 was the highest value recorded.

Fischer Assay tests were also made on all of the candidate feedstocks except bagasse. Oil yields varied from 6% (leucaena) to 15% (pineapple waste). Eucalyptus gave 11% to 13.5% oil yield.

Some additional observations that arise from examination of Fischer Assay data are:

- Sugar cane stalks gave a higher yield of water than sugar cane waste.
- Albizzia wood gave a good yield of oil, at 12.2%, despite its pithy, wet appearance in the field.
- Guinea grass gave an average oil yield of 10.7% which, also, was relatively high.

Examination of the oils produced from Fischer Assay show that the oils from sugar cane waste, pineapple waste, and guinea grass had higher carbon-to-hydrogen ratios and lower oxygen contents than the oils from the wood. Char analyses show that the sugar cane waste and grass had the highest ash content (possibly some soil attributing to it).

The composition of the gases evolved during the Fischer Assay show almost 90% of the gas is made up by four components: CO, CO_2, H_2, and CH_4. The CO_x by itself is 75% of the gas, with CO about 25% and CO_2 around 50%. Hydrogen is about 2%, as are the C_2's. Methane is about 10%, being the principal hydrocarbon gas evolved in the long residence time, low heating rate reaction system of the Fischer Assay distillation. The gases evolved were all very similar regardless of the feedstock. Also, the total gas yields from the various feedstocks do not vary very much. This leads to the conclusion that variations in reaction severity would have a much greater impact on gas yields and quality, and therefore plant design, than would changes in feedstock.

Yields and compositions of products for the Base Case design were estimated from general predictions. These were derived from laboratory, bench-scale, and PDU data generated for HYFLEX operations on lignite and peat previous to the start of this program. Subsequently, seven bench-scale (150 to 300 grams of feed) tests with eucalyptus wood and one PDU (8-1/2 lb of feed) test with leucaena wood were undertaken to verify the Base Case design assumptions.

Analysis of the test data on wood pyrolysis show that, at conditions leading to the same percentage production of organic liquid as that assumed for the Base Case design, the following generalizations apply:

- Char, LPG, water and gas production quantities will be substantially the same as for the Base Case design.
- Hydrogen consumption will be about the same as for the Base Case.
- Unit heating value of the product oil will be considerably lower than for the Base Case (11,000 to 15,000 Btu/lb versus 19.958 But/lb). This is due to higher oxygen content (14.5% to 33% versus 2.4%).
- Unit heating value of the product char is considerably lower than the Base Case (about 9000 Btu/lb versus 14,239 Btu/lb. This is also due to higher oxygen content (16.5% to 24% versus 1.8%).
- The solubility of product oil in water produced and the solubility of water produced in the product oil are both higher than for the Base Case.

Because of the decreased heating value of both oil and char, maintaining the same heating value output of products as for the Base Case requires a significant increase in the quantity of oil and/or char. Oil production can be increased by employing milder conversion conditions (lower temperature). Unfortunately, increasing oil yield in this way heightens the solubility of the oil in water.

It is apparent that the test data do not satisfactorily support the values assumed for the Base Case design. Therefore, adjusted design quantities and compositions more in line with test figures have been developed.

In order to maintain a design that will give a cost of products comparable to the Base Case design, conditions should be such that the total heating value of the desirable products (char, oil, and LPG) produced should be as high as possible. Since oil is probably the most desirable and probably the most valuable product, it seems appropriate to design for the highest heating value in oil and LPG.

It was not apparent from the test data generated that, at the temperatures and pressures contemplated, a high hydrogen concentration in the reactor gas is effective in improving yields or quality of the liquid product. A simplified process system from the Base Case design has, therefore, been devised wherein reforming of recycle gas to increase hydrogen concentration has been eliminated. Steam is not required for reforming so that the waste heat boiler following the pyrolysis reactor is replaced by a reactor feed/product exchanger. However, a feed heater must be added to make up sensible heat previously added in the reformer. Gas cleanup (for CO_2 removal) is not necessary for reducing CO_2 concentration in the recycle gas.

Whereas, in the Base Case, all gas produced in the process was used in the reformer furnace, the final design uses only a fraction of the produced gas for the feed heater. The remainder will be available for other plant use to reduce the amount of fuel wood required. Lack of sufficient funds did not permit making a new heat balance or capital investment for this final design. Undoubtedly, the capital cost will be decreased and the quantity of wood required for fuel will be reduced from the Base Case design.

For the final design the quantities and compositions of organic liquid, char, and fuel gas produced by pyrolysis of 1000 tons/day (83,333 lb/hr) of eucalyptus wood are as follow.

	Organic Liquid		Char	
	lb/hr	wt %	lb/hr	wt %
C	20,620	64.4	12,250	57.9
H	2,030	6.3	931	4.4
O	9,302	29.1	5,616	26.5
N	27	0.1	27	0.1
S	17	0.1	16	0.1
Ash	—	—	2,333	11.0
	31,996	100.0	21,173	100.0
HHV, Btu/lb	10,493		8,764	

	Fuel Gas	
	lb/hr	mol %
H_2	245	16.1
CO	9,517	45.1
CO_2	7,489	22.5
CH_4	1,473	12.2
C_2H_4	572	2.7
C_2H_6	307	1.4
	19,647	100.0
HHV, Btu/SCF	387	

In order to arrive at the cost of product production, we have used the investment and operating costs developed for the Base Case A and Base Case B designs with product quantities and quality developed for the Final Process Design. Project funding was not adequate to prepare revised investment and operating costs for the Final Process Design case. It is believed that the investment in the latter cost will be lower on account of less fuel wood required because added fuel gas will be available when the steam reforming of recycle gas is eliminated. Therefore, the figures set out hereafter for production costs will be conservative.

On the basis of 1000 tons/day (dry basis) of eucalyptus wood converted, the plant products and their heating values will be as follows:

	lb/hr	Btu/lb	10^6 Btu/hr
Organic Liquid	31,996	10,493	335.7
Char	21,173	8,764	185.6
			521.3

Table VII-1 summarizes the capital and operating costs for Case A (see Section III for details) and for Case B (see Section IV for details). Based on the above plant products producing 4.110 X 10^6 MM Btu/yr (at 90% plant service factor) and, using investment and operating costs developed for the Base Cases, the costs of organic liquid and char considered together on a Btu basis are shown below as a function of delivered wood price.

Wood Cost, $/ton	Products Cost, $/10^6 Btu	
	Case A*	Case B**
24.51	6.24	5.29
30	6.98	5.93
35	7.65	6.51
40	8.32	7.10
45	8.99	7.68
50	9.66	8.27
55	10.33	8.85
60	11.00	9.44

* Whole logs delivered to plant

** Chips delivered to plant.

Gaseous emissions from the plant will consist of flue gas from wood combustion and possibly a waste stream of principally carbon dioxide. Due to the relatively low sulfur content of eucalyptus wood, only 22 pounds per hour of sulfur is contained in vent gases. This corresponds to a heating value of 1142 million Btu/hr in the total wood utilized (0.02 lb/10^6 Btu).

It is estimated that approximately 800,000 man-hours of field construction labor will be required for plant erection. Based on a 40-hour per work week, 24-month construction period, average work force will be 192 persons with a peak of 300 persons.

Plant operating personnel is estimated to require 27 persons.

Plant area requirements, including wood storage, will be approximately 22 acres. The tallest structure will be about 150 feet high.

I. INTRODUCTION

This report describes work performed by the Institute of Gas Technology (IGT) as part of a study to investigate the feasibility of producing oils and other fuels from Hawaiian biomass. Pacific Resources, Incorporated (PRI) subcontracted to IGT under PRI's contract with the Department of Energy (DOE). IGT's work has consisted of providing process designs and estimates of investment and operating costs using IGT's HYFLEX® process.

The HYFLEX process features a short residence time hydropyrolysis. Extensive design data had been previously developed in IGT laboratories on application of HYFLEX to lignites and a significant amount on application to peat. It was contemplated that this data base on lignite and peat conversion would be sufficient for preliminary screening designs, which would then be confirmed by tests on a Hawaiian biomass to be selected during the course of the project.

IGT's project work commenced on September, 1, 1980.

Early work consisted of establishing a Base Case Process Design and, simultaneously screening various candidate feedstocks by elemental chemical analysis and Fischer Assay analysis. At the beginning of March 1981, a decision was made by PRI that the preferred feedstock would be eucalyptus wood. This decision was taken on the basis that eucalyptus would be preferred on the basis of availability. Following this all work, including the tests made to confirm the Base Case Process Design, was confined to eucalyptus.

This report describes the Base Case design and cost estimates (Sections I, II, III, and IV) the experimental work done to confirm conditions assumed in the Base Case Design (Section V), the Final Process design with necessary adjustments to the Base Case Design on account of the experimental work results (Section VI), the estimated cost of production (Section VII), description of plant effluent (Section VIII), personnel requirements for construction and operation (Section IX), and plant site area requirements (Section X).

II. BASE-CASE DESIGNS — PROCESS SUMMARY

The base case wood hydropyrolysis plant has been designed to pyrolyze eucalyptus wood in the presence of hydrogen to produce fuel oil, propane and butane (LPG), and solid char as salable products.

A gas stream which is left after the removal of propane and butane in liquefied form is subjected to catalytic steam reforming to augment the hydrogen content of the gas by steam reforming low molecular weight hydrocarbons into H_2 and CO. The reformed gas is recycled to the pyrolysis reactor as a carrier of the wood particles and also to act as a supplier of hydrogen needed for the reaction. About 80% of the reactor effluent gas is utilized for reforming and recycling. The other 20% of the gas stream is burned in the reformer furnace to provide the necessary heat. Thus, the plant does not produce any surplus fuel gas to be considered for sale.

The plant will pyrolyze 1000 tons/day (dry basis) of eucalyptus tree wood. The normal feedstock will be young eucalyptus trees (about 5 years old).*

In the Base Case design, two separate events have been considered. In one case (Base Case A), it is considered that whole logs will be delivered to the plant. That being the case, an additional 678 tons/day (dry basis) of wood is required to produce steam, electric power, process heat, and heat to dry moist wood. Alternately, it is considered that wood chips may be delivered to the plant. In the latter case (Base Case B), reduction of utilities required for chipping and grinding wood, lowers the additional wood required to 464 tons/day (a total of 1464 tons/day instead of a total of 1678 tons/day).

The plant will consume 65 gpm of water for making boiler feed water.

The plant will discharge 75 gpm of wastewater recovered from the process stream. Should it be possible to upgrade this water to boiler feed water quality, the plant will not need any outside supply of water, as the water being formed during pyrolysis of wood inside the reactor will then be able to meet the plant water demand.

The design basis is given in Table II-1.

---

* A decision was made at the beginning of March 1981 to use your eucalyptus trees as the feedstock.

Table II-1. DESIGN BASIS FOR HYFLEX WOOD CONVERSION

Design Parameter	Specification
Feed Material to Process	Eucalyptus tree wood; usually 5-year old trees.
Feed Size and Condition at Plant Delivery	For Base Case A, wood logs about 10 ft long and up to 8-in. diameter or for Base Case B, wood chips about 2 x 3/4 in. size plus fines. Maximum of 50% moisture content in either case.
Feed Delivery Rate	1668 tons/day for logs or 1464 tons/day for chips (both dry basis).
Plant Products	Fuel oil, LPG, and char
Power Supply	The plant will produce its own electrical power as required.
Water Supply	The plant will get water supply needed for making boiler feedwater to produce steam and power. Water consumption is minimized by utilization of air cooling.
Steam Supply	The plant will make its own steam as needed for the process.
Environmental Considerations	The plant is designed to operate so that the effluent water stream and vent gas streams will be within the environmentally safe and permissible values.

The Base Case processing is depicted in the process flow diagram of Figure II-1 and described below.

Wood logs are brought to the plant and chipped (Base Case A) or alternately (Base Case B), wood, chipped in the field and air-dried to approximately 30% moisture, is brought to the plant by trucks. Wood chips are taken from the stockpile by a front-end loader and fed through size-reduction and drying equipment. Here, the wood chips are ground to about 20-mesh particle size and dried to a moisture content of 5% to 10%.

Dried wood particles are elevated into the Feed Receiving Hopper, V-1. Wood particles are fed intermittently from V-1 into the Feed Lockhopper, V-2. V-2 is outfitted with a system allowing it to be alternately pressured and depressured with gas. With V-2 at atmospheric pressure, the valve between

V-1 and V-2 is opened and wood particles flow from V-1 into V-2. The connecting valve is then closed and the pressure in V-2 is raised to the process operating pressure (about 200 psig) by introducing pressurized gas. When the pressure is sufficiently high the valve between V-2 and the Feed Injection Hopper, V-3, is opened and wood particles flow from V-2 into V-3, thereby maintaining a continuous inventory of wood particles at process pressure in V-3.

Wood particles are fed from V-3 into the process at a steady rate by means of a rotary valve. The wood particles are then entrained in a stream of hot (1400° to 1600°F) gas containing about 50% hydrogen with the remainder being principally water vapor. The wood particles and hydrogen-rich gas flow through the HYFLEX Reactor, V-4. In a few seconds time at the conditions prevailing in V-4 (250 psig and 1000° to 1200°F), the wood particles are converted into oil, water, LPG, gas, and char. All products leaving V-4 are in gaseous state except char which is a solid.

Solid char is removed from the product gas stream leaving V-4 by the Cyclone Separator, V-5. The solids from V-5 intermittently flow down into the char lockhopper, V-6. The gas pressure in V-6 is then lowered to atmospheric by venting to the plant fuel gas system. Char is then removed from V-6 for shipment as solid product.

The gas stream from V-5 passes through a series of waste heat exchangers where it is cooled by successively superheating steam (E-1), boiling water for steam production (E-2), and preheating boiler feed water (E-3). In this way, process steam is produced at about 250 psi to be used at a later stage in the process.

Gaseous product is cooled by heat exchange with air (E-4) and, finally with cooling water (E-5) to 100°F. At this temperature and with a system pressure of about 200 psi, most of the oil produced in V-4, and contained in the gas, will be condensed. Liquid oils are separated from gas in Knock-Out Vessel, V-8. The liquids flow from V-8 into Flash Tower, V-9, where the pressure is lowered and dissolved gases are released to the plant fuel gas system. The stabilized liquid then flows from V-9 into Oil/Water Separator, V-10, where oil is skimmed off after separating from water. The water is produced partly as a product of the reactions in V-4 and partly by condensation of steam introduced into V-4. Oil product is ready for shipment as a crude oil product for further refining elsewhere.

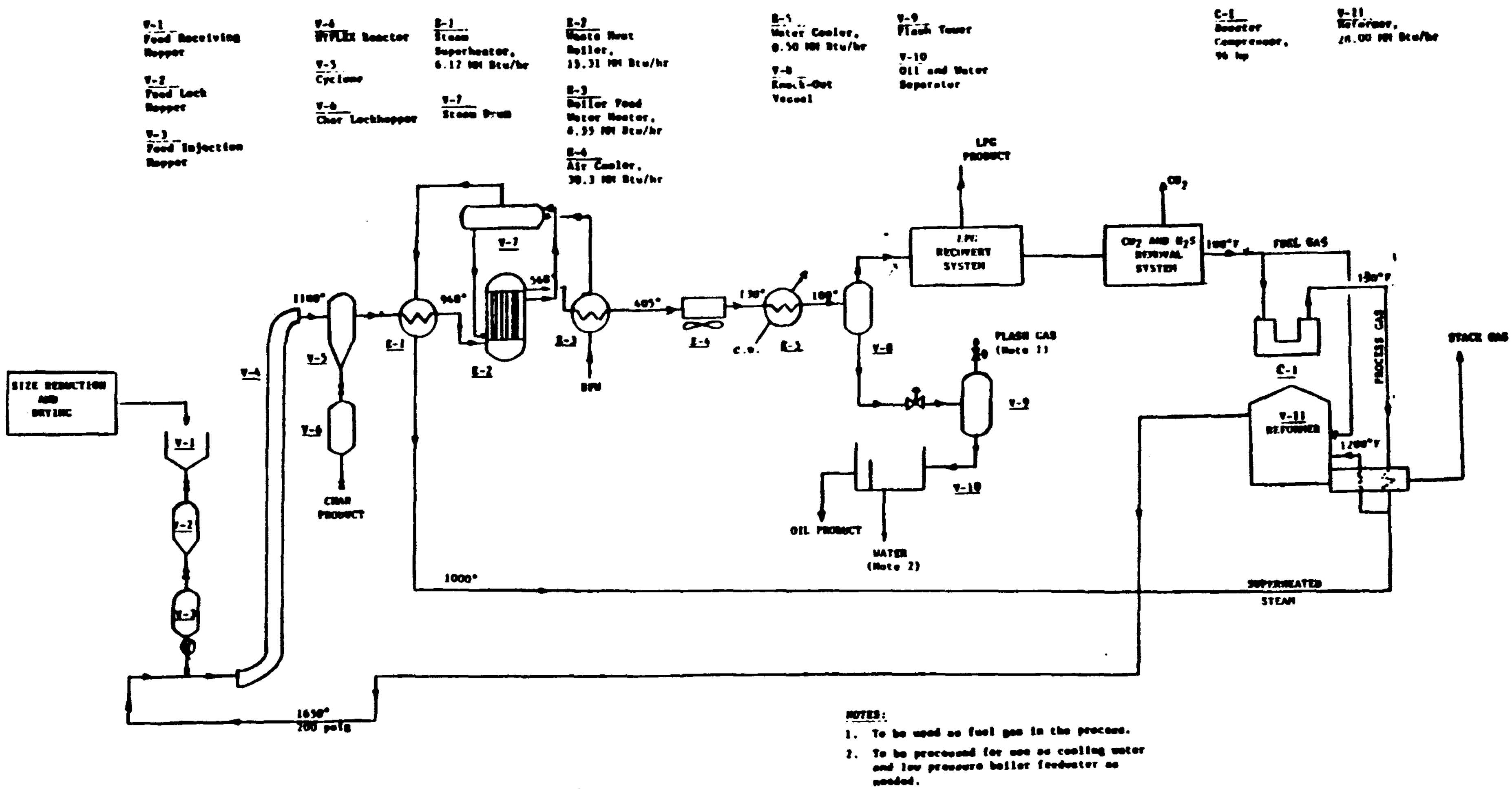


Figure II-1. PROCESS FLOWSHEET FOR BIOMASS TO OIL BY HYFLEX® (11/25/80)

Gas from V-8 is processed for recovery of propane and butane which are taken as a mixed LPG product. A number of alternate commercial systems for this operation, such as low-temperature distillation, oil absorption, and cyclic absorption on solids were investigated. Cryogenic processing was selected as being the most suitable.

Carbon dioxide (CO_2), which was formed in V-4 is then removed from the gas stream. This may be either by absorption in regenerable alkaline solutions or by adsorption on molecular sieves. Removal of CO_2 at this point and water removal in the preceding step, where oil and water are condensed out, are the means for removing from the process system the relatively high content of oxygen that is contained in the molecules of wood feed.

Following CO_2 removal a portion of the remaining gas is compressed (C-1) to compensate for system losses, preheated to about 1200°F after mixing with superheated steam, and passed through the Reformer, V-11. V-11 contains alloy steel tubes filled with nickel catalyst through which the process gas passes. The tubes are externally heated by combustion of the portion of circulating gas not compressed, and taken to the reformer tubes. Steam and components of the gas, such as methane and ethane react in the presence of the catalyst to produce hydrogen. Hot hydrogen-rich gas leaving V-11 then proceeds to pick up wood feed to carry it through V-4. This completes the cycle of circulating process gas.

III. BASE CASE A — DESIGN AND COSTS USING LOGS DELIVERED TO THE PLANT

A. Process Flow and Equipment Requirements

An important consideration for the process design is that the wood to be fed into the pyrolysis reactor has to be ground to about 20-mesh particle size. The conversion of wood logs to 20-mesh size is done in three stages. In the first stage, the logs are converted into wood chips of about 2 in. x 3/4 in. size. Wood containing as much as 50% moisture can be fed to the chipping step; but grinding of the wood chips to fine particles in an efficient manner calls for a low-moisture content, preferably not exceeding 5% to 7%. On this account, the wood chips are dried to about 5% moisture in rotary dryers. Only dried wood chips are to be subjected to grinding operation.

Wood chips are burned in a fluidized-bed wood combustion system to produce hot gas that is utilized for supplying the heat needed for drying the chips as well as the heat needed for steam and power generation and also for some process heat requirements. About 40% of the total wood feedstock will be consumed in the plant to provide heat and about 60% of the wood will be converted for the production of oil and various other products.

The plant block-flow diagram showing the sequence of processes is shown in Figure III-1. The process flow diagram for the plant is shown in Figure III-2. The stream numbers are identically identified in Figure III-1 and III-2 and the material quantities are included in Appendix A, Table A-1. Each process unit is described briefly below.

- Unit 110 — Wood Chipping

  Eucalyptus tree trunk sections and limbs, normally having a maximum diameter of 8 in. and a maximum length of 10 ft, will be delivered to the plant storage yard from the harvesting field by truck. The maximum moisture content is 50% by weight. Wood pieces will be taken from the stockpile by a front-end loader and conveyed by belt conveyor to be fed into Wood Hog machines, CR-101. The total weight of wood going to the process will be recorded on a belt weigh-scale. Wood chips (about 2 in. x 3/4 in.) will be produced by Wood Hog machines.

- Unit 120 — Fluid-Bed Wood Combustion

  Wood chips from Wood Hog machines will be divided into two parts. One part will be conveyed to a wood combustion storage silo, V-101. Wood chips will be removed from the bottom of V-101 by an auger-type unloader and conveyed to a metering bin, V-102, from which an air stream will carry it to the fluidized-bed combustion system, A-102. The wood

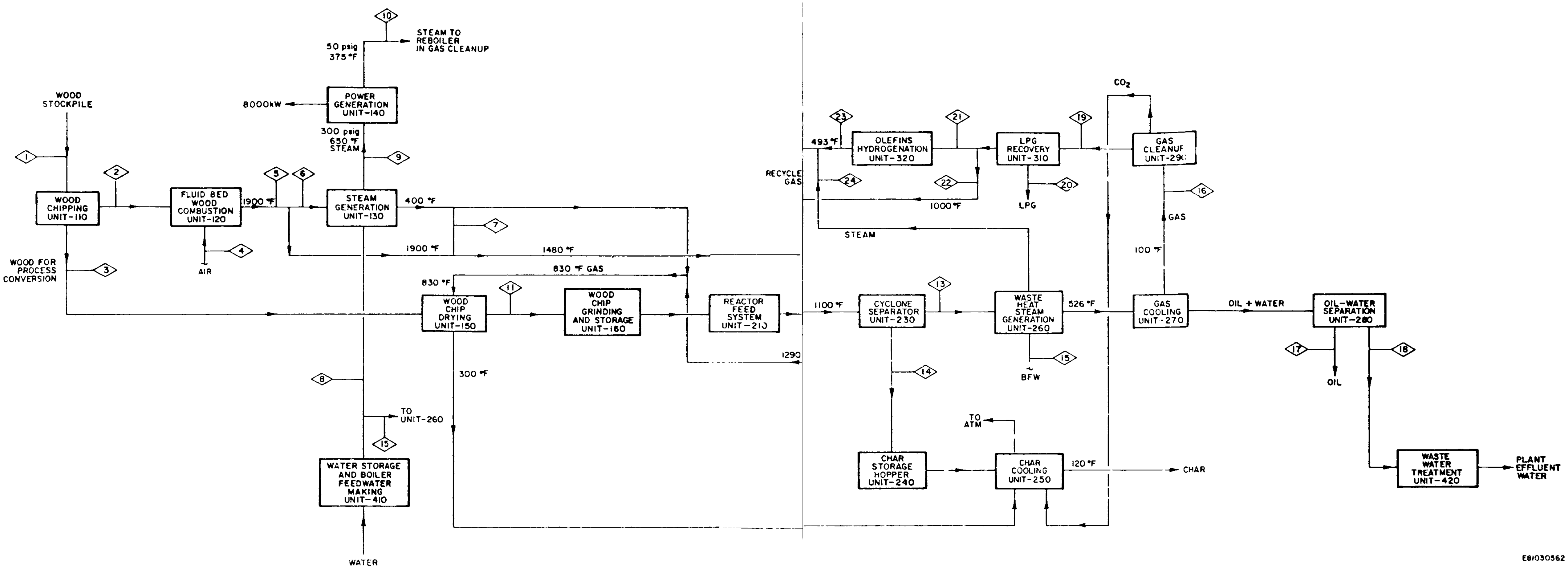


Figure 1. BLOCK FLOW DIAGRAM OF THE HYFLISION PLANT

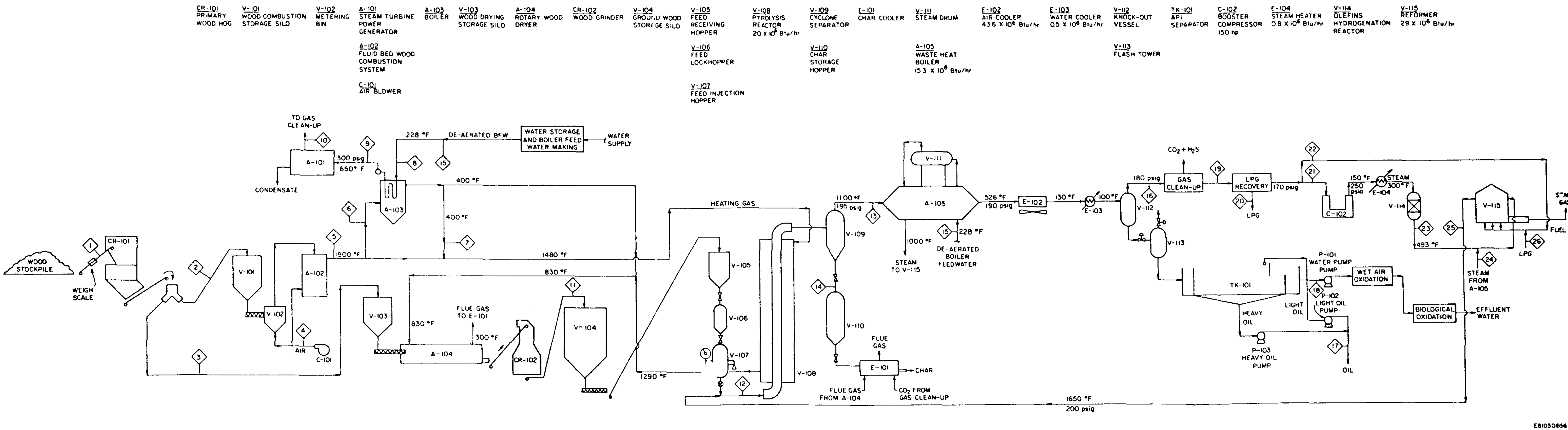


Figure 2. PROCESS FLOW DIAGRAM OF THE HYFLEX WOOD CONVERSION PLANT

particles will be burned with air supplied to the system by air blower, C-101, to generate hot gas that will be used in subsequent process units for steam generation and wood drying. The hot gas temperatyre is about 1900°F.

- Unit 130 — Steam Generation

  A major portion of the hot gas leaving Unit 120 is sent through the boiler, A-103, producing superheated steam at 300 psig and 650°F.

- Unit 140 — Power Generation

  Superheated steam will be used in extraction turbine A-101 driving a generator to make 8000 kW needed for the plant. Steam at 50 psig, extracted from the turbine, will be used for the steam reboiler in the gas cleanup section (Unit 290).

- Unit 150 — Wood-Chip Drying

  From the primary Wood Hog, CR-101, the wood chips for process conversion are conveyed to wood drying storage silo, V-103. Moist wood chips are removed from the bottom of the silo by an auger-type unloader and conveyed to the feed end of the rotary dryer, A-104. Wood combustion product hot gas after giving up most of its heat to raise steam in boiler A-103, and supplying heat to the pyrolysis reactor, V-108, will be at about 830°F, and used for drying the wood chips in rotary dryers. The hot gas is brought into direct contact with the wood chips in the dryers and leaves the dryers at around 300°F. Wood chips are dried from about 50% to 5% moisture by weight.

- Unit 160 — Wood-Chip Grinding and Storage

  Dried wood chips are conveyed to primary grinding machines to give a product size of about 1/2 in., which are further ground in secondary grinding machines, yielding 20-mesh particle size. After secondary grinding, the wood particles are stored in a ground wood storage silo, V-104.

- Unit 210 — Reactor Feed System

  The reactor feed system consists of a feed receiving hopper, V-105, a feed lockhopper, V-106, and a feed injection hopper, V-107. Dried wood particles ground to 20 mesh will be removed from the bottom of the silo, V-104, by an auger-type unloader and conveyed to the feed receiving hopper, V-105. Wood particles are fed intermittently from the feed receiving hopper into the feed lockhopper. The lockhopper is outfitted with a system to be alternately pressurized and depressurized with gas for loading of the wood particles from the feed receiving hopper and discharging them into the injection hopper. With V-106 at atmospheric pressure, the valve between V-106 and V-105 opens, and wood particles flow into V-106. The connecting valve then closes, and the pressure in V-106 is raised to the reactor pressure by introducing pressurized gas.

When pressurized, the valve between V-106 and V-107 opens, and wood particles flow into the feed injection hopper, V-107. This action maintains a continuous inventory of wood particles in the feed-injection hopper. The injection hopper is mounted on load cells and a recording instrument records the rate of flow from the hopper into the pyrolysis reactor. Wood particles are fed into the reactor at a steady rate by means of a rotary valve.

- Unit 220 — Pyrolysis Reactor

The wood particles from the feed injection hopper are entrained in a stream of hot gas at 1650°F containing about 50% hydrogen. Gas and wood flow together through the pyrolysis reactor, V-108. Indirect heat is supplied to the reactor tubes to maintain the temperature of the reactor effluent at 1100°F. By varying the heat supply the temperature can be adjusted as necessary. In a few seconds time at the conditions prevailing in the pyrolysis reactor, V-108 (200 psig and 1100°F), the wood particles are converted into oil, LPG, water, gas, and char.

- Unit 230 — Cyclone Separator

The hot effluent stream from the reactor passes through the cyclone separator where solid char particles separate out and all the other products that are in gaseous form leave near the top for further processing.

- Unit 240 — Char Storage Hopper

The solid char that separates from the gas stream leaves the cyclone separator at the bottom to be collected into char storage hoppers, V-110. Two hoppers are used in parallel. At any time, one hopper will be collecting the char from the cyclone separator, while the other will be feeding the hot char into the char cooler.

- Unit 250 — Char Cooling

Hot char will be fed from the char storage hopper into the char cooler, E-101. A rotary cooler is used. Hot char is cooled from 1100°F to about 500°F by direct contact with wood combustion flue gas supplied from the wood chip dryer, A-104, at about 300°F. Further cooling of the char to about 120°F is then done by contact with 90°F CO_2 gas that is removed from the process gas stream in the gas cleanup (Unit 290).

- Unit 260 — Waste Heat Steam Generation

The hot gas leaving the cyclone separator, V-109, passes through a waste heat boiler, A-105, to produce superheated steam at 300 psig and 1000°F. The gas is cooled from 1100° to 526°F. De-aerated boiler feed water is used for making the steam for steam reforming.

- Unit 270 — Gas Cooling

The gas leaving the waste heat boiler, A-105, is cooled in an air cooler, E-102, to about 130°F, and then further cooled to about 100°F in a water cooler, E-103. The product stream at 100°F passes into the knock-out vessel, V-112 to separate the condensate (oil and water). The gas stream flows to the gas cleanup section (Unit 290). The separated liquid stream is depressurized in the Flash Tower, V-113.

- Unit 280

The oil-water mixture enters the API separator, TK-101, and is uniformly distributed by vertical slots in baffles. Heavy oil settles at the bottom. Light oil is removed from the top and condensed water is removed as an intermediate stream. The two oil fractions, heavy and light, are combined and added to fuel oil product.

- Unit 290 — Gas Cleanup

The CO_2 present in the gas stream along with very small quantities of H_2S that may be present are removed in this unit using an amine scrubber. Steam extracted at 50 psig from an extraction turbine in the power generation unit (Unit 140), is used in the reboiler stripper. This is a licensed process available commercially.

- Unit 310 — LPG Recovery

After gas cleanup, propane and butane are removed from the gas in a liquefied form (LPG) by a licensed process available commercially.

- Unit 320 — Olefins Hydrogenation

The gas leaving the LPG recovery unit is compressed in a booster compressor, C-102, to 250 psig, and the gas is then heated in a steam heater, E-104 to 300°F, for catalytic hydrogenation of ethylene and acetylene to ethane in the presence of palladium catalysts. Hydrogenation of olefins avoids carbon deposition in the subsequent steam reforming step. Exothermic hydrogenation reactions cause the gas temperature to increase to about 493°F.

- Unit 330 — Steam Reforming

The gas leaving Unit 320 is mixed with superheated steam at 1000°F. The mixture is preheated to about 1200°F and passes through the reformer, V-115. The reformer contains alloy steel tubes filled with nickel catalyst through which the process gas passes. The tubes are externally heated by combustion of a portion (about 20%) of the gas from the outlet of the LPG recovery unit. This raises the gas temperature to 1650°F. Steam and hydrocarbons present in the gas, such as methane and ethane, react in the presence of the catalyst to produce hydrogen. Hot hydrogen-rich gas is then recycled into the pyrolysis reactor, V-108.

Unit 410 — Water Storage and Boiler Feed Water Making

Water available from the existing source of supply will be stored in a water storage tank. The water will be purified and demineralized to boiler feed water quality to make steam and generate power.

Unit 420 — Wastewater Treatment

The condensed water separated from the condensed oil in the API separator contains about 2% of organics by weight. The water is purified by wet air oxidation and then by biological oxidation treatment. About 80% of the organics will be removed by wet air oxidation. More than 99% of the organics originally present in the wastewater will be removed by the combination of wet air oxidation and biological oxidation.

B. Plant Material and Energy Balance

The plant receives only wood (moist) and water. Although the moisture content of wood may run generally about 30% to 35%, the plant design was done on a conservative basis to deal with the worst case with 50% moisture in the wood. The plant also produces 8000 kW of power needed for the process.

The plant material balance is shown in Table III-1. About 40% of the total wood consumed in the plant is utilized in a fluidized-bed wood combustion system to produce hot gas that is used for generating steam and electric power needed for the plant, and for providing heat duty for the wood dryers and other process heat requirements.

The energy efficiency of the plant is shown in Table III-2. The process energy efficiency for converting the wood, without considering any heat and electrical energy that is needed for the conversion, is about 89%. The overall process energy efficiency, considering the requirements of heat and electrical energy needed for the process, is about 60%. The plant design considers drying wood from 50% moisture content to 5% for process conversion. In considering the heat duty for the drying of wood, the overall plant energy efficiency is about 53%. In actual plant operation, the moisture content is expected to be somewhat less than 50%, about 30% to 35%, in which case an overall plant energy efficiency of 55% to 57% will be obtained.

C. Reactor Material and Energy Balance

The reactor material and elemental balance is shown in Table III-3. The percentage yield of various products is as follows:

Product	% of Wood (dry) by Weight
Oil	15.3
LPG	5.0
Char	23.3
Water	24.6
Gas	31.8
	100.0

The reactor energy balance is shown in Table III-4.

Table III-1. OVERALL PLANT MATERIAL BALANCE

Plant Input	lb/hr
Wood, consumed in plant (dry basis)	139,730
Moisture in wood	139,730
Water	32,500
Air for fluidized-bed wood combustion	560,590
	872,550
Plant Output	
Oil as product	12,765
LPG as product	3,529
Char asproduct	19,389
CO_2 vent gas	31,010
Wastewater	37,360
Gas lost in wastewater	211
Fuel gas used for reformer furnace	1,701
LPG used for reformer furnace	655
Water loss from the gas in gas treatment	144
Water loss from the water and steam system	13,455
Water lost in wood chip drying	78,947
Wood combustion stack gas	673,384
	872,550

Table III-2. ENERGY EFFICIENCY OF THE PLANT Based on Higher Heating Value (HHV)

a. Heat of Combustion of Wood for Conversion in the Process = 83,333 lb/hr x 8,169 Btu/lb = 680.7 x 10^6 Btu/hr

b. Heat of Combustion of Wood Burned in Fluid-Bed Combustion System = 56,397 lb/hr x 8,169 Btu/lb = 460.7 x 10^6 Btu/hr

This total heat is used as follows, 10^6 Btu/hr

For Steam Supply to the Process	195.8
For Heat Supply to the Process	23.0
For Power Generation	103.7
For Drying Wood	138.2
	460.7

c. Heat of Combustion of Products, 10^6 Btu/hr

Oil, 12,765 lb/hr x 19,958* Btu/lb	254.8
LPG, 3,529 lb/hr x 21,516 Btu/lb	75.9
Char, 19,389 lb/hr x 14,239 Btu/lb	276.1
Total Heat for Products	606.8

d. Process Energy Efficiency

$$= \frac{\text{Heat of Combustion of Products}}{\text{Heat of Combustion of Wood for Conversion in the Process}}$$

$$= \frac{606.8}{608.7} \times 100$$

$$= 89.1\%$$

e. Overall Process Energy Efficiency

$$= \frac{\text{Heat of Combustion of Products}}{\text{Heat of Combustion of Wood for Conversion in the Process plus Heat of Combustion of Wood for Steam, Power, and Heat Supply to the Process}}$$

$$= \frac{606.8}{680.7 + 195.8 + 103.7 + 23.0} \times 100$$

$$= 60.5\%$$

f. Overall Plant Energy Efficiency

$$= \frac{\text{Heat of Combustion of Products}}{\text{Heat of Combustion of Wood Used in the Total Plant**}}$$

$$= \frac{606.8}{680.7 + 460.7} \times 100$$

$$= 53.2\%$$

---

* Specific heating value of oil (organic liquid) was not verified by later experimental tests. Final design (see Section VI), based on experimental tests, shows a lower specific heating value (10,493 Btu/lb) but an increased quantity of oil (organic liquid). Total heat for products is 521.3 million Btu/hr.

** Includes wood burned to provide heat for drying wood chips used for conversion.

Table III-3. REACTOR MATERIAL AND ELEMENTAL BALANCE
(Quantities in lbs/hr)

INPUT	C	H	O	N	S	Ash	Total
Wood (dry)	41000.0	4983.3	35966.6	216.7	0	1166.7	83333.3
Moisture in Wood		490.8	3895.2				4386.0
Recycle Gas							
H_2		2297.8					2297.8
CO	2652.0		3532.8				6184.8
CO_2	1239.5		3302.4				4541.9
CH_4	162.1	54.4					216.5
H_2O		1411.2	11200.0				12611.2
Total Input	45053.6	9237.5	57897.0	216.7	0	1166.7	113571.5
OUTPUT							
Gas							
H_2		904.8					904.8
CO	1051.0		1400.0				2451.0
CO_2	8463.0		22547.2				31010.2
CH_4	2032.3	682.2					2714.5
C_2H_6	1537.4	387.1					1924.5
C_2H_4	345.8	58.1					403.9
C_2H_2	100.8	8.5					109.3
NH_3		37.5		173.4			210.9
Subtotal	13530.3	2087.2	23947.2	173.4	0	0	39729.1
Water		4195.3	33296.2				37491.5
LPG	3435.1	749.0					4184.0
Oil	10782.0	1693.0	303.0				12778.0
Char	17306.3	522.0	350.6	43.3	—	1166.7	19388.9
Total Output	45053.6	9237.5	57897.0	216.7	0	1166.7	113571.5

Table III-4. REACTOR ENERGY BALANCE — SUMMARY

	Energy Balance*	
Heat Input	10^6 Btu/hr**	% of Total
Heat in Wood at 60°F	680.75	76.2
Heat in Recycle Gas at 1650°F	213.19	23.8
Total	893.94	100.0
Heat Output		
Heat in Product Gas at 1100°F	258.98	29.0
Heat in Propane and Butane at 1100°F	91.71	10.3
Heat in Oil Vapor at 1100°F	260.34	29.1
Heat in Char at 1100°F	282.13	31.6
Total	893.16	100.0

* Provision has been made in the plant design to supply up to 20 million Btu/hr of heat to the reactor tubes by passing hot flue gas generated by wood combustion. This heat supply may be needed to accommodate changes in the qualtities and quantities of the products.

** See Appendix B for details of determination of the heat content of various individual streams.

D. Capital Investment and Operating Cost Estimates

The economic evaluation includes the capital requirement and annual operating cost.

The installed cost of the different plant units was determined by using information received from various process licensers and equipment vendors, and also by in-house estimates. The names of vendors or process licensers furnishing the cost information on various units are indicated in Table III-5.

The cost for general facilities is considered to account for 10% of the total plant installed cost. The plant investment cost is obtained by adding the contractor's home office cost and fee to the total plant installed cost. A 15% contingency has been added as a safety margin. The plant investment cost is \$47.5 million. The breakdown for the plant investment cost in 1st quarter 1981 dollars is shown in Table III-6.

The capital requirement (Table III-7) comprising plant investment cost, initial charge of catalysts and chemicals, spare parts, construction funds, start-up cost and working capital is \$59.7 million as shown in Table III-7.

Annual operating costs, exclusive of capital charges, based on a 90% plant service factor and a wood cost of \$24.51/ton (\$1.50/10^6 Btu) are \$16.7 million (Table III-8).

Table III-5. INSTALLED COST OF PLANT UNITS
(1st Quarter 1981 Dollars)

Unit 110 — Gruendler Wood Hogs (Model XF) from Gruendler Crusher and Pulverizer Co.
5 needed (4 in operation and 1 spare).
800 HP motor for each.
Installed cost: $1.316 MM

Unit 120 — Fluid-bed Wood Combustion from Energy Products of Idaho.
Installed cost: $2.484MM

Unit 130 — Steam Generation.
Information received from Energy Products of Idaho.
Installed cost: $1.162MM

Unit 140 — Power Generation.
Information received from Energy Products of Idaho.
Installed cost: $2.531 MM

Unit 150 — Wood Chip Drying
Rotary Dryer from Allis Chalmer.
Installed cost: $1.134MM

Unit 160 — Wood Chip Grinding and Storage
Model 40-40 Aristocrat Grinder from Gruendler Crusher and Pulverizer Co.
3 needed (2 in operation and 1 spare) for primary grinding
12 needed (9 in operation and 3 spares) for secondary grinding.
450 HP motor each.
Installed cost: $1.300 MM

Storage Silo: 2 silos needed
Installed cost: $0.650 MM

Total installed cost for Unit 160: $1.950 MM

Unit 210 — Reactor Feed System
Lockhopper system and control instrumentation from Petrocarb Inc.
Installed cost: $6.500 MM

Unit 220 — Pyrolysis Reactor
Information from Econotherm.
Installed cost: $0.500MM

Unit 230 — Cyclone Separator
Installed cost: $0.129MM

Unit 240 — Char Storage Hopper
2 hoppers needed
Installed cost: $0.522 MM

(Continued)

Table III-5, Cont. INSTALLED COST OF PLANT UNITS

Unit 250 Char Cooling
Rotary cooler from Allis Chalmer.
Installed cost: $0.130 MM

Unit 260 Waste Heat Steam Generation
Estimate from Econotherm.
Installed cost: $1.114MM

Unit 270 Gas Cooling

	Installed cost, $ MM
Air cooler	0.210
Water cooler	0.062
Knockout vessel	0.132
Flash tower	0.060
Installed cost for Unit 270:	$0.464 MM

Unit 280 Oil-Water Separation
API Separator
Installed cost: $0.150 MM

Unit 290 Gas Clean-up
Fish Engineering and Construction quoted $3.5MM and Randall Corp. quoted $4.5,, for installed cost.
Installed cost for the unit is taken to be $4.000MM

Unit 310 LPG Recovery
Fish Engineering and Construction quoted $3.0MM and Randall Corp. quoted $2.5MM for installed cost.
Installed cost for the unit is taken to be $2.750 MM

Unit 320 Olefins Hydrogenation
Catalyst information from United Catalysts.
Installed cost: $0.039 MM

Unit 330 Steam Reforming
Estimate by Kellogg
Installed cost: $2.176 MM

Unit 410 Water Storage and Boiler Feed Water Generation
Information received from Energy Products of Idaho
Installed cost: $0.641 MM

Unit 420 Waste Water Treatment

Estimate from Zimpro for installed cost of wet air oxidation: $3.3 MM

With the final step of biological oxidation, total installed cost is $3.8MM

Table III-6. PLANT INVESTMENT COST
(1st Quarter 1981 Dollars)

Unit No.	Unit Identification	Installed Cost, $MM Case A
110	Wood Chipping	1.316
120	Fluid Bed Wood Combustion	2.484
130	Steam Generation	1.162
140	Power Generation	2.531
150	Wood Chip Drying	1.134
160	Wood Chip Grinding and Storage	1.950
210	Reactor Feed System	6.500
220	Pyrolysis Reactor	0.500
230	Cyclone Separator	0.129
240	Char Storage Hopper	0.522
250	Char Cooling	0.130
260	Waste Heat Steam Generation	1.114
270	Gas Cooling	0.464
280	Oil-Water Separation	0.150
290	Gas Clean-Up	4.000
310	LPG Recovery	2.750
320	Olefins Hydrogenation	0.039
330	Steam Reforming	2.176
410	Water Storage and Boiler Feedwater Making	0.641
420	Waste Water Treatment	3.800
		33.492
	General Facilities*	3.721
	Total Installed Cost	37.213
	Contractor's Home Office Cost and Fee	4.134
		41.347
	Contigency at 15%	6.202
	Total Plant Investment	47.549

* Site Preparation, Plant Roads, Building, Electrical Distribution, Yard Piping, Flare System, Sanitary Water, Shipping and Receiving Facilities, etc.

Table III-7. CAPITAL REQUIREMENT
(1st Quarter 1981 Dollars)

		Case A, $ million
Total Plant Investment		47.549
Initial Charge of Catalyst and Chemicals		0.100
Spare Parts		0.250
Interest During Construction (Plant Investment Cost x Average Spending Period of 1.5 years x 10%)		7.132
Start-Up Cost (20% of Gross Annual Operating Cost)		3.337
Working Capital		
Raw Materials Cost for 1 Month	1.234	
Payroll Burden for 1 Month	0.119	1.353
Total Capital Requirements		59.721

Table III-8. ANNUAL OPERATING COST*
(1st Quarter 1981 Dollars)

	Case A, $ million
Wood — 69.9 or 61.0 tons/hr (dry basis) at $24.51/ton of dry wood**	13.507
Water — 65 gpm at $1.00/1000 gallons	0.031
Catalysts and Chemicals	0.050
Process Operating Labor — 20 men at $20K (average)	0.400
Supervision at 20% of Process Operating Labor	0.080
Administration and General Overhead at 60% of Process Operating Labor	0.240
Maintenance at 3% of Plant Investment Cost (50% Labor plus 50% Material)	1.426
Taxes and Insurance at 2% of Plant Investment Cost	0.951
Total	16.685

* Based on 90% plant service factor

** At $1.50/10^6$ Btu based on higher heating value.

IV. BASE CASE B — DESIGN AND COST USING WOOD CHIPS DELIVERED TO PLANT

A. Modification in Equipment Requirements and Costs

1. Wood Chipping and Grinding

Preliminary information developed by PRI in discussions with manufacturers of tree harvesting equipment has indicated that it will be desirable to chip trees in the forest rather than at the plant site. This will facilitate movement of wood to the plant as contrasted to hauling whole logs. Consequently, the plant investment requirement can be reduced by an amount equal to the cost of chipping equipment previously included. Furthermore, plant power requirements will incidentally be reduced leading to further investment requirement reductions for steam and power generation equipment.

Additionally, it has been indicated that field chipping equipment will increase production of fines during the shipping operation so that the investment and power requirement for grinding at the plant will also be reduced.

As a consequence of these considerations plant equipment costs and power requirements have been reduced as shown in Table IV-1. The original specifications and costs referred to are from Table III-5 of the previous section.

In addition to the direct effect on chipping and grinding equipment, the reduction in power requirements affects equipment required for electric power generation, steam generation, fluid-bed wood combustion, water storage, and boiler feedwater. Consideration for these items is described below (Items 3 to 6).

2. Gas Cleanup

The original (Base Case A) design contemplated using an amine scrubbing system for removal of CO_2 and H_2S in the Gas Cleanup Section (Unit 290). Amine solution regeneration requires 120,000 lb/hr of 50 psig steam turbine extraction steam to supply 146 million Btu/hr. This represents 12.8% of the total heat energy of wood supplied to the plant.

The Benfield Corporation (Pittsburgh, PA) has responded to our inquiry for investment requirement and heat requirement for a carbonate scrubbing system. Benfield estimates (letter of August 10, 1981) a capital investment of $1.5 million and a regeneration heat requirement of 20 million Btu/hr. This represents a reduction of $2.5 million in the installed cost and a reduction of 126 million Btu/hr previously estimated for an amine system.

Table IV-1. REDUCTIONS IN EQUIPMENT COST AND POWER REQUIREMENTS FOR WOOD CHIPPING AND GRINDING

	Reduction	
	Installed Cost, $	Operating Power, kW
Eliminate Unit 110, wood chipping; originally $1,316,000 and 2390 kW	1,316,000	2390
Reduce Unit 160, wood chip grinding and storage from 15 units (total) to 9 units (total) and from 11 units operating to 7 units operating; originally $1,300,000 and 3700 kW	520,000	1340
Total reduction for changes in chipping and grinding equipment requirements	1,836,000	3730

3. Power Generation

Reductions in wood chipping and grinding requirements reduce the total plant operating power requirement by 3730 kW, from 8000 kW to 4270 kW. The estimated installed cost for the turbogenerator (Unit 140) is thereby reduced by $1 million (from $2,531,000 to $1,531,000). High-pressure (300 psig, (650°F) steam required is reduced to 72,000 lb/hr (including 20,000 lb/hr of extraction steam to gas cleanup).

4. Steam Generation

Reduction of high-pressure steam required from 166,250 lb/hr to 72,000 lb/hr results in a cost reduction of $522,000 (from $1,162,000 to $640,000) for steam generation (Unit 130).

5. Fluid-Bed Combustion

Reduced steam generation required lowers the duty required from wood combustion from 429 to 294 million Btu/hr. Cost for Fluid-Bed Wood Combustion (Unit 120) is reduced by $544,000 ($2,484,000 to $1,940,000).

6. Water Storage and Boiler Feedwater

Reduced steam generation required lowers the cost of boiler feedwater facilities (Unit 410) by $256,000 (from $641,000 to $385,000).

B. Summary of Revised Costs

Revised costs are summarized in the attached tables. Corresponding figures from Base Case A are included for comparison. Modifications in wood chipping and grinding and in the gas cleanup equipment result in the revised installed costs shown in Table IV-2.

Capital requirements are revised as shown in Table IV-3.

Table IV-4 shows revised annual costs. On account of reduced wood-burning requirement total wood requirement is reduced from 1678 to 1464 tons/day. This includes 1000 tons/day to the process.

Table IV-2. PLANT INVESTMENT COST
(1st Qr. 1981 Dollars)

Unit No.	Unit Identification	Case A	Case B**
		— Installed Cost, $MM —	
110	Wood Chipping	1.316	1.316
120	Fluid Bed Wood Combustion	2.484	1.940
130	Steam Generation	1.162	0.640
140	Power Generation	2.531	1.531
150	Wood Chip Drying	1.134	1.134
160	Wood Chip Grinding and Storage	1.950	1.430
210	Reactor Feed System	6.500	6.500
220	Pyrolysis Reactor	0.500	0.500
230	Cyclone Separator	0.129	0.129
240	Char Storage Hopper	0.522	0.522
250	Char Cooling	0.130	0.130
260	Waste Heat Steam Generation	1.114	1.114
270	Gas Cooling	0.464	0.464
280	Oil-Water Separation	0.150	0.150
290	Gas Clean-Up	4.000	1.500
310	LPG Recovery	2.750	2.750
320	Olefins Hydrogenation	0.039	0.039
330	Steam Reforming	2.176	2.176
410	Water Storage and Boiler Feedwater Making	0.641	0.385
420	Waste Water Treatment	3.800	3.800
		33.492	26.884
	General Facilities*	3.721	2.987
	Total Installed Cost	37.213	29.871
	Contractor's Home Office Cost and Fee	4.134	3.319
		41.347	33.190
	Contigency at 15%	6.202	4.979
	Total Plant Investment	47.549	38.169

* Site Preparation, Plant Roads, Building, Electrical Distribution, Yard Piping, Flare System, Sanitary Water, Shipping and Receiving Facilities, etc.

** Revised costs for delivery of wood chips and fines to plant instead of logs and for hot carbonate gas cleanup instead of amine.

Table IV-3. CAPITAL REQUIREMENT
(1st Quarter 1981 Dollars)

		Case A		Case B*
		$ million		
Total Plant Investment		47.549		38.169
Initial Charge of Catalyst and Chemicals		0.100		0.100
Spare Parts		0.250		0.250
Interest During Construction (Plant Investment Cost x Average Spending Period of 1.5 Years x 10%)		7.132		5.725
Start-Up Cost (20% of Gross Annual Operating Cost)		3.337		2.901
Working Capital				
Raw Materials Cost for 1 Month	1.234		1.076	
Payroll Burden for 1 Month	0.119	1.353	0.119	1.195
Total Capital Requirement		59.721		48.340

Table IV-4. ANNUAL OPERATING COST**

	Case A	Case B*
Wood — 69.9 or 61.0 tons/hr (dry basis) at $24.51/ton of dry wood***	13.507	11.807
Water — 65 gpm at $1.00/1000 gallons	0.031	0.022
Catalysts and Chemicals	0.050	0.050
Process Operating Labor — 20 men at $20K (average)	0.400	0.400
Supervision at 20% of Process Operating Labor	0.080	0.080
Administration and General Overhead at 60% of Process Operating Labor	0.240	0.240
Maintenance at 3% of Plant Investment Cost (50% Labor plus 50% Material)	1.426	1.146
Taxes and Insurance at 2% of Plant Investment Cost	0.951	0.763
Total	16.685	14.508

* Revised costs for delivery of wood chips and fines to plant instead of logs and for hot carbonate gas cleanup instead of amine.

** Based on 90% plant service factor

*** At $1.50/10^6$ Btu based on higher heating value.

V. EXPERIMENTAL VERIFICATION OF DESIGN

A. Feedstock Analysis

A wide variety of feedstocks were originally contemplated for the HYFLEX®-BIOMASS process, with corroborative yield data for the most important feedstock to be obtained on IGT's continuous-flow, short residence time hydropyrolysis units that have been used successfully for peat and coal feedstocks. Some problems were encountered in feeding the lightweight, fibrous biomass materials to these units so that initial designs did not have the benefit of all desirabl information. The main laboratory tests for screening feedstocks and estimating yields were chemical analyses and Fischer Assays. The feedstocks received from Hawaii (HNEI) were given a Proximate and Ultimate analysis followed by a Fische Assay to establish approximate product yields. The Proximate and Ultimate analyses for some of the potential feedstocks and for other materials of interest, are given in Table V-1.

Referring to Table V-1, Feedstock Analyses, the main distinguishing featur from one feedstock to another is the ash content. Leucaena and eucalyptus have very similar analyses and very low ash contents of around 1.5 weight percent. Their sulfur and nitrogen content is also low. Bagasse has higher ash than the woods, at 3.4 weight percent, but is otherwise quite similar. So also, the pineapple waste, but the sulfur and nitrogen content is significantly higher for this feedstock. The sugar cane waste analysis shows a very high ash content (21.9 wt % on the Proximate analysis).

As can be seen in Table V-1, sugar cane stalk had a very high water content (68.9%) as would be expected. Also, its hydrogen-to-carbon ratio (H/C) of 1.75 was the highest value recorded. In general, sugar cane stalk had an ultimate analysis very similar to that of cellulose, which is also shown in Table V-1, both as absorbent cotton and as reagent-grade cellulose.

B. Fischer Assay Analyses

The Fischer Assay technique is a form of pyrolytic conversion of the feed stock and thus simulates, to some degree, the conversion and product yield generation to be expected in continuous-flow pyrolysis, such as the short resi dence time (SRT) hydropyrolysis of the HYFLEX process. However, the Fischer Assay was developed for use with coal and shale and must be adapted for use

Table V-1. FEEDSTOCK ANALYSES

Feedstock	Eucalyptus Limbs	Leucaena Limbs	Pineapple Waste	Sugar Cane Waste	Bagasse	Reed Sedge Peat (PL-10)*	Sugar Cane Stalk	Ohio Wood	Albizzia Wood	Guinea Grass	Cellulose* J.T. Baker Reagent	Absorbent* Cotton, USP	Lignin* (Westvaco)
Proximate Analysis, wt %													
Moisture	10.9	8.2	6.5	8.1	9.0	2.6	68.9	7.8	22.5	6.5			
Volatile Matter	73.3	74.3	73.7	57.7	75.4	57.8	25.7	70.8	65.8	68.9			
Ash	1.2	1.4	4.1	21.9	3.1	16.4	0.3	2.2	0.5	8.1			
Fixed Carbon	14.6	16.1	15.7	12.3	12.5	23.2	5.1	19.2	11.2	16.5			
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0			
Ultimate Analysis, wt %													
Ash	1.40	1.51	23.86	23.86	3.44	16.81	1.02	2.38	0.66	8.62	0.00	0.03	1.30
Carbon	49.20	49.20	36.70	36.70	48.70	48.80	44.20	51.30	49.90	44.20	44.55	44.71	63.37
Hydrogen	5.98	6.05	4.55	4.55	5.77	5.16	6.43	5.63	6.14	5.57	6.30	6.35	5.86
Sulfur	0.00	0.03	0.14	0.14	0.07	0.21	0.11	0.07	0.04	0.3	—	—	—
Nitrogen	0.26	0.47	0.62	0.62	0.25	2.38	0.00	0.26	0.10	0.88	—	—	—
Oxygen (by difference)	43.16	42.74	34.14	34.14	41.77	26.64	48.24	40.36	43.16	40.60	49.15	48.91	29.47
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
H/C Atomic	1.46	1.48	1.53	1.49	1.42	1.27	1.75	1.32	1.48	1.51	1.70	1.70	1.11
Gross Heating Value, Btu/lb	8169	8200	7941	6006	8120	8224	7437	8535	—	7392	—	—	—

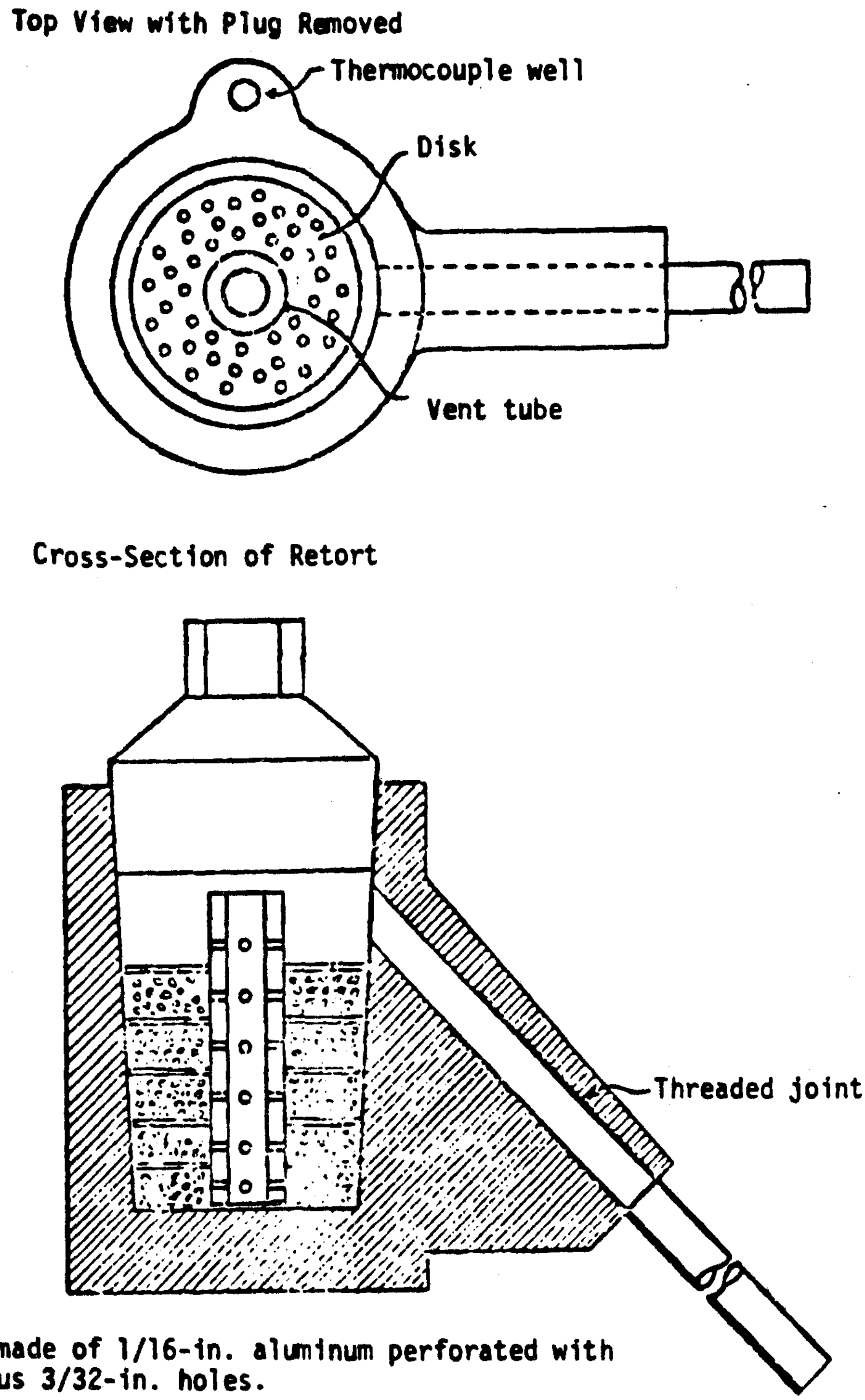
* Analyses made on IGT account — for comparison only.

with biomass materials. This adaptation and modification have been undertaken; it is too early to be sure of the correlation between Fischer Assay results and those from SRT hydropyrolysis. Preliminary indications, based on reed sedge peat runs in the continuous PDU, are that the oil yield and conversion for the Fischer Assay are slightly lower than for hydropyrolysis to maximum oil yield (10% oil and 49% conversion versus 12% and 60% for hydropyrolysis of peat).

The Fischer Assay is a type of batch distillation and the retort used is shown in Figure V-1. Perforated aluminum plates are spaced throughout the charge to increase heat transfer. The main assembly is shown in Figure V-2. The oven is now electrically heated and better controlled than earlier ones, when a gas burner was used. The general technique is to raise 100 grams of sample to 500°C in 40 minutes and hold for about 40 minutes at 500° until all the oil has evolved. The biggest problem in adapting the procedure to biomass materials is getting enough charge from these low bulk-density materials.

Early Fischer Assays of leucaena, eucalyptus, and pineapple waste are compared with a "control" sample of reed sedge peat in Table V-2. The Fischer Assays shown in Table V-2, were run before a technique for charging enough biomass had been developed, and, as a consequence, the amounts of products were low. There was insufficient oil to determine specific gravity, for example. These first Fischer Assays on eucalyptus, leucaena, and pineapple waste were generally similar in yields, with the oil yield varying from 8.1 to 10.0. A repeat run was made on eucalyptus later, with a higher charge to the retort. The yields from this run were somewhat different than the first three, with lower water and more gas. The oil yield was 10.4 weight percent and a sample of reed sedge peat run in parallel under identical conditions had an oil yield of 10.0 weight percent. The paired eucalyptus and peat runs are shown on the right side of Table V-2.

Gas analyses of the early Fischer Assays indicated excess air leakage into the aluminum retorts. The mouths and lids of the retorts have been lapped, provision made for an argon purge, and an improved pressure control system installed, in order to ensure consistent results. Later, Fischer Assays had the benefit of these improvements.



Disks made of 1/16-in. aluminum perforated with numerous 3/32-in. holes.

Vent tube made of 3/4-in. aluminum with 3/8-in. center and numerous 3/32-in. holes.

Figure 1. MODIFIED FISCHER RETORT CHARGED WITH OIL SHALE

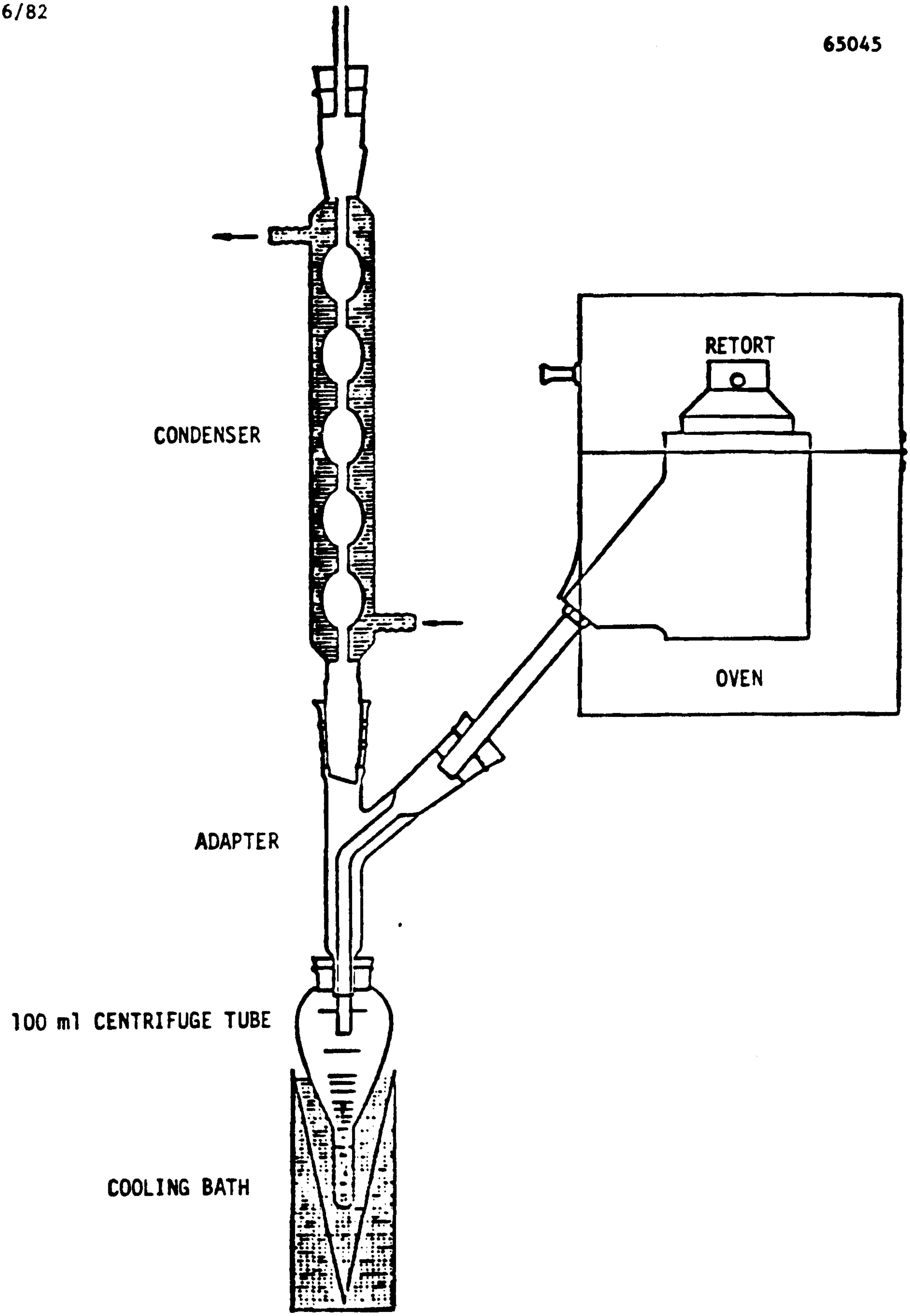


Figure 2. FISCHER APPARATUS ASSEMBLY

Table V-2. EARLY FISCHER ASSAYS

Feedstock Date Run	Eucalyptus Limbs 9-9-80	Leucaena Limbs 9-5-80	Pineappple Waste 9-9-80	Eucalyptus Limbs 9-30-80	Reed Sedge Peat 9-30-80
Weight Percent on Moisture-Free Basis					
Oil	8.1	10.0	8.3	10.4	10.0
Water	41.2	40.2	38.7	33.7	15.1
Residue	32.3	31.8	30.3	29.6	51.2
Gas & Loss	18.4	18.0	22.7	26.3	23.7
Total	100.0	100.0	100.0	100.0	100.0
Moisture, wt %	9.7	8.85	—	—	—
Oil Sp. Gr. 60/60F	*	*	*	1.120	1.007

* Insufficient oil for Sp. Gr., but it was heavier than water.

The potential oil and gas yields from candidate feedstocks was continued for all of the varieties of feedstock received. When we learned, on March 2, 1981, that the study was being confined to eucalyptus trees (about 5 years old) we cancelled any outstanding analytical work stemming from the Fischer Assays. Some feedstocks, therefore, have received only the Fischer Assay itself, and not the detailed gas, water, and oil analyses which were run earlier as a matter of course.

Later Fischer Assays, with the improved technique mentioned above, are displayed in Table V-3. Additional analytical information, such as gas, water, and oil analyses are included in Appendixes A and B.

The Fischer Assay oil yield of pineapple waste reported in Table V-3 (14.9%) is higher than the 8.3% value reported earlier (analysis of 9/9/80). The Fischer Assay technique was modified and improved in the interim, so that the later data, shown in Table V-3, should be more accurate. Some assays (generally important samples) have been run in duplicate. Both results are recorded separately here to give an idea of reproducibility. As can be seen from the table, it is generally quite good.

There was a surprising difference in the recorded oil yields from leucaena and eucalyptus that had not been indicated in earlier Fischer Assays. The new results were obtained in duplicate so would be expected to be quite accurate. Although leucaena showed a low yield of oil, the yield of organics in the water phase was high, about 10.6% compared with 8.2% for eucalyptus. These high values of organics in the water yield from Fischer Assay are caused by the low temperature "wood distillation" technique used. The water effluent from a continuous pyrolysis reactor, operating at relatively high temperature, will not be burdened with such a heavy content of organic acids and other oxygenated, hydrophilic species.

Pure lignin was run on Fischer Assay, as well as cellulose, in order to provide a basis of comparison. These assays were made on IGT account, but were of particular interest to this project. The lignin had the higher recorded oil yield (19.3%) and the lowest H/C value (1.11%). Unlike most pyrolysis feedstocks, the H/C ratio, by itself, it not a good correlator of oil yield, such as it is for steam-cracking of naphtha and gas oil feedstocks. The oxygen content of the biomass feedstock is also a factor. For lignin, the oxygen content was a low 29.47% compared with 49% for cellulose.

Table V-3. FISCHER ASSAYS: WITH IMPROVED TECHNIQUE

Feedstock / Date Run	Leucaena 12-11-80		Eucalyptus 12-11-80		Sugar Cane Waste 2-19-81	Sugar Cane Stalks 3-3-81	Pineapple Waste 2-19-81	Ohia Wood 2-26-81	Albizzia Wood 3-31-81	Guinea Grass 2-19-81		Cellulose* (J.T. Baker Reagent) 1-29-81		Absorbent* Cotton, USP 2-19-81	Lignin* (Westvaco) 2-19-81
Yield, Wt % (Moisture Free)															
Oil	6.3	6.1	10.9	13.5	8.2	6.9	14.9	10.6	12.1	11.2	10.2	8.9	8.1	8.2	19.3
Water	41.2	40.5	36.4	31.7	26.7	48.1	34.4	37.3	40.9	31.5	32.4	51.6	49.2	52.8	18.9
Residue	30.3	30.5	33.4	31.6	47.8	28.0	31.3	32.2	28.6	34.7	34.2	23.5	23.3	21.6	54.7
Gas & Loss	22.2	22.9	19.3	23.2	17.3	17.0	19.4	19.9	18.4	22.6	23.2	16.1	19.4	17.4	7.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.00	100.00	100.0	100.0	100.0	100.0
% C in Water	19.4	19.6	21.2	19.2	-	-	-	-	-	-	-	-	-	-	-
Oil Sp. Gr. 60/60 F	1.13	1.13	1.15	1.17	1.07	1.12	1.05	1.13	1.15	1.05	1.05	1.26	1.25	1.17	1.23

* Runs made on ICT account to supply a datum plane for comparison.

Some additional observations that arise from the tabulated Fischer Assay data are:

- The oil from cellulose had a higher specific gravity than that for lignin.
- The oil yield from lignin was much greater than from cellulose.
- Sugar cane stalks gave a higher yield of water than sugar cane waste.
- Albizzia wood gave a good yield of oil, at 12.1%, despite its pithy, wet appearance in the field.
- Guinea grass gave an average oil yield of 10.7% which, also, was relatively high.

The ultimate analyses of the oils and chars produced by Fischer Assay are listed in Table V-4. The oils from sugar cane waste, pineapple waste, and guinea grass had higher carbon-to-hydrogen ratios and lower oxygen contents than the oils from the wood and, somewhat surprisingly, the cellulose sample. They were, in fact, closer to the lignin-derived oil in content.

In looking over the char analyses, the sugar cane waste and grass had the highest ash content (possibly some soil adding to it). All of the potential feedstock samples had higher ash contents than either the cellulose or lignin, which would be expected.

The composition of the gases evolved during the Fischer Assay distillations has been determined by mass spectrometer analysis and displayed in Table V-5. While 28 different components have been identified by analysis, almost 90% of the gas is made up by four components: CO, CO_2, H_2, and CH_4. The CO_x by itself is 75% of the gas, with CO about 25% and CO_2 around 50%. Hydrogen is about 2%, as are the C_2's, and methane runs about 10%, being the principal hydrocarbon gas evolved in the long residence time, low heating rate reaction system of the Fischer Assay distillation.

The varying nitrogen content of the gas analyses is a function of the amount of air inadvertently drawn in during the Fischer Assay distillation procedure.

There is very little LPG material formed during Fischer Assay, so that the 2% to 3% yields of LPG observed in the continuous reactor test work must be formed by the cracking and/or hydrocracking of heavier materials, such as some of the Fischer Assay oil products.

Finally, perhaps the most significant observation that can be made from this vast array of numbers is that the gases evolved were all very similar regardless of the feedstock. Also, the total gas yields from the various feedstocks do not vary very much, as can be seen in Table V-5. This leads to the conclusion that variations in reaction severity would have a much greater impact on gas yields and quality, and therefore plant design, than would changes in feedstock.

C. Continuous Reactor Tests in PDU

A process development unit that has been used successfully in converting peat to gas, oil, and char was put into service to convert biomass in a continuous hydropyrolysis. The unit is depicted schematically in Figure V-3. The electrically heated reactor is 60 feet of nominal 1-inch Incoloy tubing; it can be fed with a variety of carrier gases, which serve to carry the solid feed through the reactor and set the residence time. The upper limits of operation of the reactor are 1500°F and 1000 psig. A cyclone is used to trap char, and a series of heat exchangers and cold traps are used to separate oil and gas for measurement, collection, and analysis. The residence time used for peat conversion and anticipated for the Hawaiian biomass treatment was 5 to 10 seconds. The maximum yield of oil from peat was obtained with the maximum reactor temperature around 1100°F.

The solids feeding system consists of a pressurized hopper feeding through a nominal 1-inch-diameter downcomer into a horizontal screw feeder. The screw feeder discharges into another short (about 6-inch) downcomer that feeds the solids directly into the heated carrier gases issuing from the carrier gas furnace. The carrier gas plus solids proceed directly into the heated, downward-flowing, helical reactor.

Our general premise was that the biomass materials should be ground to the same consistency as that used for peat in PDU runs, namely, 10 x 20 mesh. The biomass materials are not significantly more fibrous than peat, but they are lighter. One consequence is that they have a greater tendency to bridge across the throats of feeding downcomers. This was the main problem in making PDU runs. We tried a finer consist, with stray long fibers removed, in an attempt to improve flow characteristics. The situation in the PDU was hindered by the very small scale of operations; the downcomer throats are

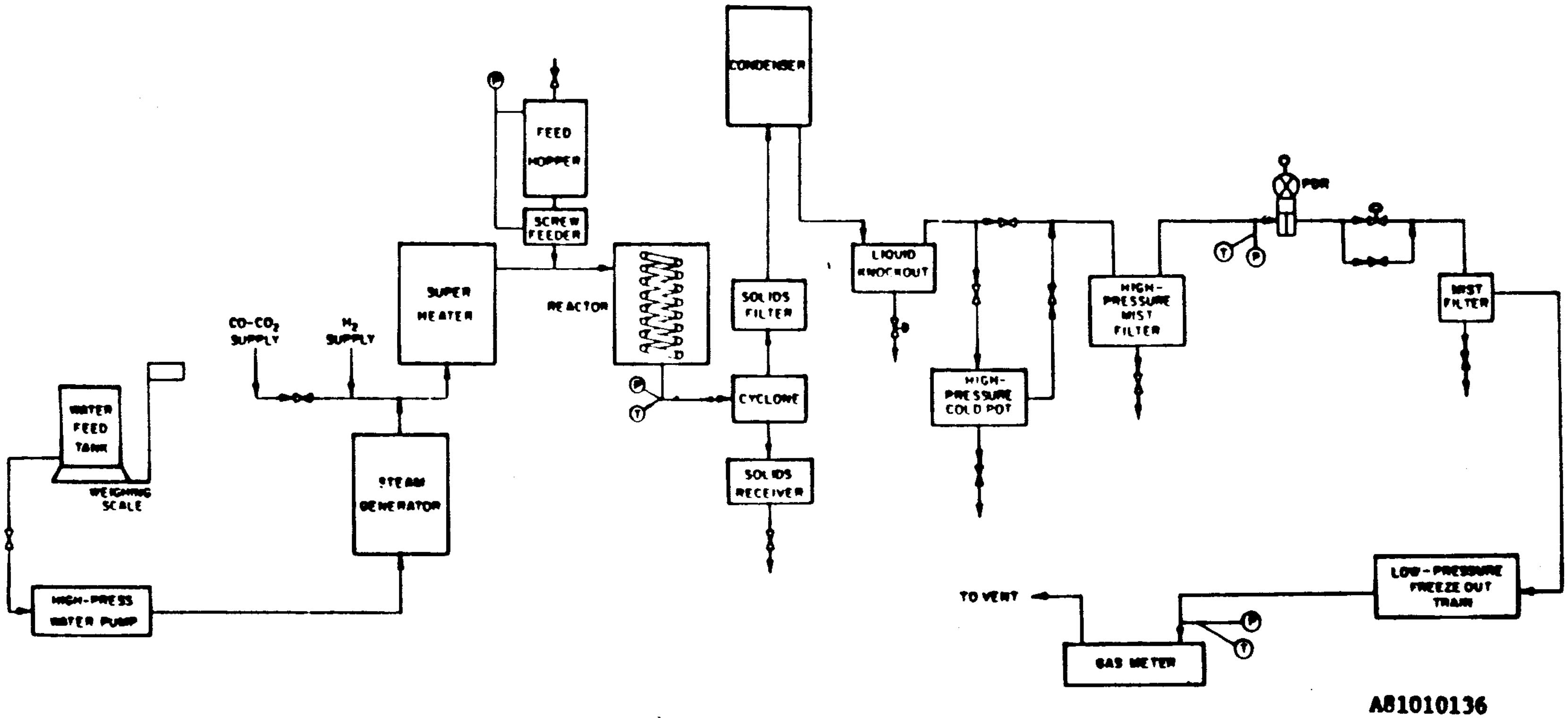


Figure V-3. PDU SCHEMATIC DIAGRAM

about 3/4-inch in diameter. On the positive side, the small amount of char generated appeared to be completely charred throughout the cross-section of the largest pieces, as was the case with peat char in earlier work.

In addition to our own feed preparation efforts, using both hammer mills and "meat-grinder" types of size reduction equipment to supply ground feedstock for test work, we contacted three vendors of commercial grinding equipment for information and testing (in their labs) of the Hawaiian woods. Based on discussions with these vendors, we do not anticipate that feed preparation will be a problem, other than finding the most economical combination of processing techniques.

The second downcomer of this feeding system proved to be the stumbling block in feeding Hawaiian wood material. Leucaena ground to −14 mesh has been used but without 100% success. All run attempts were stopped by a "bird-nest" type of plugging in the second downcomer. In the most successful run (WC-1), three hours of continuous operation was achieved before plugging — in the second downcomer — stopped the run. The feedstock in this case was −14 mesh leucaena mixed with 75% by weight of similar-sized sand to help carry the wood through the reactor feeding system.

For the record, the Maui Hardwoods' sawdust also bridged in the helical-coil PDU feed hopper. A prototype agitation device to break up bridges was fabricated and tested in a Plexi-glass model, but the time and expense involved in translating it to the PDU (requires new high-pressure flanges) was considered unwarranted, in view of our success with the free-fall reactor.

D. Continuous Reactor Tests in Free-Fall Unit

Because of continuing feeding problems with the helical-coil PDU we switched the product yield test work to a free-fall reactor and made a series of six runs at varying conditions to simulate the operation of an entrained-flow reactor such as that proposed in the HYFLEX system.

The bench-scale free-fall equipment used is illustrated in Figure V-4. It is composed of a feed-gas handling system, a reactor and furnace system, and a product gas and liquids handling system.

The feed gas handling system is designed to supply the carrier gas at the temperature, pressure, composition, and flow rate desired. During the

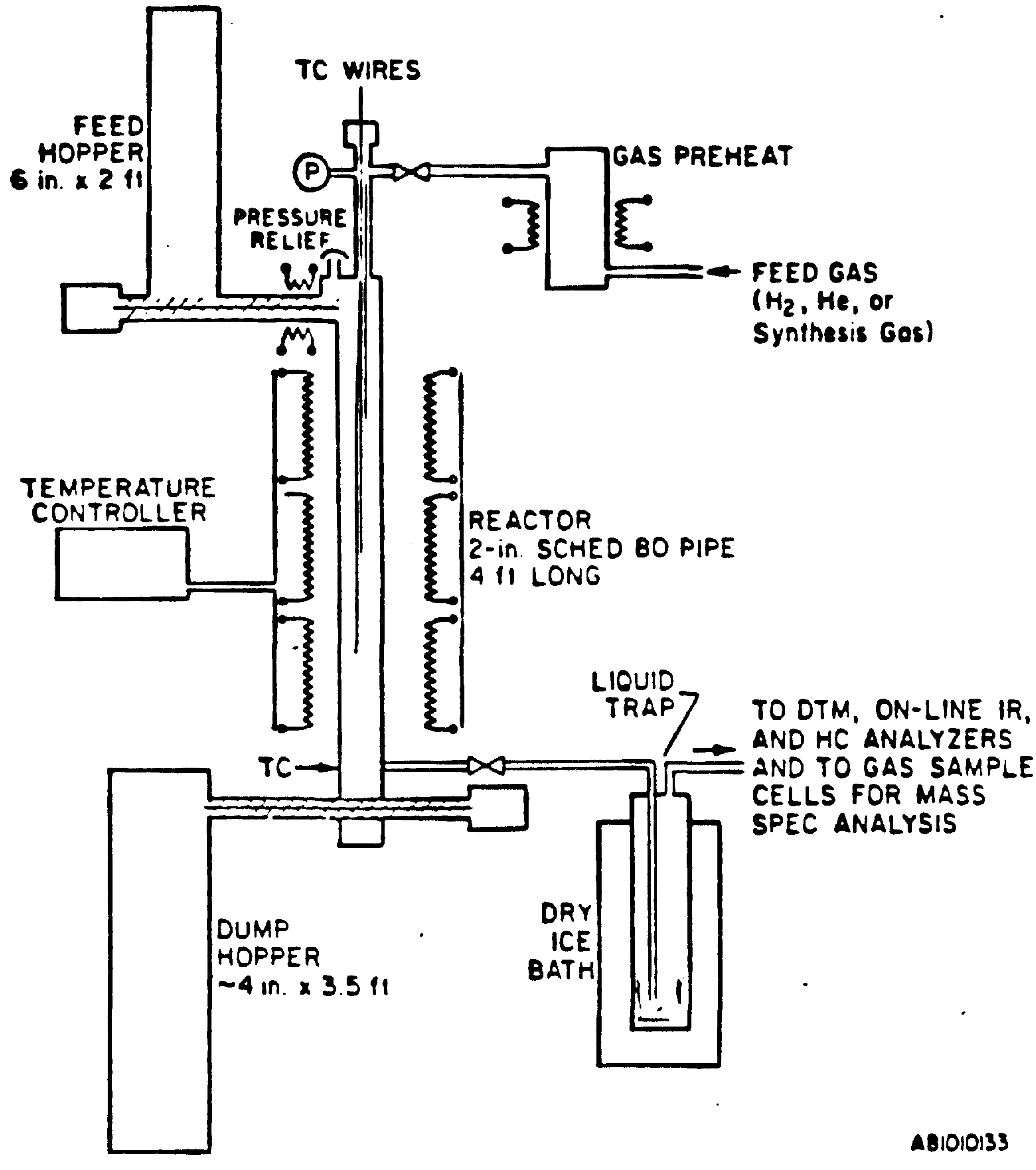


Figure V- 4. BENCH-SCALE FREE-FALL REACTOR course of a run, the carrier gas flow rate is monitored by measuring the pressure drop across a "pigtail" coil of 1/6-inch-diameter tubing. The reactor pressure is maintained with a dome-loaded back pressure regulator installed in the product gas exhaust line. A pressurized, stirred feed hopper with a screw auger to feed the solids is installed on top of the reactor. A screw auger at the bottom of the reactor discharges the char into a dump hopper. The reactor sections are coupled with 4-inch "Graylok" connectors. The reactor can be heated by a clam-shell electric furnace to about 1400°F (760°C).

The feed solids enter at the top of the reactor. The preheated feed gases are delivered to the reactor approximately 3 inches below the solid feed position in cocurrent downward flow through the 4-foot reactor section. The temperature in the reactor is monitored by four centerline thermocouples. The gaseous and liquid products pass through a 200-mesh filter inside the reactor above the bottom char discharge section. The char is rapidly discharged from the bottom of the reactor by the screw auger to a cold dump hopper to quench any further reaction.

The product gas-handling system is comprised of a dry-ice liquid trap, back-pressure regulator, dry-test meter, and on-line gas analysis and sampling systems. The liquid trap is constructed from a 3.5-ft long by 3.5-in. diameter pipe with a 1/2-inch-diameter dip-tube extending to within 6 inches of the bottom of the sealed pipe. The trap houses a glass liner bottle to collect the condensing liquids. This liner is weighed before and after each run to obtain the total weight of liquids produced. A back-pressure regulator is used after the dry-ice trap to maintain the desired reactor pressure. The volumetric flow rate of the gases, free of the condensed liquids, is measured with a dry-test meter. A part of the metered gases are passed through continuous on-line infrared CO and CO_2 analyzers. The on-line infrared analyzer are used for partial product gas analysis as well as to check for steady-state conditions. Exhaust from the IR analyzers passes through a gas sampling manifold where periodic product gas samples are taken for mass spectral analysis.

At the beginning of each run, the feed hopper was charged with 400 to 600 g of prepared feed. The reactor was then purged with nitrogen and checked for pressure leaks. After the temperature was steady, the reactor was flushed with the desired carrier gas, either H_2 or He. The feed and discharge screws were turned on to start the run. The wood sample was fed at rates of 1 to 3 grams per minute to undergo devolatilization and reaction in the free-fall region. The measured free-fall time, in the reactor, for the −12+16 mesh particles was about 0.3 seconds. It was observed that, in all the runs, steady-state operation was attained within 5 to 10 minutes after starting the feed. Usually feeding was continued for another 50 minutes or more, at which point the run was terminated by shutting off the screw feeders, electric heaters, and finally, the gas flow. After the reactor had cooled and was depressurized, the devolatilized char was weighed and analyzed.

E. Experimental Verification of Base Case Design

Yields and compositions of products for the Base Case design were estimated from general predictions. These were derived from laboratory, bench-scale, and PDU data generated for HYFLEX operations on lignite and peat previous to the start of this program. Subsequently, seven bench-scale tests were undertaken with eucalyptus wood (Test Runs E-1 through E-7) and one PDU test with leucaena wood (Test Run WC-1).

The PDU test is on a scale of about 8-1/2 pounds of wood fed. It was necessary in this test to add about 3 pounds of sand to each pound of wood in order to facilitate flow of the fibrous wood through the equipment. The total material balance for this test showed 7.9% unaccounted for loss of material including the sand feed. This represents about 30% on the basis of wood fed.

The bench-scale equipment did not require sand to be mixed with the wood for successful operation. The six tests made were on a scale of about 150 to 300 grams of wood fed. Material balances show 10% to 40% unaccounted for loss of material.

In order to put the test data on a consistent basis it is necessary to adjust the output quantities of the various products (gas, LPG, oil, water, and char) so that the total output equals the total input. The most likely materials to elude recovery are the liquids (oil and water), which may occlude to the apparatus and elude washing out. With that in mind, the following procedure was adopted for adjusting the elements in and out:

1. Add entire carbon deficiency to oil out.
2. Add oxygen and hydrogen to oil out in proportion to carbon added in Step 1, maintaining measured oil composition.

3. Add remaining oxygen deficiency to water out.
4. Add hydrogen to water out in proportion to oxygen added in Step 3 to maintain water composition.
5. Account for any difference in hydrogen in and out as "hydrogen added" from the gas atmosphere. This number will be positive if net hydrogen is moved from the gas atmosphere to the products, or negative if net hydrogen moves into the gas atmosphere.

Table V-6 summarizes the information obtained in the seven tests made on eucalyptus wood made in the bench-scale equipment and the single test on leucaena wood in the PDU equipment. Fischer Assay test information on each, while not directly comparable, is included. Also, quantities for the Base Case design are included for comparison.

Tabulations of elemental component quantities from measured flow rates and chemical analyses for eucalyptus are included in Appendix F. Corresponding data for adjusted material balances are also included.

Table 7 shows analyses of eucalyptus and leucaena woods used as feeds for the tests.

Table V-7. PROXIMATE AND ULTIMATE ANALYSES OF WOOD FEED MATERIALS

	Eucalyptus	Leucaena
Moisture	10.9	8.2
Volatile	73.3	74.3
Fixed C	14.6	16.1
Ash	1.2	1.4
C	49.0	49.2
H	5.9	6.1
O	42.1	42.7
N	0.1	0.5
S	0.1	--
Ash	2.8	1.5
	100.0	100.0

Table V-6. PYROLYSIS OF EUCALYPTUS AND LEUCAENA

	Eucalyptus								Leucaena		
	Base Case	E-3	E-1	E-2	E-7	E-6	E-5	Fischer Assay, 12/11/80	E-4	WC-1	Fischer Assay, 12/11/80
Temperature, °F	1100	1220	1015	1030	980	990	1040	932	805	1234	932
Pressure, psig	200	100	100	100	100	100	100	0	100	250	0
Atmosphere	52% H_2	H_2	H_2	H_2	H_2	52% H_2	He	He	H_2	40% H_2	He
Products, wt %[a]											
Gas	31.8	46.5	29.7	34.3	17.2	23.6	30.5	21.2 (Gas + LPG)	10.5	41.1	22.6 (Gas + LPG)
LPG	5.0	4.1	3.9	4.7	1.0	1.8	1.5		0.5	3.6	
Char	23.3	22.3	21.2	23.1	38.9	29.5	21.7	32.5	50.4	7.6	30.4
Oil	15.3	10.4	33.7	27.6	30.7	33.1	36.7	12.2	35.0	24.3	6.2
Water[b]	24.6	19.8	12.8	12.6	12.3	14.8	9.7	34.1	4.7	24.5	40.8
Hydrogen[c]	1.6	1.9	0.9	0.6	0.0	0.4	0.0	--	0.0	1.8	--
Oil Composition, wt %											
C	84.4	72.7	61.1	59.0	57.7	61.2	59.0	49.4	52.2	81.5	55.3
H	13.2	9.3	7.8	7.0	6.4	6.2	7.6	7.5	6.3	6.2	7.7
O	2.4	14.5	30.6	33.0	35.4	32.6	33.2	43.1	40.9	12.3	37.0
Oil HHV, Btu/lb[d]	19,958	14,821	11,042	10,074	9268	9,926	10,425	8,255	8,085	14,338	9,674
Char Composition, wt %											
C	89.3	63.1	57.1	54.7	59.9	54.0	58.7	76.1	52.0	67.4	85.1
H	2.7	3.1	3.9	3.6	4.5	4.0	3.9	2.5	5.2	8.8	2.9
O	1.8	16.5	24.0	22.6	26.2	23.7	23.4	7.3	34.9	--	7.1
N	0.2	0.1	--	0.2	0.2	0.2	0.3	--	0.2	--	--
Ash	6.0	17.2	15.0	19.1	9.0	18.1	13.7	14.1	7.7	20.0	4.9
Char HHV, Btu/lb[d]	14,239	9,530	8,600	8,186		8,247	8,872	11,699	7,843	14,875	13,228
Solubility, wt %											
Oil in Water	2	8.0	26.6	30.5	(e)	(e)	(e)	20.2[f]	N.A.	1.2[f]	19.5[f]
Water in Oil		1.1	8.9	10.1	(e)	(e)	(e)	N.A.	42.7	18.6	N.A.

[a] wt % of moisture-free feed.

[b] Net above water in with feed wood.

[c] Hydrogen used from atmosphere. Included in products.

[d] Calculated.

[e] Total miscibility.

[f] Carbon only.

Referring to Table V-6 and comparing the values for the Base Case with the test data, it is apparent that conversion conditions somewhere between Test E-3 and Test E-1 or E-2 will produce the same percentage yield of product oil (15.3%) as taken for the Base Case.* At such conditions, the following generalizations are also apparent for the test values as contrasted to the Base Case:

- Char yield will be about the same as for the Base Case (21% to 22% versus 23%).
- LPG yield may be slightly lower than for the Base Case (3.9% to 4.7% versus 5.0%).
- Water production may be somewhat lower and gas production somewhat higher than for the Base Case.
- Hydrogen consumption will be about the same as for the Base Case (0.6% to 1.9% versus 1.6%).
- Unit heating value of the product oil will be considerably lower than for the Base Case (11,000 to 15,000 Btu/lb versus 19,958 Btu/lb). This is due to higher oxygen content (14.5% to 33% versus 2.4%).
- Unit heating value of the product char is considerably lower than the Base Case (about 9,000 Btu/lb versus 14,239 Btu/lb). This is also due to higher oxygen content (16.5% to 24% versus 1.8%).
- The solubility of product oil in water produced and the solubility of water produced in the product oil are both higher than for the Base Case.

Because of the decreased heating value of both oil and char, maintaining the same heating value output of products as for the Base Case would require a significant increase in the quantity of oil and/or char. Oil production can be increased by employing milder conversion conditions (lower temperature) as is apparent in comparing the oil yields for Tests E-1 (33.7%) and E-2 (27.6%) with E-3 (10.4%). Char yield remains essentially constant over this range. Unfortunately, increasing oil yield in this way heightens the solubility of the oil in water.

Heating value of the dissolved oil may be recovered to some extent by wet air oxidation as was contemplated for wastewater treatment in the Base Case.

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* See Page III-8.

The significant contribution of a hydrogen atmosphere during pyrolysis is evident by examination of the results shown for Tests E-6 and E-5, where the atmosphere consisted of 56% H_2 — 44% helium and 100% helium, respectively, when contrasted with Tests E-1 and E-2 where the atmosphere was 100% hydrogen. Reduction in hydrogen partial pressure at essentially the same conversion temperature increases mutual solubility of oil and water to the extent that no liquid phase separation is evident in Tests E-6 and E-5.

It is apparent that the test data do not satisfactorily support the values assumed for the Base Case design. Therefore, adjusted design quantities and compositions more in line with test figures have been developed as described in the following section.

VI. FINAL PROCESS DESIGN AND PRODUCT DISTRIBUTION

In order to maintain a design that will give a cost of products favorably comparable to the Base Case design, conditions should be such that the total heating value of the desirable products (char, oil, and LPG) produced should be as high as possible. Figure VI-1 shows, for the test data, the heating value contained in desirable products as a function of gas produced. (Gas produced is a good measure of the degree of conversion, since it is considered to be the most accurately measured quantity of all the products obtained in the tests.) It can be seen from Figure VI-1 that, as the severity of conversion changes, the Btu value of the oil passes through a maximum. That is because, as severity (temperature) increases, the quantity of oil produced decreases (see Figure VI-2), but, at the same time, the unit heating value of the oil increases.

Since oil is probably the most desirable and probably the most valuable product, it seems appropriate to design for the highest heating value in oil and LPG according to Figure VI-1. This is at a conversion severity giving gas production of about 25%. Figure VI-2 shows the yield of all products as a function of the nominal reaction temperature for the test runs. Twenty-five percent gas yield corresponds to 970°F and other product yields are as follows:

Char	26%
Water	12%
Oil	33%
LPG	4%
Gas	25%

In order to make a complete material balance of the hydropyrolysis system and to define the composition of each of the products, it is necessary to know how each of the elements (C, H, O, etc.) contained in the feed are disposed into the various products. For this purpose, the experimental data generated from the continuous feed tests described in the previous section of this report, have been utilized. Charts showing the percentages of individual feed elements converted to organic liquid, char, hydrocarbon gases, carbon oxides, and water have been prepared and are included here as Figure VI-3 through VI-9.

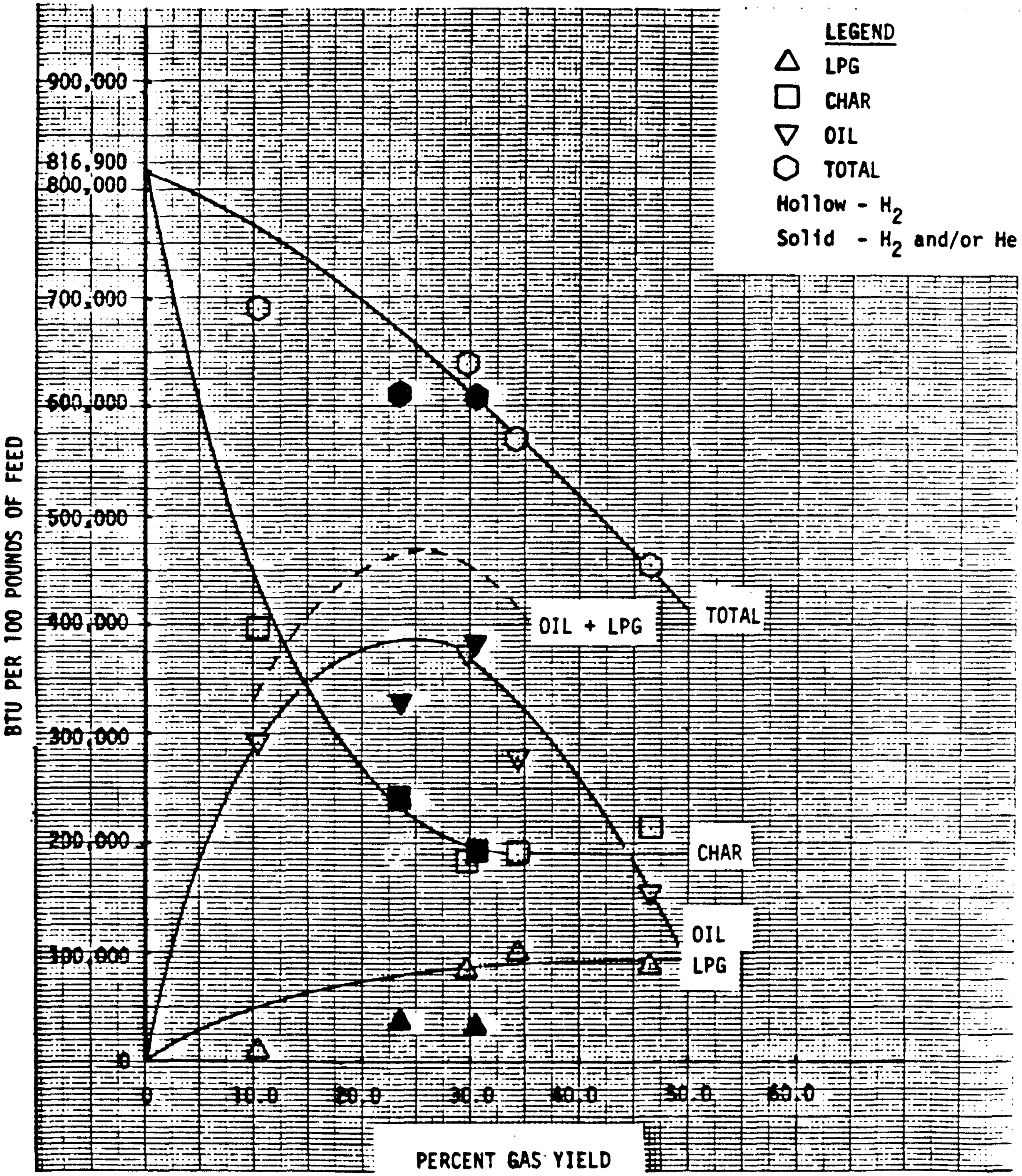

Figure VI-1. Btu YIELDS OF OIL, CHAR, AND LPG PER 100 POUNDS OF FEED VERSUS PERCENT GAS YIELD

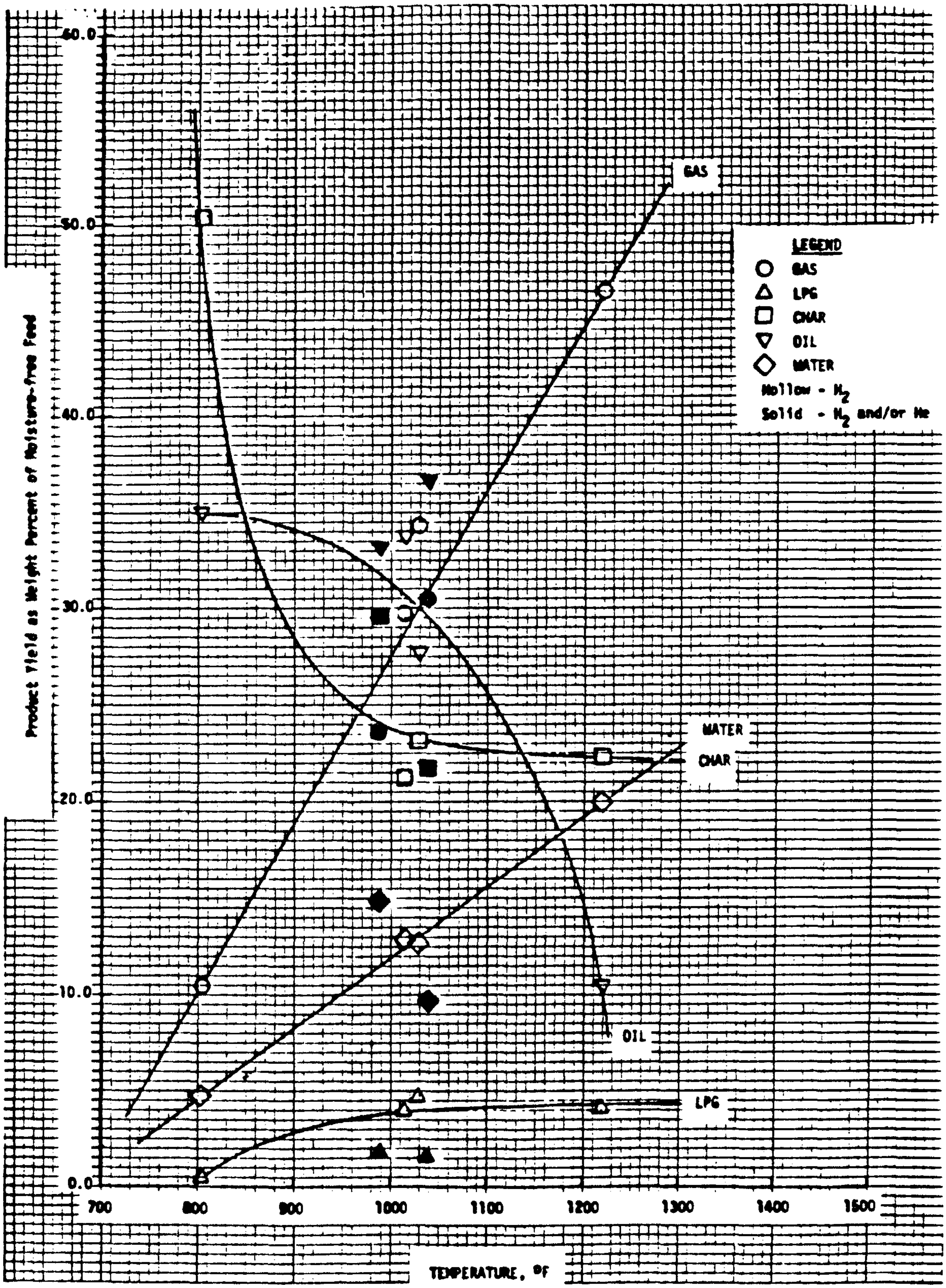

Figure VI-2. PYROLYSIS OF EUCALYPTUS — Product Yields as Weight Percent of Moisture-Free Feed Versus Temperature

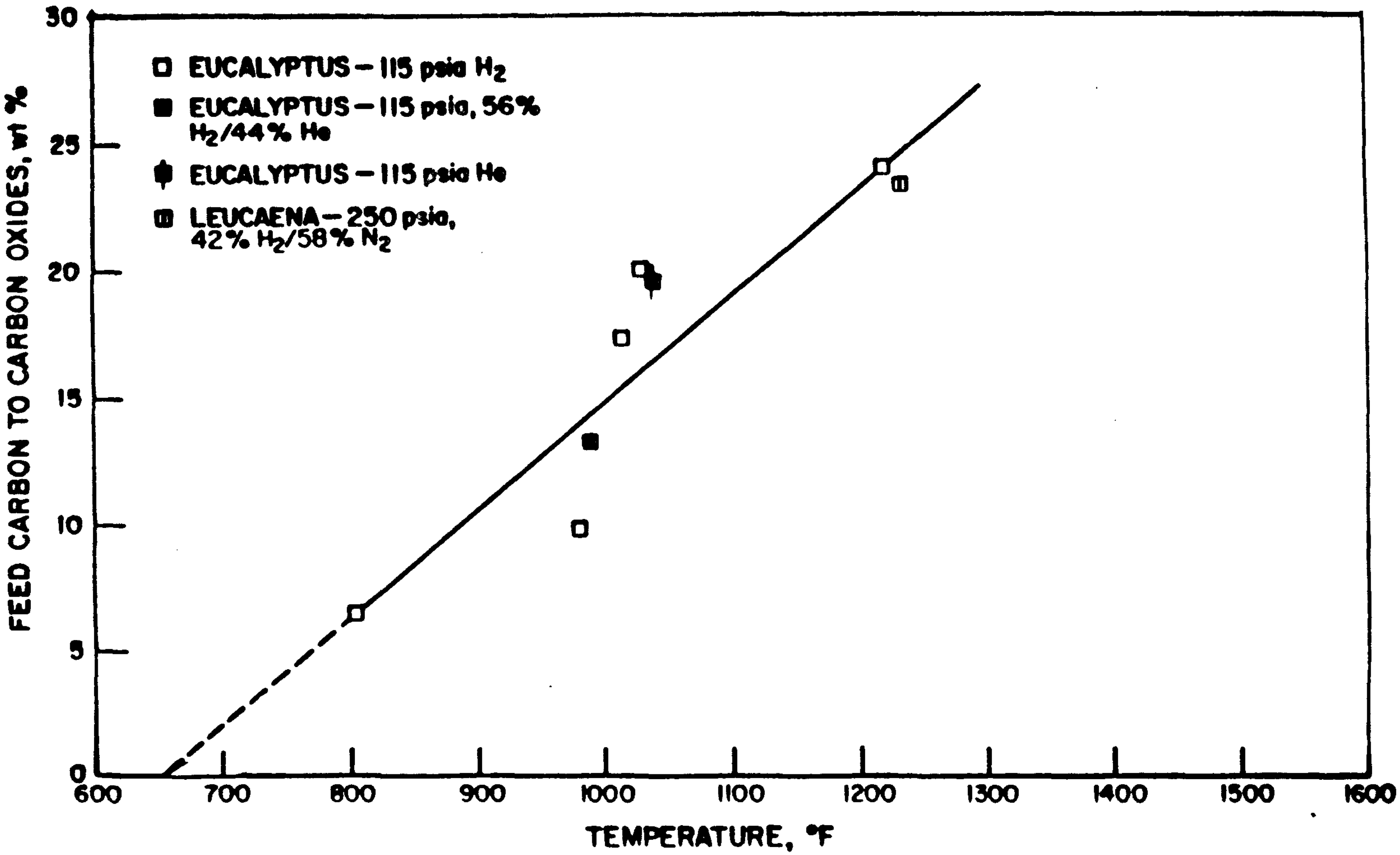

Figure VI-3. CONVERSION TO CARBON OXIDES VERSUS PYROLYSIS TEMPERATURE

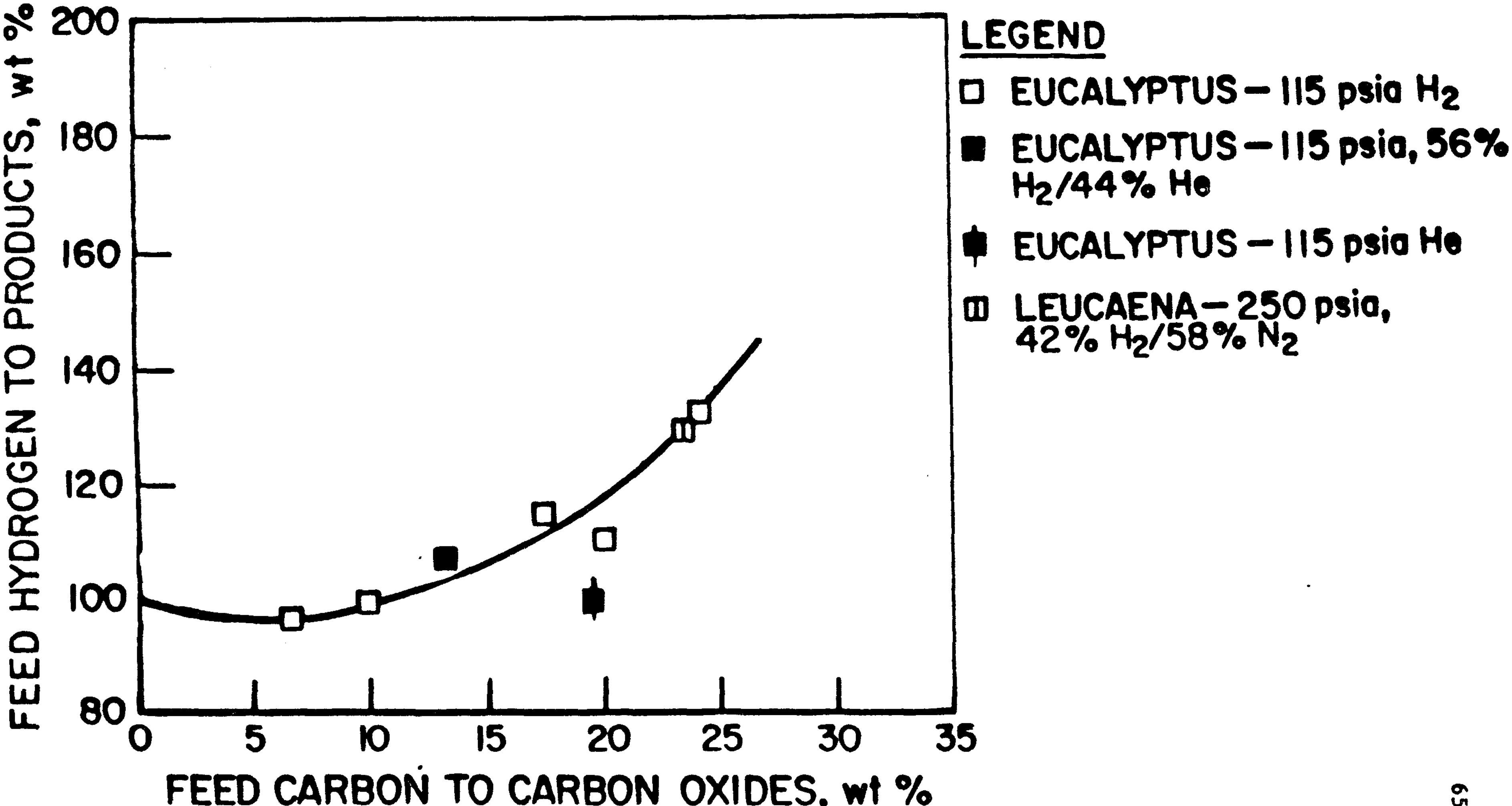

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Figure VI-4. TOTAL FEED HYDROGEN TO PRODUCTS

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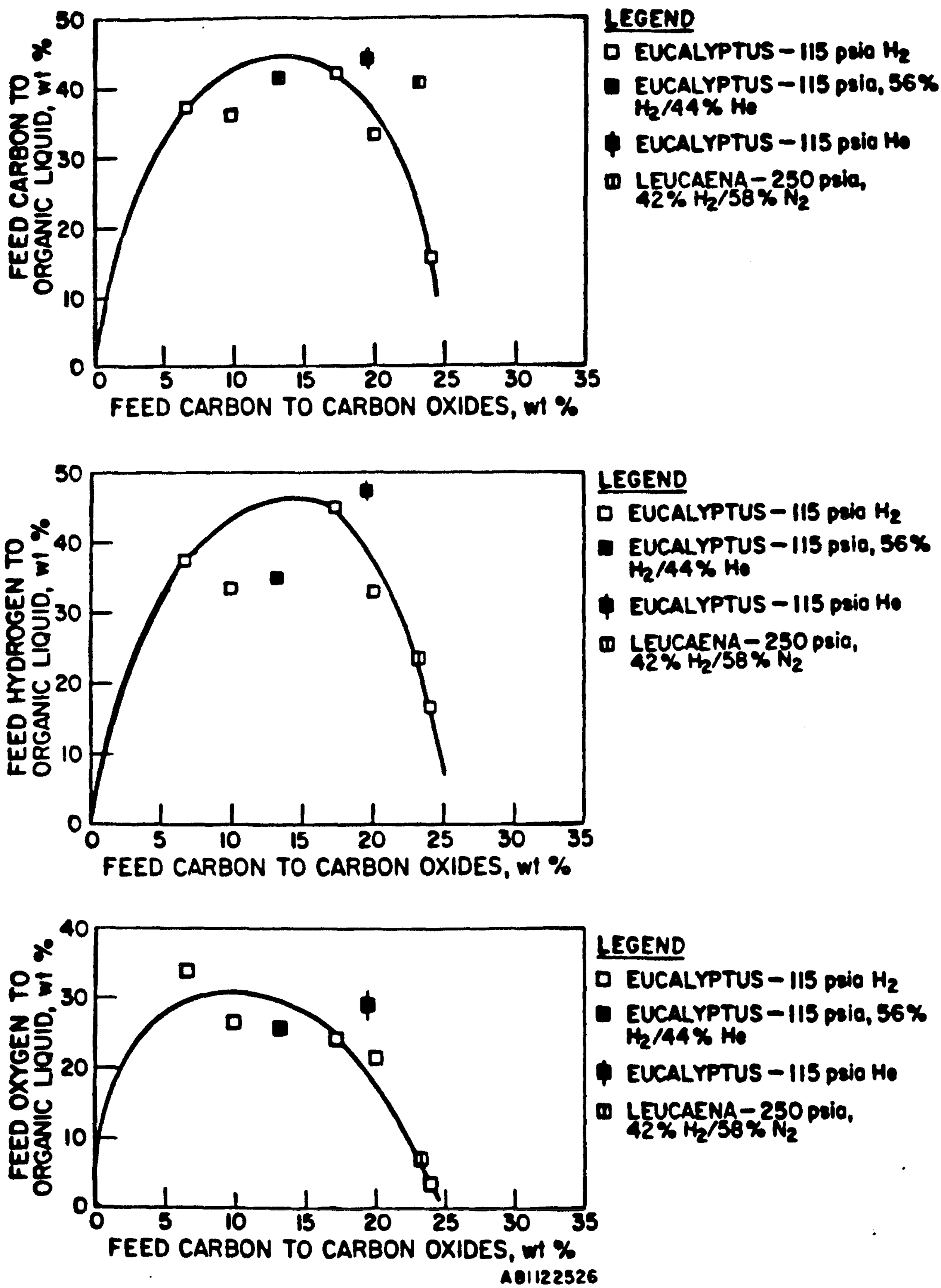

Figure VI-5. CONVERSION OF FEED ELEMENTS TO ORGANIC LIQUID

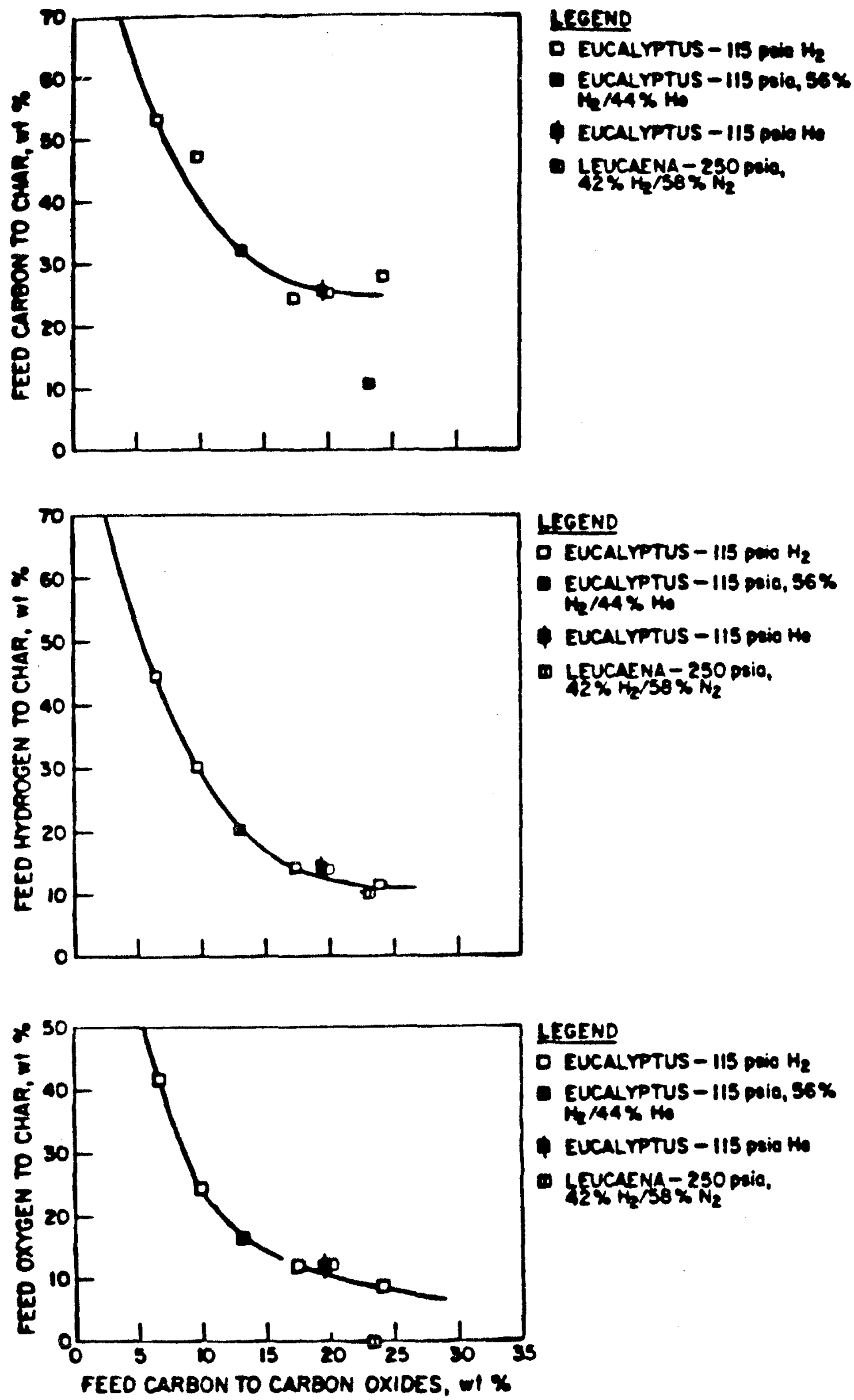

Figure VI-6. CONVERSION OF FEED ELEMENTS TO CHAR

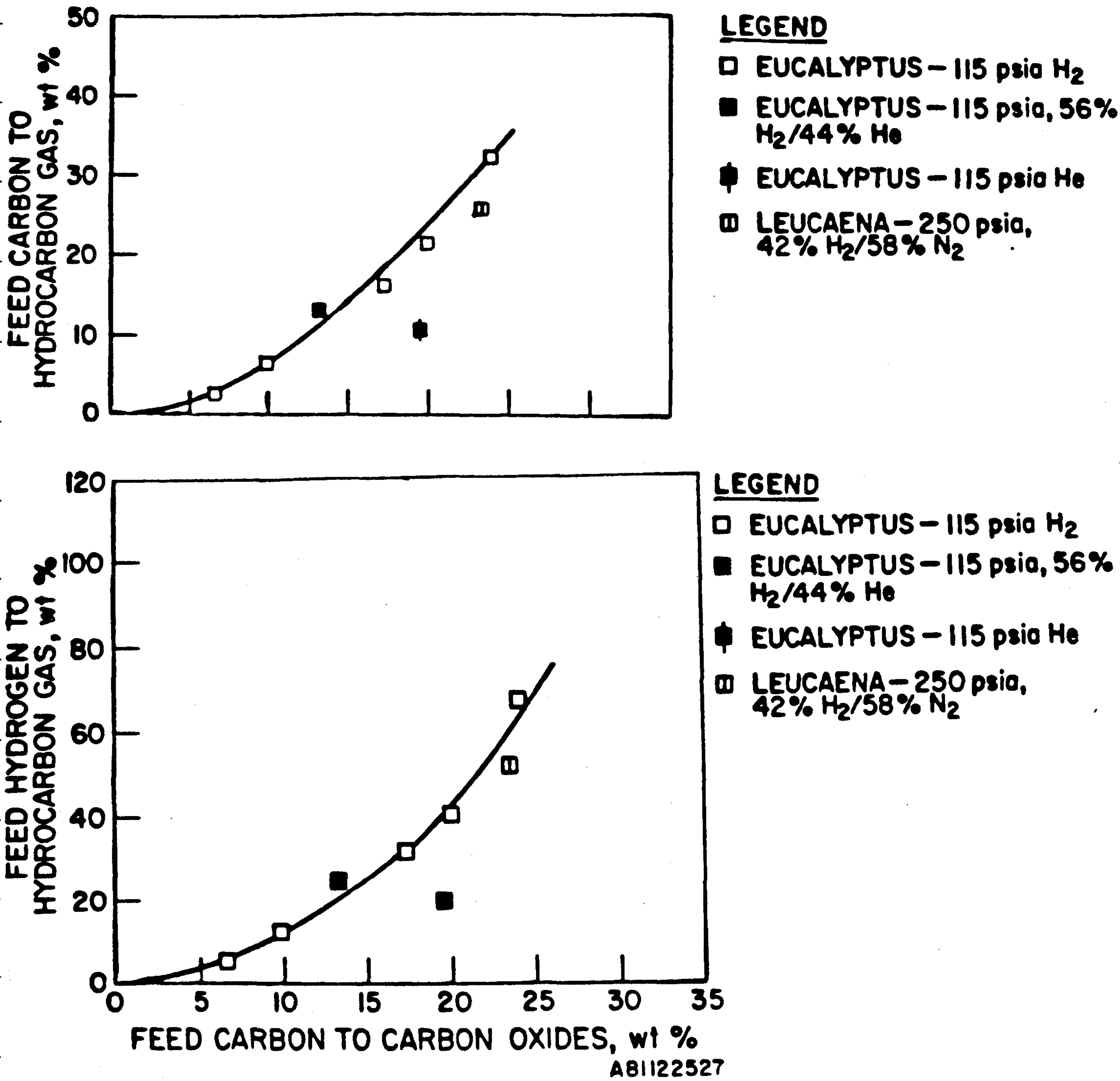

Figure VI-7. CONVERSION OF FEED ELEMENTS TO HYDROCARBON GASES

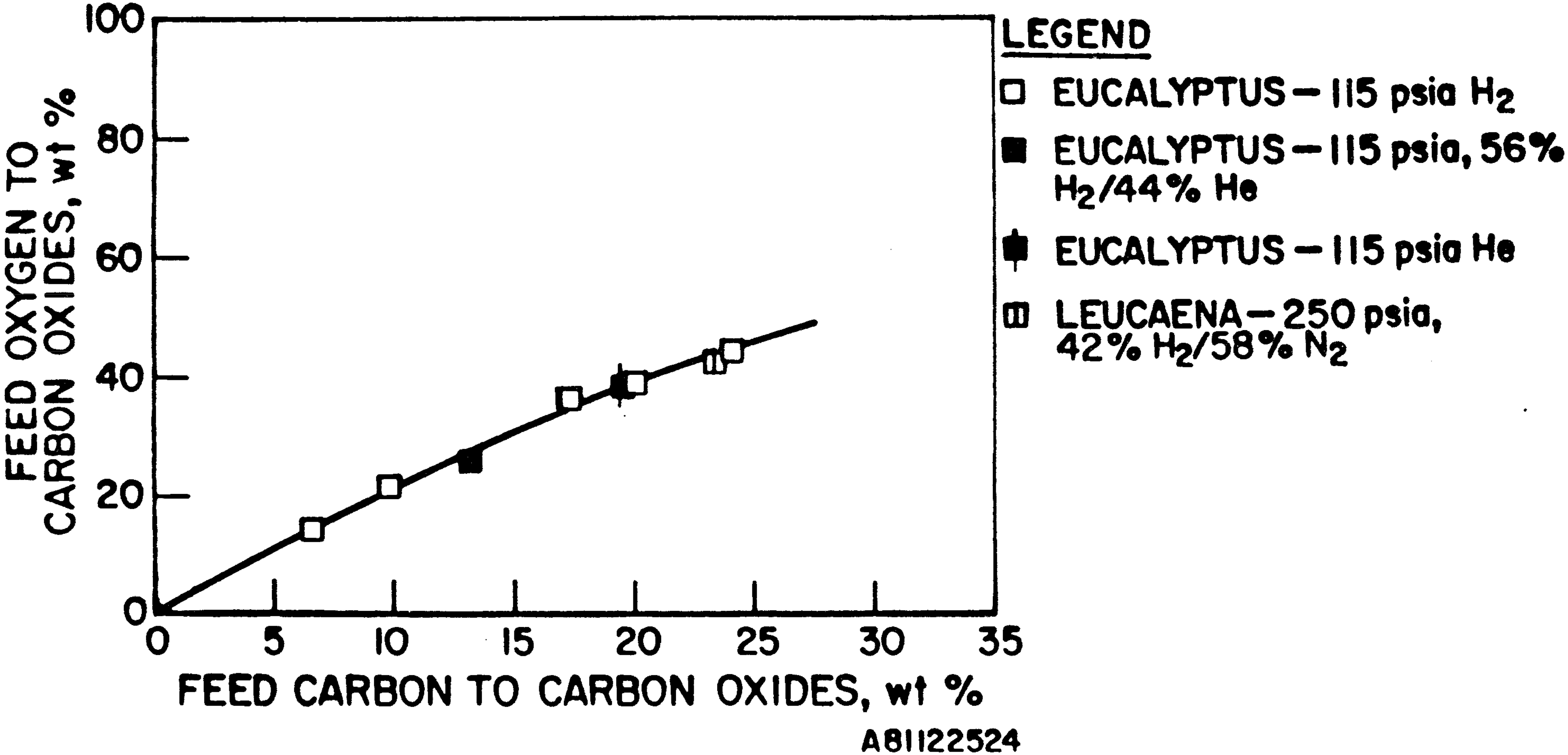

Figure VI-8. CONVERSION OF FEED ELEMENTS TO WATER

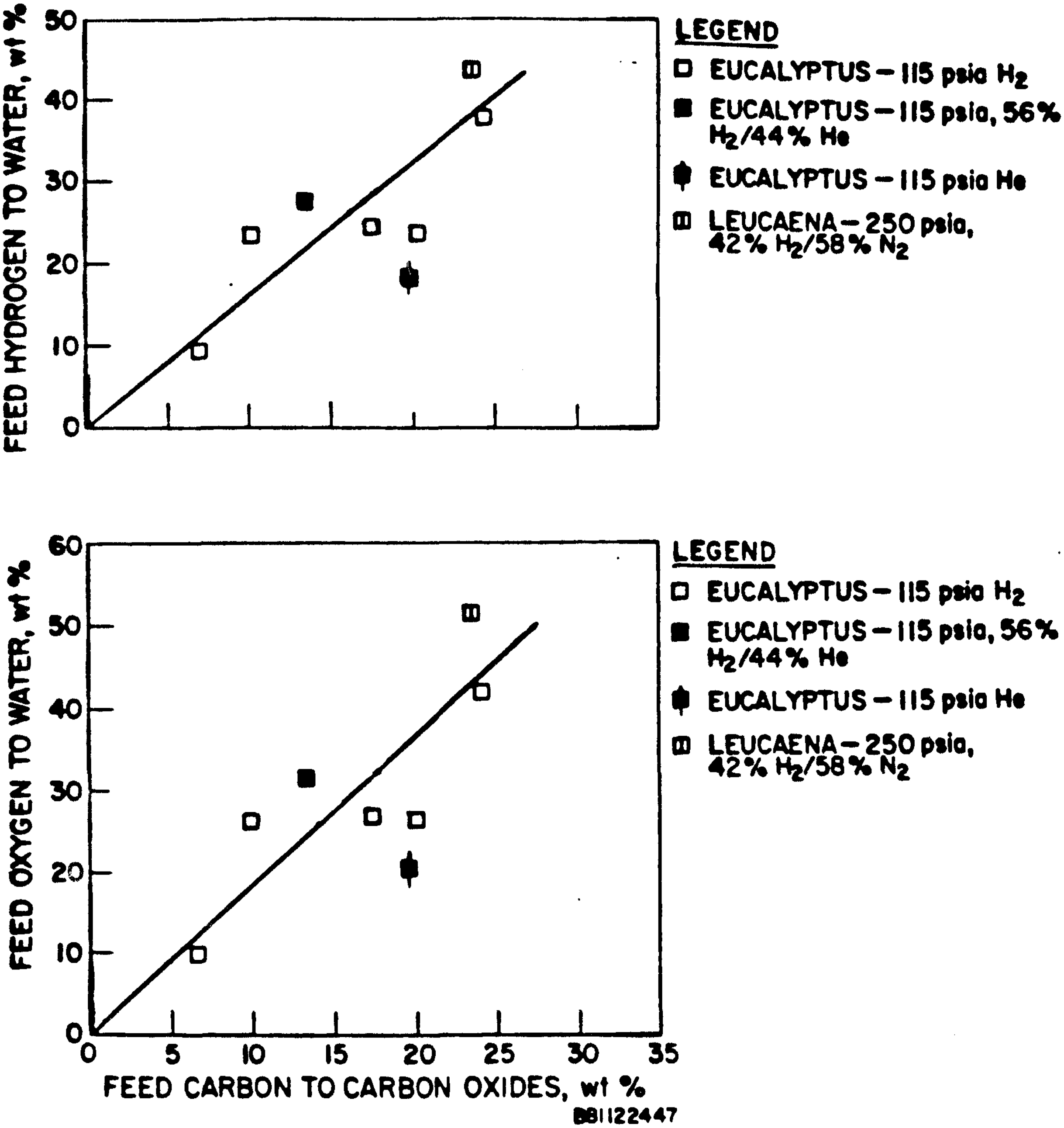

Figure VI-9. CONVERSION OF FEED ELEMENTS TO WATER

In order to develop the position and shape of the yield curves for these charts from the limited data available on wood hydropyrolysis, more extensive similar data on peat hydropyrolysis was utilized. The methods used are described in a paper included as Appendix G, "Correlation of Hydropyrolysis Data."

Extensions to pyrolysis products of values determined from Figures VI-6 through VI-9 at a carbon-to-carbon oxide conversion of 15% (corresponding to about 1000°F according to Figure VI-3) are shown in Table VI-1. Gas production is 23.5% of wood feed which corresponds adequately to the maximum heating value in oil (organic liquid) product as shown in Figure VI-1.

Table VI-2 shows the overall elemental material balance for the hydropyrolysis section for 1000 tons/day (dry basis) of eucalyptus wood feed. This takes into account distribution of water in feed wood, ash, sulfur, and nitrogen to the various products.

Table VI-3 summarizes the material balance showing the quantities of each of the plant products.

Table VI-4 shows compositions and estimated heating value of organic liquid, char, and gas produced.

It was not apparent from the test data generated to verify the Base Case design that, at the temperatures and pressures contemplated, a high hydrogen concentration in the reactor gas is effective in improving yields or quality of the liquid product. A simplified process system from the Base Case design has, therefore, been devised wherein reforming of recycle gas to increase hydrogen concentration has been eliminated. Steam is not required for reforming so that the waste heat boiler following the pyrolysis reactor is replaced by a reactor feed/product exchanger. However, a feed heater must be added to make up sensible heat previously added in the reformer. Gas cleanup (for CO_2 removal) is not necessary for reducing CO_2 concentration in the recycle gas.

This suggested revised process flow diagram is shown in Figure VI-10. Whereas, in the Base Case, all gas produced in the process was used in the reformer furnace,* the new design will use only a fraction of the produced gas for the feed heater. The remainder will be available for other plant use to reduce the amount of fuel wood required. Lack of sufficient funds did not

* Some LPG was also required to supplement the gas.

permit making a new heat balance or capital investment for this final design. Undoubtedly, the capital cost will be decreased and the quantity of wood required for fuel will be reduced from the Base Case design.

Table VI-1. DISTRIBUTION OF FEED ELEMENTS TO PYROLYSIS (Dry Feed Basis)

	% of Feed Element	X	Element in Feed, lb/hr	=	Product, lb/hr	% of Feed
H to Gas	5.0		4,892		245	
C to CO_x	15.0		40,833		6,125	
O to CO_x	31.0		35,100		10,881	
C to Hydrocarbon Gas	4.5		40,833		1,838	
H to Hydrocarbon Gas	10.5		4,892		514	
Total Gas					19,603	23.5
C to Organic Liquid*	50.5		40,833		20,620	
H to Organic Liquid*	41.5		4,892		2,030	
O to Organic Liquid	26.5		35,100		9,302	
Total Organic Liquid					31,952	38.3
C to Char	30.0		40,833		12,250	
H to Char	19.0		4,892		931	
O to Char	16.0		35,100		5,616	
Total Char					18,797	22.6
H to Water	24.0		4,892		1,172	
O to Water	26.5		35,100		9,301	
Total Water					10,473	12.6

* Includes LPG.

Table VI-2. FINAL DESIGN — PROCESS SECTION — MATERIAL BALANCE

	C	H	O	N	S	Ash	Total
	lb/hr						
Wood Feed (dry basis)	40,833	4892	35,100	108	67	2333	83,333
Moisture in Wood	--	487	3,899				4,386
Total Feed	40,833	5379	38,999	108	67	2333	87,719
Net Products							
H_2		245					245
CO	4081	--	5,436				9,517
CO_2	2044	--	5,445				7,489
CH_4	1103	370	--				1,473
C_2H_4	490	82	--				572
C_2H_6	245	66	--				307
Total Gas (to fuel)	7963	759	10,881	27*	17*		19,647
C_3H_6	306	51					357
C_3H_8	306	69					375
C_4+ organic	20,008	1910	9,302				31,220
Organic Liquid	20,620	2030	9,302	27*	17*		31,996
Char	12,250	931	5,616	27*	16*	2333	21,173
Water	--	1659	13,200	27*	17*		14,903
Total Products	40,833	5379	38,999	108	67	2333	87,719

* Arbitrary distribution.

Table VI-3. PROCESS MATERIAL BALANCE SUMMARY

	lb/hr	wt %**
In		
Wood Feed	83,333	100.0
Water in Wood	4,386	5.3
	87,719	105.3
Out		
Oil	31,220	37.5
LPG Product	732	0.9
Char	21,305	25.6
Gas (to plant fuel)	19,603	23.5
Water	14,859	17.8
	87,719	]05.3

* Does not include 19,043 lb/hr of steam to reformer.

** Percent of dry wood.

Table VI-4. COMPOSITION OF HYDROPYROLYSIS PRODUCTS

	Organic Liquid		Char	
	lb/hr	wt %	lb/hr	wt %
C	20,620	64.4	12,250	57.9
H	2,030	6.3	931	4.4
O	9,302	29.1	5,616	26.5
N	27	0.1	27	0.1
S	17	0.1	16	0.1
Ash	--	--	2,333	11.0
	31,996	100.0	21,173	100.0
HHV, Btu/lb*	10,493		8,764	

Fuel Gas

	lb/hr	mol %
H_2	245	16.1
CO	9,517	45.1
CO_2	7,489	22.5
CH_4	1,473	12.2
C_2H_4	572	2.7
C_2H_6	307	1.4
	19,647	100.0
HHV, Btu/SCF	387	

* Calculated from elements.

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V-104 GROUND WOOD STORAGE SILO
V-105 FEED RECEIVING HOPPER
V-106 FEED LOCKHOPPER
V-107 FEED INJECTION HOPPER
V-108 PYROLYSIS REACTOR 20 X 10[6] Btu/hr
V-109 CYCLONE SEPARATOR
V-110 CHAR STORAGE HOPPER
E-101 CHAR COOLER
E-102 AIR COOLER 43.6 X 10[6] Btu/hr
E-103 WATER COOLER 0.5 X 10[6] Btu/hr
V-112 KNOCK-OUT VESSEL
V-113 FLASH TOWER
TK-101 API SEPARATOR
C-102 BOOSTER COMPRESSOR 150 hp

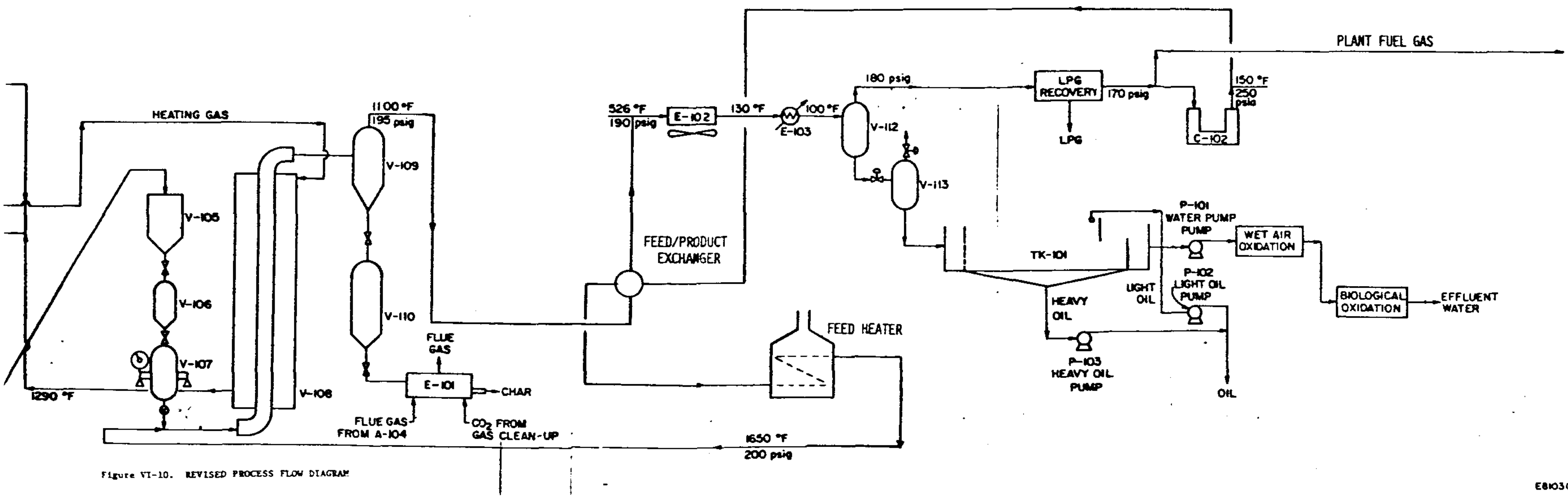

Figure VI-10. REVISED PROCESS FLOW DIAGRAM

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VII. PRODUCTION COST OF PRODUCTS

In order to arrive at the cost of product production, we have used the investment and operating costs developed for the Base Case A (Section III) and Base Case B (Section IV) designs with product quantities and quality developed for the Final Process Design (Section VI). Project funding was not adequate to prepare revised investment and operating costs for the Final Process Design Case. It is believed that the investment in the latter case will be lower than for both of the Base Cases. Likewise, the operating cost will be lower on account of less fuel wood required because added fuel gas will be available when the steam reforming of recycle gas is eliminated. Therefore, the figures set out hereafter for production costs will be conservative.

On the basis of 1000 tons/day (dry basis) of eucalyptus wood converted, the plant products and their heating values will be as follows:

	lb/hr	Btu/lb	10^6 Btu/hr
Organic Liquid	31,996	10,493	335.7
Char	21,173	8,764	185.6
			521.3

Table VII-1 summarizes the capital and operating costs for Case A (see Section III for details) and for Case B (see Section IV for details). Based on the above plant products producing 4.110 X 10^6 MM Btu/yr (at 90% plant service factor) the costs of organic liquid and char considered together on a Btu basis are $6.24 and $5.29/million Btu. On an oil equivalent basis of 6 million Btu/bbl, these are equivalent to $37 and $32 per barrel.

Cost of wood delivered to the plant has been assumed to be $24.51/ton on a moisture-free basis. This is equivalent to $1.50/10^6 Btu. It is expected that this is a very minimum cost that may vary upward to as much as $44/ton.

The following table shows the effect of wood cost on the manufactured cost of products.

Table VII-1. CAPITAL AND OPERATING COSTS
(1st Quarter 1981 Dollars)

Case A (Whole Logs Delivered to Plant)

	$ million
Total Capital Required	59.721
Annual Costs*	
Capital Charges at 15% of Total Capital Required	8.958
Wood at $24.51/ton** (dry basis)	13.507
Other Operating Costs***	3.178
Total Annual Cost of Production	25.643

Case B (Wood Chips and Fines Delivered to Plant)

	$ million
Total Capital Required	48.340
Annual Costs*	
Capital Charges at 15% of Total Capital Required	7.251
Wood at $24.51/ton** (dry basis)	11.807
Other Operating Costs***	2.701
Total Annual Cost of Products	21.759

* Based on 90% plant service factor.

** Equivalent to $1.50/10^6 Btu on higher heating value.

*** Includes water, catalyst and chemicals, operating labor, supervisor, administrative and general overhead, maintenance, local taxes and insurance.

Wood Cost, $/ton	Products Cost, $/10^6 Btu	
	Case A*	Case B**
24.51	6.24	5.29
30	6.98	5.93
35	7.65	6.51
40	8.32	7.10
45	8.99	7.68
50	9.66	8.27
55	10.33	8.85
60	11.00	9.44

* Whole logs delivered to plant

** Chips delivered to plant.

Figure VII-1 shows graphically the effect of wood price on production cost.

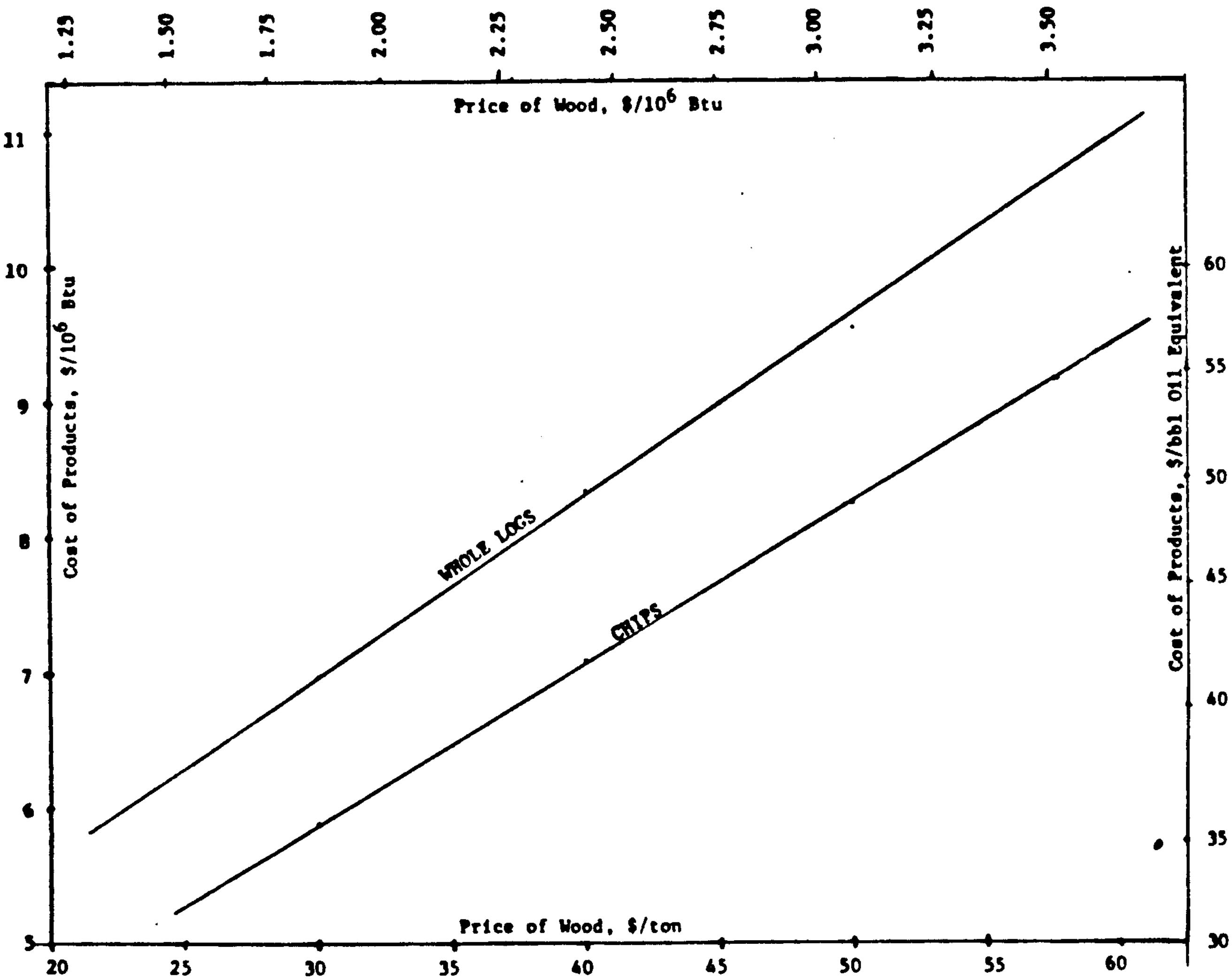


Figure VII-1. COMBINED COST OF ORGANIC LIQUID AND CHAR

VIII. PLANT EFFLUENTS

The two main gas streams vented to the atmosphere from the plant are:

1. CO_2 gas recovered from the process gas in the gas cleanup section.
2. Flue gas generated by burning wood/char in the fluid-bed combustion system A-102.

CO_2 Gas Vented to the Atmosphere*

The sulfur content of the eucalyptus wood is taken to be 0.03%.

The composition of the reactor effluent gas stream for the Base Case Design will be:

Component	Mols/Hr
H_2	448.8
CO	87.5
CO_2	704.6
CH_4	169.2
C_2H_6	64.0
C_2H_4	14.4
C_2H_2	4.2
H_2S	0.16
COS	0.002
H_2O	2081.0
Total	3573.862

A typical composition of the CO_2 gas recovered in the gas cleanup section will be:

Component	Mols/Hr
CO_2	669.4
H_2S	0.16
COS	0.001
Total	669.561

* Applies to Base Case design. Final design leaves CO_2 in fuel gas. It will, therefore, be included in flue gas.

This CO_2 will be vented to the atmosphere. It will contain 239 ppmv of H_2S and 1.5 ppmv of COS. The total sulfur thus released to the air corresponds to only 0.0076 lb of S per million Btu of eucalyptus wood pyrolyzed in the process. The amount of sulfur vented to the air is about 5.2 lb/hr.

Flue Gas Vented to the Air

The quantity of eucalyptus wood burned in the fluid-bed combustion in the Base Case design is 56,397 lb/hr (dry basis) and the amount of S at 0.03% weight will be 16.9 lb/hr. Thus, 16.9 lb of S in the form of SO_2 will be present in the flue gas.

The composition of the flue gas will be:

Component	Mols/Hr
CO_2	2,322.9
H_2O	4,815.0
N_2	15,364.5
O_2	1,693.7
SO_2	0.5
Total	24,196.6

The amount of S emitted to the air with the flue gas is about 0.04 lb of S per MM Btu of wood combusted.

The plant sulfur emissions are as follows:

Sulfur emission as H_2S and COS in the vented CO_2 gas	5.2 lbs of S/hr
Sulfur emission as SO_2 in the vented flue gas	16.9 lbs of S/hr
Total Sulfur emission	22.1 lbs of S/hr
Heat in wood for process	681 MM Btu/hr
Heat in wood for combustion	461 MM Btu/hr
Total	1142 MM Btu/hr
Total Sulfur emitted per MM Btu of wood used in the plant	0.02 lb.

Plant Effluent Wastewater

The main liquid stream to be discharged from the plant is the process derived wastewater. About 75 gpm of wastewater will be purified by wet air oxidation treatment followed by biological oxidation prior to disposal.

The wastewater will typically contain about 2% by weight of organic materials as shown below.

	Wt %
Acetic acid	0.50
Other organic acids	0.25
Methanol	0.20
Phenols	0.15
Acetone	0.25
Acetaldehyde	0.10
Other organics	0.55
Total	2.00

There is no biological treatment process now available that alone can handle the wastewater under consideration. Wet air oxidation (WAO) as a pretreatment of the water stream prior to biological oxidation is considered necessary and so recommended. WAO would convert the wastewater to a much more biodegradable form.

We consider an 80% to 90% reduction in the total organic content of the wastewater. Some of the organic components are, however, more easily destroyed by the treatment. Phenol, for instance, would be at concentrations of less than 15 ppm.

The exact composition of the wastewater after biological oxidation treatment will depend upon a number of variable factors, the process selected and the extent of purification needed for disposal at the site under consideration. However, we consider that after biological oxidation treatment and after final polishing, an effluent water stream to contain 0.1 to 1.0 ppm of organics by weight will be achieved. We do not anticipate any formidable problem to sufficiently purify the wastewater stream and dispose it off to meet the environmental guidelines.

IX. PERSONNEL REQUIREMENTS

Field Construction Personnel Requirements

Field personnel required for construction of the plant to convert 1000 tons/day (dry basis) of eucalyptus wood have been estimated. Based on a total installed plant cost of $37 million ($60.7 million capital required), approximately $12 million will be required for field construction labor. At an average of $15 per man-hour, 800,000 man-hours will be required. With 40 hours per work week and a 24-month construction period, an average work force of 192 persons will be required.

Personnel loading over the 24-month construction period has been estimated as shown in Figure IX-1. Maximum loading of 300 persons occurs during a 7-month period between the 10th and 17th months.

Plant Operating and Service Personnel Requirements

Plant personnel for the 1000 ton/day wood conversion system are estimated to be 27 persons required. Classifications are as follows:

4 Operators per shift requires	16
Plant Superintendent	1
Plant Assistant Superintendent	1
Maintenance Foreman	1
Maintenance Mechanics	4
Clerk	1
Secretary	1
Chemist	1
Lab Technician	1
Total Plant	27

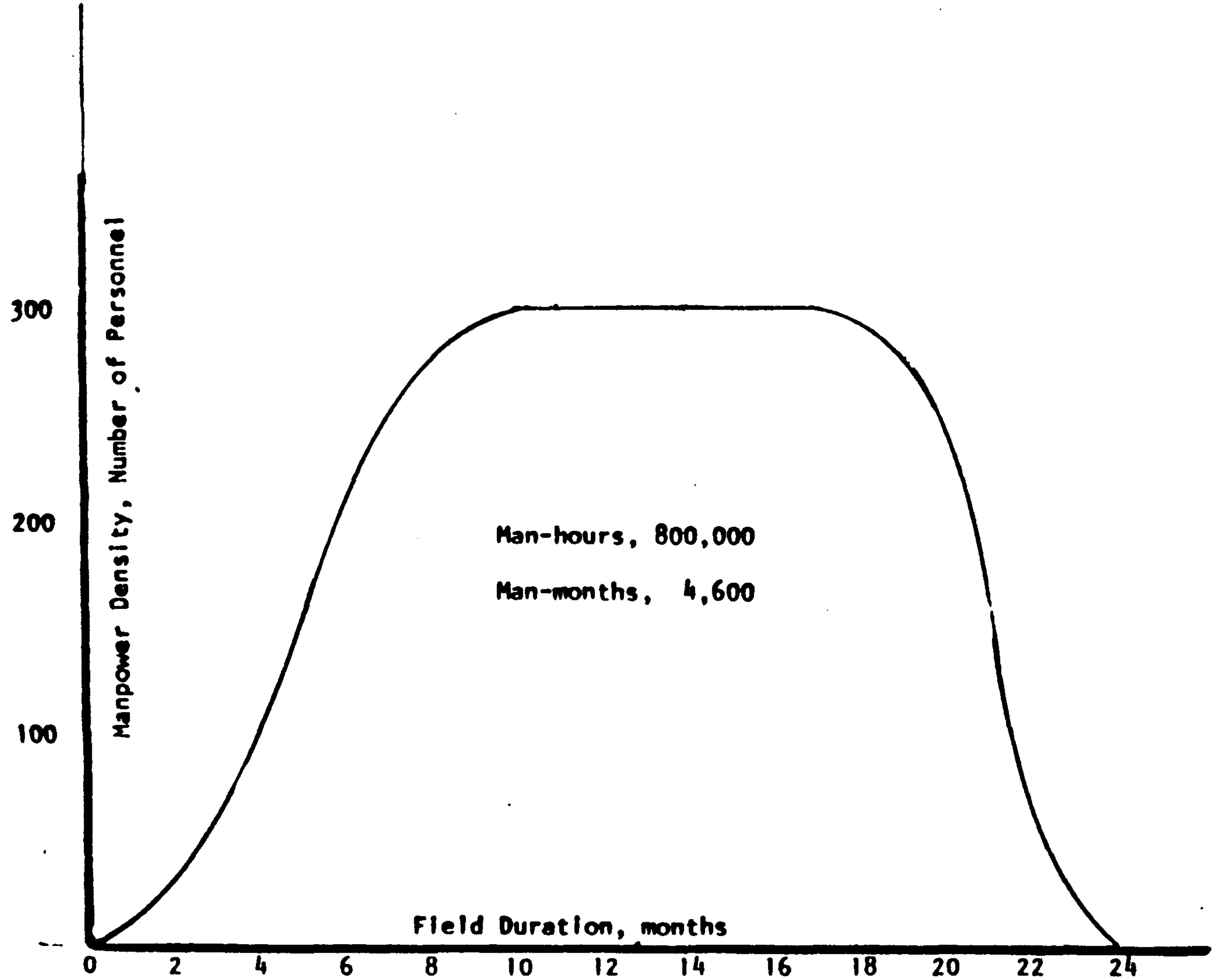


Figure IX-1. ESTIMATED FIELD CONSTRUCTION LABOR FOR 24-MONTH SCHEDULE

X. PLANT SITE REQUIREMENTS

A preliminary plot plan for facilities arrangement has been prepared. This is shown in Figure X-1. As shown, the plant battery limits with operational buildings occupies a rectangular space approximately 1000 x 500 ft (about 12 acres). Additional area has been allowed for wood storage (120,000 tons of storage for a 3-month backlog), so that the entire space required is 1200 x 750 ft (22 acres).

An elevation view is shown in Figure X-2 indicating the height of the principal items of equipment presenting a high silhouette. The tallest item will be the guyed flare stack at 150 ft high. The reactor feeding system consists of vessels rising up to 125 feet in height. These vessels will be supported in a structural steel framework.

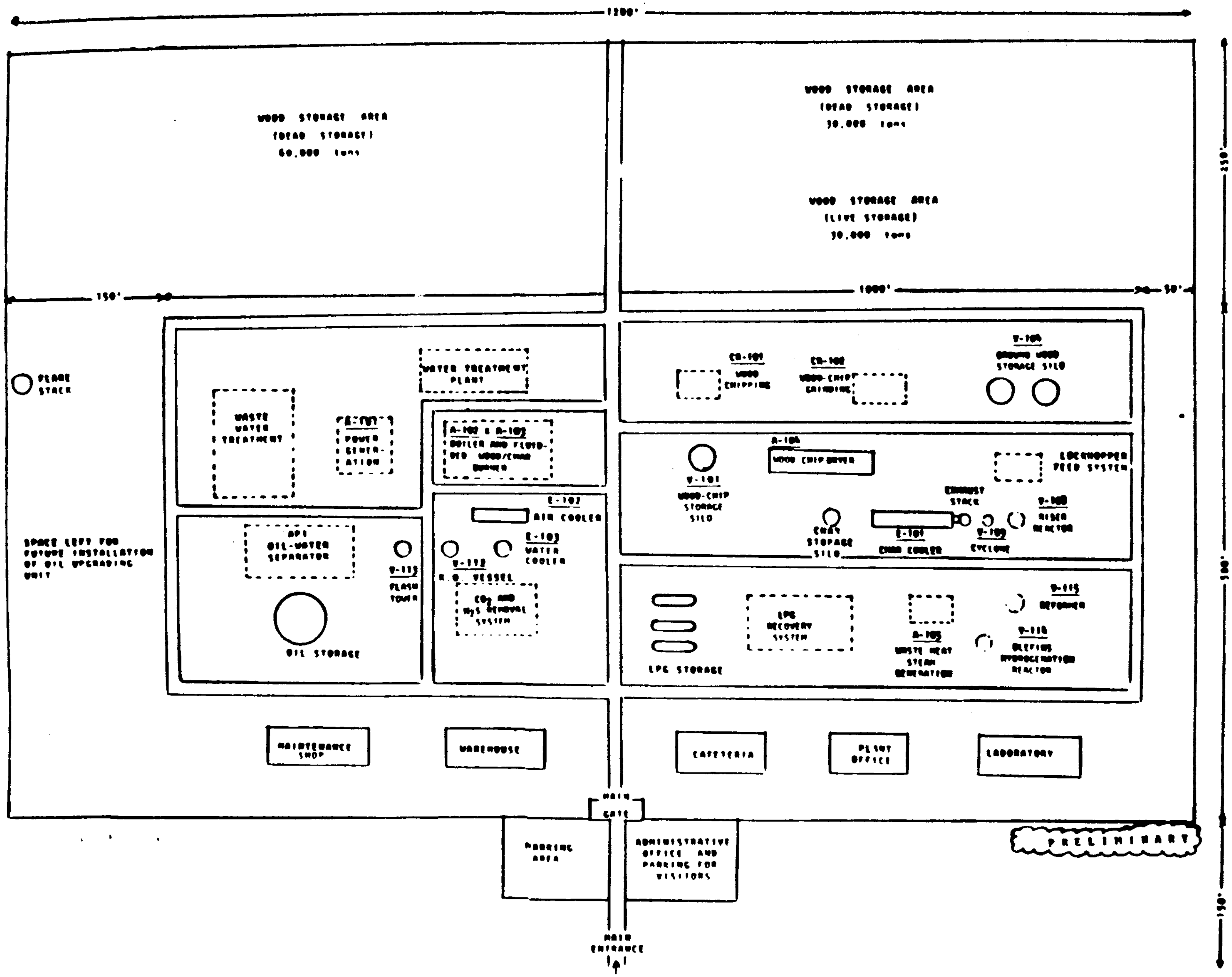


Figure X-1. PLOT PLAN FOR WOOD HYDROPYROLYSIS PLANT FOR HAWAII

6/82

65045

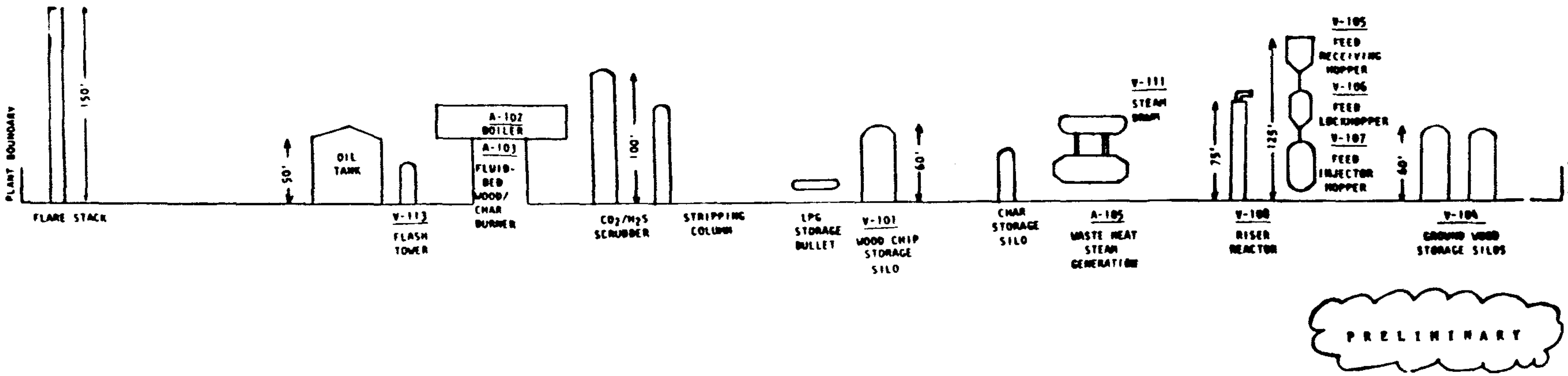
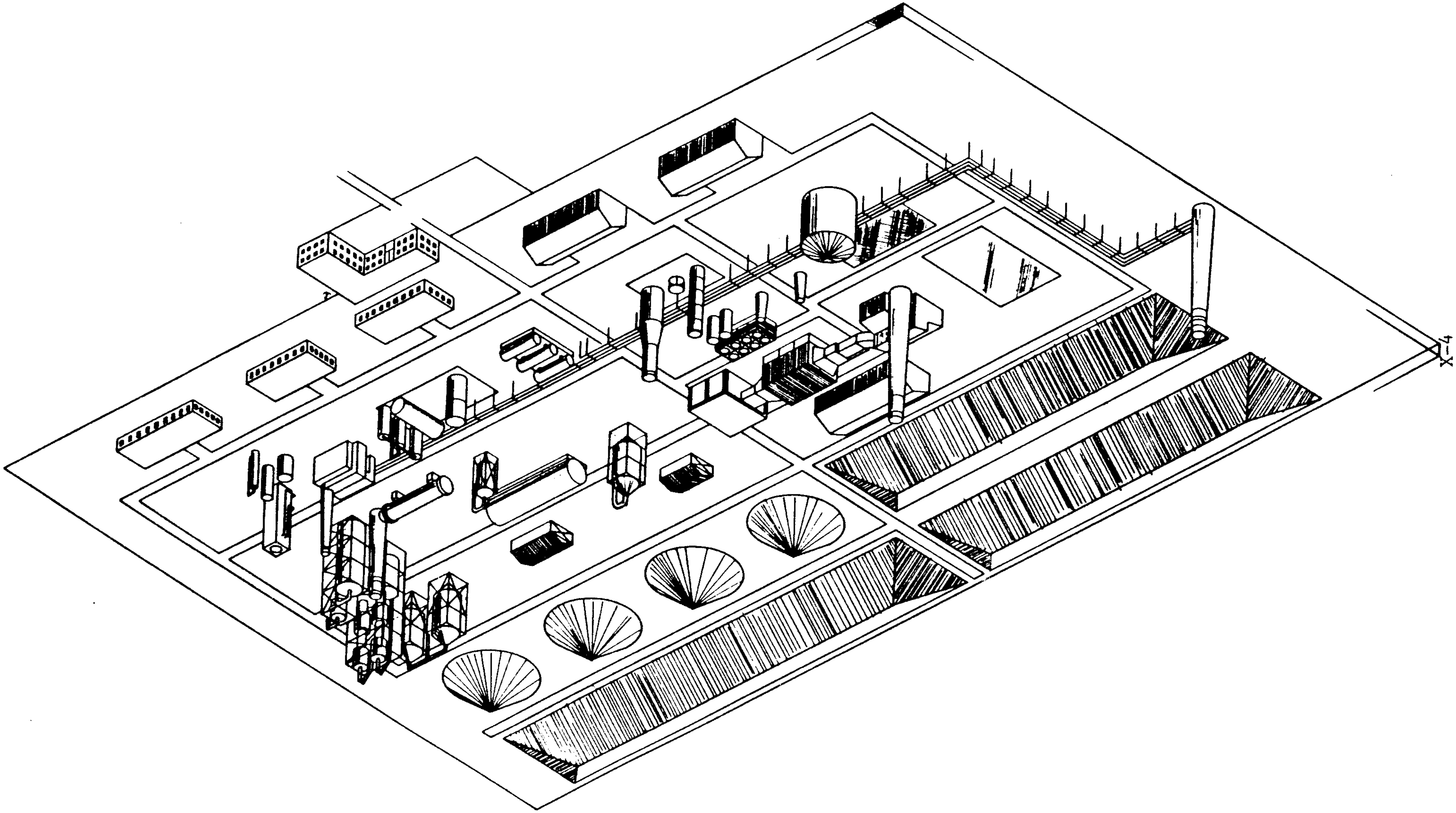


Figure X-2. PLANT VIEW FROM THE MAIN GATE SIDE
(Key Elements Shown)



APPENDIX A

Base Case Line Flows

Table A-1. MATERIAL FLOW QUANTITIES FOR BASE CASE DESIGN

STREAM NUMBER	1		2		3		4	
STREAM IDENTIFICATION	Total Wood to plant		Wood for combustion		Wood for process		Air for combustion	
COMPONENT	Mol/Hr	Lb/Hr	Mol/Hr	Lb/Hr	Mol/Hr.	Lb/Hr	Mol/Hr	Lb/Hr
H_2								
CO								
CO_2								
CH_4								
C_2H_6								
C_2H_4								
C_2H_2								
H_2S								
NH_3								
N_2							15271.2	
O_2							4059.5	
Total dry	139730		56397		83333		19330.7	
Water			----					
Total Wet								
Propane								
Butane								
Oil								
Solids								
C		68747		27747		41000		
H		8356		3373		4983		
O		60308		24341		35967		
N		363		147		216		
S		-		-		-		
Ash		1956		789		1167		
Total Stream		279460		112794		166666	19330.7	560590
Pressure (psig)								
Temp., °F								

Table A-1. MATERIAL FLOW QUANTITIES FOR BASE CASE DESIGN, Cont'd.

STREAM NUMBER	5		6		7		8		9	
STREAM IDENTIFICATION	Wood combustion hot gas		Hot gas for making steam and power		Boiler stack gas for mixing with hot combustion gas		De-Aerated boiler feed water		Steam to Steam Turbine	
COMPONENT	Mol/Hr.	Lb/Hr	Mol/Hr	Lb/Hr	Mol/Hr	Lb/Hr	Mol/Hr	Lb/Hr	Mol/Hr.	Lb/Hr
H_2										
CO										
CO_2	2322.9	102232	1515.5	66699	378.8	8883				
CH_4										
C_2H_6										
C_2H_4										
C_2H_2										
H_2S										
NH_3										
N_2	15364.5	430207	10024.2	280677	2506.1	37382				
O_2	1693.7	54198	1105.0	35360	276.3	4710				
Total dry	19381.1	586637	12644.7	382736	3161.2	50975				
Water	4815.0	86747	3141.4	56595	785.3	7538		175000	9227.9	166250
Total wet	24196.1	673384	15786.1	439331	3946.5	58513				
Propane										
Butane										
Oil										
Solids										
C										
H										
O										
N										
S										
Ash										
Total Stream	24196.1	673384	15786.1	439331	3946.5	58513		175000	9227.9	166250
Pressure (psig)									300	
Temp., °F	1900		1900		400		228		650	

Table A-1. MATERIAL FLOW QUANTITIES FOR BASE CASE DESIGN, Cont'd.

STREAM NUMBER	10		11		12		13		14	
STREAM IDENTIFICATION	Steam to gas clean up		Wood chips for grinding		Feed material to reactor		Reactor effluent product stream		Product char to storage hopper	
COMPONENT	Mol/hr	Lb/Hr	Mol/Hr	Lb/Hr	Mol/Hr	Lb/Hr	Mol/Hr	Lb/Hr	Mol/Hr	Lb/Hr
H_2					1139.8	2298	448.8	905		
CO					220.8	6185	87.5	2451		
CO_2					103.2	4542	704.6	31010		
CH_4					13.5	217	169.2	2714		
C_2H_6							64.0	1924		
C_2H_4							14.4	404		
C_2H_2							4.2	109		
H_2S										
NH_3							12.4	211		
N_2										
O_2										
Total dry					1477.3	13242	1505.1	39728		
Water	6660.7	120000		6386	700.0	12611	2081.0	37491		
Total Wet					2177.3	25853	3586.1	77219		
Propane							55.6	2452		
Butane							29.8	1732		
Oil								12778		
Solids										
C				41000		41000				17306
H				4983		4983				522
O				35967		35967				351
N				216		216				43
S				--		--				--
Ash				1167		1167				1167
Total Stream	6660.7	120000		87719	2177.3	113572		94181		19389
Pressure (psig)	50				200		195	1100		
Temp., °F	375									

Table A-1. MATERIAL FLOW QUANTITIES FOR BASE CASE DESIGN, Cont'd.

STREAM NUMBER	15		16		17		18		19	
STREAM IDENTIFICATION	De-Aerated BFW to waste heat steam generation		Cooled gas to gas clean-up		Oil product		Effluent waste water for treatment		Gas stream to LPG recovery	
COMPONENT	Mol/Hr	Lb/Hr	Mol/Hr	Lb/Hr	Mol/Hr	Lb/Hr	Mol/Hr	Lb/Hr	Mol/Hr	Lb/Hr
H_2			448.8	905					448.8	905
CO			87.5	2451					87.5	2451
CO_2			704.6	31010						
CH_4			169.2	2714					169.2	2714
C_2H_6			64.0	1924					64.0	1924
C_2H_4			14.4	404					14.4	404
C_2H_2			4.2	109					4.2	109
H_2S										
NH_3								211		
N_2										
O_2										
Total dry			1492.7	39517					788.1	8507
Water			8.0	144				37347	4.0	72
Total wet		20000	1500.7	39661					792.1	8579
Propane			55.6	2452					55.6	2452
Butane			29.8	1732					29.8	1732
Oil						12765		13		
Solids										
C										
H										
O										
N										
S										
Ash										
Total Stream		20000	1586.1	43845		12765		37571	792.1	12763
Pressure (psig)		325	180							
Temp., °F		228	100						100	

Table A-1. MATERIAL FLOW QUANTITIES FOR BASE CASE DESIGN, Cont'd.

STREAM NUMBER	20		21		22		23		24	
STREAM IDENTIFICATION	LPG product		Gas stream to olefins hydrogenation		Fuel gas to reformer furnace		Gas stream to steam reforming		Steam for reforming	
COMPONENT	Mol/Hr	Lb/Hr	Mol/Hr	Lb/Hr	Mol/Hr	Lb/Hr	Mol/Hr	Lb/Hr	Mol/Hr	Lb/Hr
H_2			359.9	724	89.8	181	340.7	687		
CO			70.0	1961	17.5	490	70.0	1961		
CO_2										
CH_4			135.4	2171	33.8	543	135.4	2171		
C_2H_6			51.2	1539	12.8	385	66.1	1987		
C_2H_4			11.5	323	2.9	80				
C_2H_2			3.4	87	0.8	22				
H_2S										
NH_3										
N_2										
O_2										
Total dry			630.5	6806	157.6	1701	612.2	6806		
Water									1057	190[illegible]3
Total wet			630.5	6806	157.6	1701	612.2	6806		
Propane		2452								
Butane		1732								
Oil										
Solids										
C										
H										
O										
N										
S										
Ash										
Total Stream		4184	630.5	6806	157.6	1773	612.2	6806	1057.2	19[illegible]
Pressure (psig)			170						300	
Temp., °F			100		100		493		1000	

Table A-1. MATERIAL FLOW QUANTITIES FOR BASE CASE DESIGN, Cont'd.

STREAM NUMBER	25		26	
STREAM IDENTIFICATION	Reformed gas for recycle		LPG fuel for reformer	
COMPONENT	Mol/Hr	Lb/Hr	Mol/Hr	Lb/Hr
H_2	1139.8	2298		
CO	220.8	6185		
CO_2	103.2	4542		
CH_4	13.5	217		
C_2H_6				
C_2H_4				
C_2H_2				
H_2S				
NH_3				
N_2				
O_2				
Total dry	1477.3	13242		
Water	700.0	12611		
Total wet	2177.3	25853		
Propane			8.8	386
Butane			4.6	269
Oil				
Solids				
C				
H				
O				
N				
S				
Ash				
Total Stream	2177.3	25853	13.4	655
Pressure (psig)	200			
Temp., °F	1650			

APPENDIX B

Reactor Energy Balance

Table B-1. REACTOR ENERGY BALANCE SUMMARY

	Energy Balance*	
Heat Input	**MM Btu/Hr****	**% of Total**
Heat in wood at 60°F	680.75	76.2
Heat in recycle gas at 1650°F	213.19	23.8
Total	893.94	100.0
Heat Output		
Heat in product gas at 1100°F	258.98	29.0
Heat in propane and butane at 1100°F	91.71	10.3
Heat in oil vapor at 1100°F	260.34	29.1
Heat in char at 1100°F	282.13	31.6
Total	893.16	100.0

*Provision has been made in the plant design to supply up to 20 MM Btu/hr of heat to the reactor tubes by passing hot flue gas generated by wood combustion. This heat supply may be needed to accommodate changes in the qualities and quantities of the products.

** The following pages show details of determination of the heat content of various individual streams shown above.

Table B-2. REACTOR ENERGY BALANCE
(Based on HHV and 60°F Datum temp.)

Heat in Wood Feedstock at 60°F			MM Btu/Hr
Heat of combustion: 83333 lbs/hr @ 8169 Btu/lb	=		680.75
Heat in Recycle Gas at 1650°F			
Heat of combustion			
H_2	$1139.8 \frac{\text{lb mols}}{\text{hr}} \times 122796 \frac{\text{Btu}}{\text{lb.mol}}$	= 139.96	
CO	$220.8 \frac{\text{lb mols}}{\text{hr}} \times 121659 \frac{\text{Btu}}{\text{lb.mol}}$	= 26.86	
CH_4	$13.5 \frac{\text{lb mols}}{\text{hr}} \times 383548 \frac{\text{Btu}}{\text{lb mol}}$	= 5.13	
		172.00	172.00
Sensible heat			
H_2	$1139.8 \frac{\text{lb mols}}{\text{hr}} \times 11272 \frac{\text{Btu}}{\text{lb mol}}$	= 12.85	
CO	$220.8 \frac{\text{lb. mols}}{\text{hr}} \times 11940 \frac{\text{Btu}}{\text{lb mol}}$	= 2.64	
CH_4	$13.5 \frac{\text{lb mols}}{\text{hr}} \times 22195 \frac{\text{Btu}}{\text{lb mol}}$	= 0.30	
CO_2	$103.2 \frac{\text{lb mols}}{\text{hr}} \times 18619 \frac{\text{Btu}}{\text{lb mol}}$	= 1.92	
H_2O	$700 \frac{\text{lb mols}}{\text{hr}} \times 14460 \frac{\text{Btu}}{\text{lb mol}}$	= 10.12	
		27.82	27.83
Latent heat in steam			
	$700 \frac{\text{lb mols}}{\text{hr.}} \times 10.016 \frac{\text{lb}}{\text{lbmol}} \times 1059.7 \frac{\text{Btu}}{\text{lb}}$ =	13.36	13.36
Total heat in Recycle Gas			213.19

Table B-2. REACTOR ENERGY BALANCE, Cont'd

Heat in Product Gas at 1100°F			MM Btu/hr	
Heat of combustion				
H_2	448.8 lb mols/hr x 122796 Btu/lb mol	=	55.11	
CO	87.5 lb mols/hr x 121659 Btu/lb mol	=	10.65	
CH_4	169.2 lb mols/hr x 383548 Btu/lb mol	=	64.90	
C_2H_6	64.0 lb mols/hr x 671588 Btu/lb mol	=	42.98	
C_2H_4	14.4 lb mols/hr x 607537 Btu/lb mol	=	8.75	
C_2H_2	4.2 lb mols/hr x 558267 Btu/lb mol	=	2.34	
			184.73	184.73
Sensible heat				
H_2	448.8 lb mols/hr x 7291	=	3.27	
CO	87.5 lb mols/hr x 7567	=	0.66	
CH_4	169.2 lb mols/hr x 12658	=	2.14	
C_2H_6	64.0 lb mols/hr x 21211	=	1.36	
C_2H_4	14.4 lb mols/hr x 16957	=	0.24	
C_2H_2	4.2 lb mols/hr x 13881	=	0.06	
CO_2	704.6 lb mols/hr x 11451	=	8.07	
H_2O	2081.0 lb mols/hr x 8998	=	18.72	
			34.52	34.52

Table B-2. REACTOR ENERGY BALANCE, Cont'd

			MM BTU/HR
Latent heat in steam			
2081.0 $\frac{\text{lbs mols}}{\text{hr}}$ x 18.016 $\frac{\text{lbs}}{\text{lbs mol}}$ x 1059.7 $\frac{\text{Btu}}{\text{lb}}$	=		39.73
Total heat in product gas			258.98
Heat in Propane and Butane @ 1100°F			
Heat of combustion			
Propane 2452 $\frac{\text{lbs}}{\text{hr}}$ x 21660 $\frac{\text{Btu}}{\text{lb}}$	=	53.11	
Butane 1732 $\frac{\text{lbs}}{\text{hr}}$ x 21310 $\frac{\text{Btu}}{\text{lb}}$	=	36.91	
		90.02	90.02
Sensible heat			
Propane 2452 x 0.3881 x (1100-60)	=	0.99	
Butane 1732 x 0.3867 x (1100-60)	=	0.70	
		1.69	1.69
Total heat in propane and butane			91.71
Heat in Oil Vapor at 1100°F			
Heat of combustion			
12778 $\frac{\text{lbs}}{\text{hr}}$ x 19958 $\frac{\text{Btu}}{\text{lb}}$	=		255.02
Sensible heat			
12778 x 0.4 x (1100-60)	=		5.32
Total heat in oil vapor			260.34
Heat in Char @ 1100°F			
Heat of combustion			
19389 $\frac{\text{lbs}}{\text{hr}}$ x 14239 $\frac{\text{Btu}}{\text{lb}}$	=		276.08
Sensible heat			
19389 x 0.3 x (1100-60)	=		6.05
Total heat in char			282.13

APPENDIX C

Fischer Assay Data A - Leucaena

APPENDIX C

Complete Fischer Assay Data for Leucaena (Kao Haole)

Includes:

1. Fischer Assay
2. Oil Phase Analysis
3. Char Analysis
4. Gas Analyses
5. Organic Components in Water by GLC
6. Analysis of Major Components in Oil by GLC
7. Total Organic Carbon in Water

INSTITUTE OF GAS TECHNOLOGY

ANALYTICAL REPORT - MODIFIED FISCHER ASSAY

CHEMICAL AND PHYSICAL TESTING LABORATORY

Project No. 6504S-00 Requested by DUNCAN Lab No. 44729

Sample GROUND & DRIED KOAHAOLE

Fischer Assay, Moisture-Free Basis

	#1	#2	AVG
Oil, wt%	6.3	6.1	6.2
Water, wt.%	41.2	40.5	40.8
Residue, wt.%	30.3	30.5	30.4
Gas + Loss, wt.%	22.2	22.9	22.6
Total	← 100.0 →		
Oil Yield, Gal/Ton	13.3	12.8	13.1
Water, Gal/Ton	98.7	97.1	97.9

Oil Phase

	#1	#2	AV
Sp. Gr. 60/60F	1.1329	1.1094	1.1[illegible]
Ultimate Analysis			
Carbon, wt.%	56.44	54.21	55.3
Hydrogen, wt.%	7.57	7.72	7.65
Sulfur, wt.%			
Nitrogen, wt.%			
Ash, wt.%	0	0	0
C/H weight ratio	7.46	7.02	7.23

Moisture, wt% (Air Dried Sample) 0.86

Raw Shale Analysis, Moisture-Free Basis

Carbon, (Organic) wt.%	
Hydrogen, wt.%	
Sulfur, wt.%	
Nitrogen, wt.%	
Ash, corrected, wt.%	
Carbon Dioxide, wt.%	

* **Assay Residue Analysis, Moisture-Free Bas**

	#1	#2	AVG
Carbon, (~~Organic~~ TOTAL) wt.%	84.55	85.54	85.0
Hydrogen, wt.%	2.81	2.97	2.8
Sulfur, wt.%			
Nitrogen, wt.%			
Ash, wt.%, UN corrected	5.40	4.36	4.88
Carbon Dioxide, wt.%			

Notes * UPDATED 2-12-81 TO INCLUDE RESIDUE ANALYSIS

Analyst Alan Jano

Date 12-11-80

AGS
Supervisor

INSTITUTE OF GAS TECHNOLOGY
MASS SPECTROMETER LABORATORY

PROJECT NO. 65045-00 — RUN NO. J136
REQUESTED BY JANOS — DATE OF RUN 12-10-80
SAMPLE DATE ON
DATE OFF 12- 9-80 — TIME OFF 0.00
LAB #647291 Retort # 1

KOAHAOLE

Abs Pressure = 318 mm Hg

	MOLE %		MOLE %
AIR (FREE)	9.0	ETHYLENE	0.27
HYDROGEN SULFIDE	0.0	PROPYLENE	0.36
NITROGEN	5.0	BUTENES	0.13
CARBON MONOXIDE	26.8	PENTENES	0.05
OXYGEN	0.0	HEXENES	0.04
CARBON DIOXIDE	47.0	HEPTENES	0.00
HYDROGEN	2.8	BUTADIENE	0.10
ARGON	1.2	PENTADIENE	0.02
HELIUM	0.00	CYCLOPENTADIENE	0.04
METHANE	18.6	ACETYLENE	0.12
ETHANE	1.4	M.ACET./PROPADIENE	0.00
PROPANE	0.38	BENZENE	0.01
N-BUTANE	0.01	TOLUENE	0.00
I-BUTANE	0.13	XYLENE	0.00
PENTANES	0.02	ETHYL BENZENE	0.00
HEXANES	0.04	STYRENE	0.00
HEPTANES	0.01	TOTAL	100.01

FURANS	0.58
ESTERS	0.47
KETONES	0.73
CHLOROMETHANE	1.2

INSTITUTE OF GAS TECHNOLOGY
MASS SPECTROMETER LABORATORY

PROJECT NO. 65045-00		RUN NO. J837	
REQUESTED BY JANOS		DATE OF RUN	12-10-80
SAMPLE DATE ON			
DATE OFF 12- 9-80		TIME OFF	0.00
LAB #447292	Retort # 2		

KoAHAOLE

Abs. Pressure ~ 373 mm Hg

	MOLE %		MOLE %
AIR (FREE)	9.2	ETHYLENE	0.30
HYDROGEN SULFIDE	0.0	PROPYLENE	0.37
NITROGEN	4.2	BUTENES	0.13
CARBON MONOXIDE	2[illegible].3	PENTENES	0.06
OXYGEN	0.0	HEXENES	0.04
CARBON DIOXIDE	4[illegible].[illegible]	HEPTENES	0.00
HYDROGEN	2.[illegible]	BUTADIENE	0.10
ARGON	1.[illegible]	PENTADIENE	0.02
HELIUM	0.00	CYCLOPENTADIENE	0.05
METHANE	13.[illegible]	ACETYLENE	0.11
ETHANE	1.[illegible]	M.ACET./PROPADIENE	0.00
PROPANE	0.33	BENZENE	0.01
N-BUTANE	0.02	TOLUENE	0.00
I-BUTANE	0.07	XYLENE	0.00
PENTANES	0.02	ETHYL BENZENE	0.00
HEXANES	0.04	STYRENE	0.00
HEPTANES	0.01	TOTAL	99.96
Furans	0.58		
Esters	0.71		
Ketones	0.99		
[illegible]	1.[illegible]		

IGT

ANALYTICAL REPORT

CHROMATOGRAPHY LABORATORY

Project No. 65045-00 Date 1/22/81 Requested by Duncan

Lab. No. 80-1327 (#44729-1)

Sample: Water from Fischer Assay on Koehoole

Remarks: Analysis for organics in Water.

Component	Wt. %	Component	Wt. %
Acetone	0.5	Phenol + o-cresol	0.3
Methanol	2.6	m+p-cresols + C_2-phenols	1.4
2-Butanone	0.1	Other organics	9.0
Methylene Chloride	0.2		
2-Pentanone	0.01	Total Organics	26 %
Toluene	0.08		
Methylfuran	0.1		
Acetic Acid	9.6		
2-Furaldehyde	0.3		
5-Methyl-2-furaldehyde	0.1		
Cyclohexanone	0.3		
2-Hydroxy-3-methyl-2-cyclopenten-1-one	0.6		
o-Methoxyphenol	0.8		
Dimethoxybenzene	0.5		

Analyst JK

Form AI-373-1976-KW

IGT

Chromatography Laboratory
Analytical Report

ct: 65045-00

Date: 1/29/81

: Oil from Fischer Assay on Eucalyptus and Koa haole wood

Lab No. 80-1310 (#44699-1) + 80-1326 (#44729-1)

Analysis for major components in the oil (weight %)

Component	Eucalyptus	Koa haole
Benzene	0.1	0.2
Toluene	0.03	0.1
C_2-Benzenes	0.03	0.1
C_3-Benzenes	0.1	0.2
Indan	—	0.02
Indene	—	0.02
Naphthalene	0.006	0.02
Methylnaphthalene	—	0.06
Benzofuran	0.05	0.06
Methylbenzofurans	0.02	0.1
C_2-Benzofurans	—	0.2
Methyldibenzofuran	0.03	—
2-Furaldehyde	0.7	0.3
Furfuryl Alcohol	0.05	0.2
Methylcyclopentenone (C_6H_8O)	0.05	0.08

INSTITUTE OF GAS TECHNOLOGY

IGT

Chromatography Laboratory
Analytical Report

Project: 65045-00

Date:

Type:

Lab No.

Page 2

Component	Eucalyptus	Koohoole
Phenol	0.1	0.2
Cresols	0.2	0.4
C_2-Phenols	0.1	0.3
C_3-Phenols	—	0.2
Catechol	0.1	0.1
Vanillin	—	0.04
Methoxyphenol ($C_7H_8O_2$)	0.3	0.8
Methylmethoxyphenols	0.06	0.2
Vinylmethoxyphenol ($C_9H_{10}O_2$)	0.05	0.3
Propenylmethoxyphenol	0.04	0.7
Dimethoxyphenol ($C_8H_{10}O_3$)	0.9	0.4
Methyldimethoxyphenols	0.9	0.4
C_2-Dimethoxyphenols	0.5	0.3
C_3-Dimethoxyphenols	0.2	0.1
C_4-Dimethoxyphenols	0.2	0.1
Propenyldimethoxyphenol	0.4	0.3
Dimethoxybenzene ($C_8H_{10}O_2$)	0.3	0.7
Methyldimethoxybenzenes	0.2	0.7
C_2-Dimethoxybenzenes	0.04	0.1
C_3-Dimethoxybenzenes	0.1	0.3
C_4-Dimethoxybenzenes	0.09	0.06

INSTITUTE OF GAS TECHNOLOGY

ANALYTICAL REPORT - MISCELLANEOUS

CHEMICAL AND PHYSICAL TESTING LABORATORY

Project No. 65045-00 Requested by D. Duncan Lab. No.

Sample 44729-1+2

LAB NO.	SAMPLE DESCRIPTION	2 C		
44729-1	Water From Fisher Assay on KOAHAOLE Trial #1	19.4 %		
44729-2	" Trial #2	19.6 %		

Analyst B. Baseley

Date 2-11-81

Supervisor

APPENDIX D

Complete Fischer Assay Data for Eucalyptus

Includes:

1. Fischer Assay
2. Oil Phase Analysis
3. Char Analysis
4. Gas Analyses
5. Organic Components in Water by GLC
6. Analysis of Major Components in Oil by GLC
7. Total Organic Carbon in Water

INSTITUTE OF GAS TECHNOLOGY

ANALYTICAL REPORT - MODIFIED FISCHER ASSAY

CHEMICAL AND PHYSICAL TESTING LABORATORY

Project No. 65045-00 Requested by DUNCAN Lab No. 44699

Sample GROUND EUCALYPTUS WOOD

Fischer Assay, Moisture-Free Basis

	#1	#2	AVG
Oil, wt%	10.9	13.5	12.2
Water, wt.%	36.4	31.7	34.0
Residue, wt.%	33.4	31.6	32.5
Gas + Loss, wt.%	19.3	23.2	21.3
Total	← 100.0 →		
Oil Yield, Gal/Ton	22.8	27.7	25.2
Water, Gal/Ton	87.2	76.0	81.6

Oil Phase

	#1	#2	AV
Sp. Gr. 60/60F	1.474	1.1663	1.1[illegible]
Ultimate Analysis			
Carbon, wt.%	51.26	47.55	49.
Hydrogen, wt.%	7.45	7.48	7.4[illegible]
Sulfur, wt.%			
Nitrogen, wt.%			
Ash, wt.%	0	0	0
C/H weight ratio	6.88	6.36	6.58

Moisture, wt% (Air Dried Sample) 1.95

Raw Shale Analysis, Moisture-Free Basis

Carbon, (Organic) wt.%	
Hydrogen, wt.%	
Sulfur, wt.%	
Nitrogen, wt.%	
Ash, corrected, wt.%	
Carbon Dioxide, wt.%	

***Assay Residue Analysis, Moisture-Free Bas**

	#1	#2	AVG.
Carbon, TOTAL ~~(Organic)~~ wt.%	76.24	75.85	76.0[illegible]
Hydrogen, wt.%	2.57	2.49	2.5
Sulfur, wt.%			
Nitrogen, wt.%			
Ash, wt.%, un corrected	13.54	14.64	14.09
Carbon Dioxide, wt.%			

Notes * UPDATED 2-12-81 TO INCLUDE RESIDUE ANALYSIS. [initials]

Analyst Alan Jones

Date 12-11-80

AGS
Supervisor

INSTITUTE OF GAS TECHNOLOGY
MASS SPECTROMETER LABORATORY

PROJECT NO. 66045-00 RUN NO. 345
REQUESTED BY JANOS DATE OF RUN 12- 2-80
SAMPLE DATE ON
DATE OFF 12- 1-80 TIME OFF 0.00
LAB #445991 REPORT #1

EUCALYPTUS

Abs Pressure = 130 mm Hg

	MOLE %		MOLE %
AIR (FREE)	11.3	ETHYLENE	0.63
HYDROGEN SULFIDE	0.0	PROPYLENE	0.14
NITROGEN	3.1	BUTENES	0.00
CARBON MONOXIDE	25.9	PENTENES	0.02
OXYGEN	0.0	HEXENES	0.04
CARBON DIOXIDE	51.4	HEPTENES	0.00
HYDROGEN	2.8	BUTADIENE	0.11
ARGON	1.1	PENTADIENE	0.01
HELIUM	0.00	CYCLOPENTADIENE	0.03
METHANE	11.2	ACETYLENE	0.00
ETHANE	1.2	M.ACET./PROPADIENE	0.00
PROPANE	0.13	BENZENE	0.01
N-BUTANE	0.00	TOLUENE	0.00
I-BUTANE	0.07	XYLENE	0.00
PENTANES	0.00	ETHYL BENZENE	0.00
HEXANES	0.22	STYRENE	0.00
HEPTANES	0.01	TOTAL	100.01
METHANOL	0.72		
CHLOROMETHANE	0.97		
ACETONE	0.81		
FURANS	0.56		

INSTITUTE OF GAS TECHNOLOGY
MASS SPECTROMETER LABORATORY

PROJECT NO. 65045-07 RUN NO. 455
REQUESTED BY JONES DATE OF RUN 12- 2-80
SAMPLE DATE ON
DATE OFF 12- 1-80 TIME OFF 0.00
LAB #445992 REPORT #2

EUCALYPTUS

Abs. Pressure = 133 mmHg

	MOLE %		MOLE %
AIR (FREE)	1.8	ETHYLENE	0.72
HYDROGEN SULFIDE	0.0	PROPYLENE	0.01
NITROGEN	7.4	BUTENES	0.00
CARBON MONOXIDE	26.6	PENTENES	0.01
OXYGEN	0.0	HEXENES	0.05
CARBON DIOXIDE	45.4	HEPTENES	0.00
HYDROGEN	2.8	BUTADIENE	0.12
ARGON	1.2	PENTADIENE	0.01
HELIUM	0.00	CYCLOPENTADIENE	0.03
METHANE	11.8	ACETYLENE	0.00
ETHANE	1.0	M.ACET./PROPADIENE	0.00
PROPANE	0.13	BENZENE	0.01
N-BUTANE	0.00	TOLUENE	0.00
I-BUTANE	0.05	XYLENE	0.00
PENTANES	0.00	ETHYL BENZENE	0.00
HEXANES	0.28	STYRENE	0.00
HEPTANES	0.01	TOTAL	100.0
METHANOL	0.91		
CHLOROMETHANE	0.88%		
ACETONE	0.35		
FURANS	0.29		

IGT

ANALYTICAL REPORT

CHROMATOGRAPHY LABORATORY

Project No. 65045-00 Date 1/22/81 Requested by Duncan

Lab No. 80-1311 (#44699-2)

Sample: Water from Fischer Assay on Eucalyptus Wood

Remarks: Analysis for organics in Water

Component	Wt. %	Component	Wt.
Acetone	0.9	Phenol + o-cresol	0.2
Methanol	3.6	m+p-Cresols + C_2-phenols	0.6
2-Butanone	0.1	Other organics	6.0
Methylene Chloride	0.3		
2-Pentanone	0.02	Total Organics	24
Toluene	0.03		
Methylfuran	0.3		
Acetic Acid	9.5		
2-Furaldehyde	1.2		
5-Methyl-2-furaldehyde	0.2		
Cyclohexanone	0.2		
2-Hydroxy-3-methyl-2-cyclopenten-1-one	0.5		
o-Methoxyphenol	0.5		
Dimethoxybenzene	0.3		

Analyst JK

Form AI-373-1978-KW

IGT
EDUCATION RESEARCH

Chromatography Laboratory
Analytical Report

:5045-00 — Date: 1/29/81

il from Fischer Assay on Eucalyptus and Koahaele Wood — Lab No. 80-1310 (#44699-1) + 80-1326 (#44729-1)

nalysis for major components in the oil (weight %)

Component	Eucalyptus	Koahaele
Benzene	0.1	0.2
Toluene	0.03	0.1
C_2-Benzenes	0.03	0.1
C_3-Benzenes	0.1	0.2
Indan	—	0.02
Indene	—	0.02
Naphthalene	0.006	0.02
Methylnaphthalene	—	0.06
Benzofuran	0.05	0.06
Methylbenzofurans	0.02	0.1
C_2 - Benzofurans	—	0.2
Methyldibenzofuran	0.03	—
2-Furaldehyde	0.7	0.3
Furfuryl Alcohol	0.05	0.2
Methylcyclopentenone (C_6H_8O)	0.05	0.08

IGT

Chromatography Laboratory
Analytical Report

ect: 65045-00

le

Date:

Lab No.

Page 2

Component	Eucalyptus	Koohoole
Phenol	0.1	0.2
Cresols	0.2	0.4
C_2-Phenols	0.1	0.3
C_3-Phenols	—	0.2
Catechol	0.1	0.1
Vanillin	—	0.04
Methoxyphenol ($C_7H_8O_2$)	0.3	0.8
Methylmethoxyphenols	0.06	0.2
Vinylmethoxyphenol ($C_9H_{10}O_2$)	0.05	0.3
Propenylmethoxyphenol	0.04	0.7
Dimethoxyphenol ($C_8H_{10}O_3$)	0.9	0.4
Methyldimethoxyphenols	0.9	0.4
C_2-Dimethoxyphenols	0.5	0.3
C_3-Dimethoxyphenols	0.2	0.1
C_4-Dimethoxyphenols	0.2	0.1
Propenyldimethoxyphenol	0.4	0.3
Dimethoxybenzene ($C_8H_{10}O_2$)	0.3	0.7
Methyldimethoxybenzenes	0.2	0.7
C_2-Dimethoxybenzenes	0.04	0.1
C_3-Dimethoxybenzenes	0.1	0.3
C_4-Dimethoxybenzenes	0.09	0.06

TECHNOLOGY

INSTITUTE OF GAS TECHNOLOGY

ANALYTICAL REPORT - MISCELLANEOUS

CHEMICAL AND PHYSICAL TESTING LABORATORY

Project No. 65045-00 Requested by D. Duncan Lab. No. 44699-1+2

Sample

LAB NO.	SAMPLE DESCRIPTION	2 C		
44699-1	Water from Fresher Assay on EUCALYPTUS Trial #1	21.22		
44699-2	" Trial #2	19.22		

Analyst B. Beasley

Date 2-11-81

Supervisor

APPENDIX E

The following raw data for Run WC-1 is included in this section.

- Gas Analyses
- Liquid Analyses
- Operating Conditions and Data Reduction

APPENDIX E, Continued

GAS ANALYSES - RUN WC-1

Notes

- Gas samples taken at intervals throughout the run.
- Carrier gas (hydrogen plus nitrogen) content in the gas is relatively high because of heavy dilution of leucaena feedstock by sand. Carrier gas to product gas ratio went up accordingly.

INSTITUTE OF GAS TECHNOLOGY
MASS SPECTROMETER LABORATORY

J. Paganessi

PROJECT NO. 65045-00 RUN NO. T909
REQUESTED BY PAGANESSI DATE OF RUN 11-6-80
SAMPLE DATE ON
DATE OFF 11-5-80 TIME OFF 0.00
RUN WC-1 PROD. 15 MIN

	MOLE %		MOLE %
AIR (FREE)	0.0	ETHYLENE	0.03
HYDROGEN SULFIDE	0.0	PROPYLENE	0.01
NITROGEN	60.3	BUTENES	0.00
CARBON MONOXIDE	0.5	PENTENES	0.00
OXYGEN	0.0	HEXENES	0.00
CARBON DIOXIDE	0.1	HEPTENES	0.00
HYDROGEN	38.6	BUTADIENE	0.00
ARGON	0.00	PENTADIENE	0.00
HELIUM	0.00	CYCLOPENTADIENE	0.00
METHANE	0.30	ACETYLENE	0.00
ETHANE	0.09	M.ACET./PROPADIENE	0.00
PROPANE	0.02	BENZENE	0.00
N-BUTANE	0.00	TOLUENE	0.00
I-BUTANE	0.00	XYLENE	0.00
PENTANES	0.00	ETHYL BENZENE	0.00
HEXANES	0.00	STYRENE	0.00
HEPTANES	0.00	TOTAL	99.95

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MASS SPECTROMETER LABORATORY

PROJECT NO. 65045-00 RUN NO. T910
REQUESTED BY PAGANESSI DATE OF RUN 11- 5-80
SAMPLE DATE ON
DATE OFF 11- 5-80 TIME OFF 0.00
RUN MC-1 PROD. 30 MIN

	MOLE %		MOLE %
AIR (FREE)	0.0	ETHYLENE	0.02
HYDROGEN SULFIDE	0.0	PROPYLENE	0.01
NITROGEN	59.4	BUTENES	0.00
CARBON MONOXIDE	0.6	PENTENES	0.00
OXYGEN	0.0	HEXENES	0.00
CARBON DIOXIDE	0.1	HEPTENES	0.00
HYDROGEN	39.5	BUTADIENE	0.00
ARGON	0.00	PENTADIENE	0.00
HELIUM	0.00	CYCLOPENTADIENE	0.00
METHANE	0.26	ACETYLENE	0.00
ETHANE	0.10	M.ACET./PROPADIENE	0.00
PROPANE	0.02	BENZENE	0.00
N-BUTANE	0.01	TOLUENE	0.00
I-BUTANE	0.00	XYLENE	0.00
PENTANES	0.00	ETHYL BENZENE	0.00
HEXANES	0.00	STYRENE	0.00
HEPTANES	0.00	TOTAL	100.02

INSTITUTE OF GAS TECHNOLOGY
MASS SPECTROMETER LABORATORY

PROJECT NO. 65045-00 RUN NO. T911
REQUESTED BY PAGANESSI DATE OF RUN 11-6-80
SAMPLE DATE ON
DATE OFF 11-5-80 TIME OFF 6.00
RUN WC-1 PROD. 60 MIN

	MOLE %		MOLE %
AIR (FREE)	0.0	ETHYLENE	0.01
HYDROGEN SULFIDE	0.0	PROPYLENE	0.01
NITROGEN	58.0	BUTENES	0.00
CARBON MONOXIDE	0.6	PENTENES	0.00
OXYGEN	0.0	HEXENES	0.00
CARBON DIOXIDE	0.1	HEPTENES	0.00
HYDROGEN	40.8	BUTADIENE	0.00
ARGON	0.00	PENTADIENE	0.00
HELIUM	0.00	CYCLOPENTADIENE	0.00
METHANE	0.28	ACETYLENE	0.00
ETHANE	0.10	M.ACET./PROPADIENE	0.00
PROPANE	0.03	BENZENE	0.00
N-BUTANE	0.01	TOLUENE	0.00
I-BUTANE	0.01	XYLENE	0.00
PENTANES	0.00	ETHYL BENZENE	0.00
HEXANES	0.00	STYRENE	0.00
HEPTANES	0.00	TOTAL	99.95

INSTITUTE OF GAS TECHNOLOGY
MASS SPECTROMETER LABORATORY

PROJECT NO. 65045-00 RUN NO. T912
REQUESTED BY PAGANESSI DATE OF RUN 11- 6-80
SAMPLE DATE ON
DATE OFF 11- 5-80 TIME OFF 0:00
RUN MC-1 PROD 90 MIN

	MOLE %		MOLE %
AIR (FREE)	0.0	ETHYLENE	0.02
HYDROGEN SULFIDE	0.0	PROPYLENE	0.01
NITROGEN	56.6	BUTENES	0.00
CARBON MONOXIDE	0.6	PENTENES	0.00
OXYGEN	0.0	HEXENES	0.00
CARBON DIOXIDE	0.1	HEPTENES	0.00
HYDROGEN	42.2	BUTADIENE	0.00
ARGON	0.00	PENTADIENE	0.00
HELIUM	0.00	CYCLOPENTADIENE	0.00
METHANE	0.27	ACETYLENE	0.00
ETHANE	0.10	M.ACET./PROPADIENE	0.00
PROPANE	0.03	BENZENE	0.01
N-BUTANE	0.01	TOLUENE	0.00
I-BUTANE	0.01	XYLENE	0.00
PENTANES	0.00	ETHYL BENZENE	0.00
HEXANES	0.00	STYRENE	0.00
HEPTANES	0.00	TOTAL	99.96

INSTITUTE OF GAS TECHNOLOGY
MASS SPECTROMETER LABORATORY

PROJECT NO. 65045-00 RUN NO. T913
REQUESTED BY PAGANESSI DATE OF RUN 11- 6-80
SAMPLE DATE ON
DATE OFF 11- 5-80 TIME OFF 0.00
RUN MC-1 PROD 120 MIN

	MOLE %		MOLE %
AIR (FREE)	0.0	ETHYLENE	0.02
HYDROGEN SULFIDE	0.0	PROPYLENE	0.01
NITROGEN	56.5	BUTENES	0.00
CARBON MONOXIDE	0.7	PENTENES	0.00
OXYGEN	0.0	HEXENES	0.00
CARBON DIOXIDE	0.1	HEPTENES	0.00
HYDROGEN	42.2	BUTADIENE	0.00
ARGON	0.00	PENTADIENE	0.00
HELIUM	0.00	CYCLOPENTADIENE	0.00
METHANE	0.34	ACETYLENE	0.00
ETHANE	0.11	M.ACET./PROPADIENE	0.00
PROPANE	0.03	BENZENE	0.01
N-BUTANE	0.01	TOLUENE	0.00
I-BUTANE	0.01	XYLENE	0.00
PENTANES	0.00	ETHYL BENZENE	0.00
HEXANES	0.00	STYRENE	0.00
HEPTANES	0.00	TOTAL	100.04

INSTITUTE OF GAS TECHNOLOGY
MASS SPECTROMETER LABORATORY

PROJECT NO. 65045-00 RUN NO. 7914
REQUESTED BY PAGANESSI DATE OF RUN 11- 6-80
SAMPLE DATE ON
DATE OFF 11- 5-80 TIME OFF 0.00
RUN HC-1 PROD 150 MIN

	MOLE %		MOLE %
AIR (FREE)	0.0	ETHYLENE	0.02
HYDROGEN SULFIDE	0.0	PROPYLENE	0.01
NITROGEN	58.6	BUTENES	0.00
CARBON MONOXIDE	0.7	PENTENES	0.00
OXYGEN	0.0	HEXENES	0.00
CARBON DIOXIDE	0.1	HEPTENES	0.00
HYDROGEN	40.0	BUTADIENE	0.00
ARGON	0.00	PENTADIENE	0.00
HELIUM	0.00	CYCLOPENTADIENE	0.00
METHANE	0.34	ACETYLENE	0.00
ETHANE	0.12	M.ACET.,PROPADIENE	0.00
PROPANE	0.04	BENZENE	0.01
N-BUTANE	0.02	TOLUENE	0.00
I-BUTANE	0.00	XYLENE	0.00
PENTANES	0.00	ETHYL BENZENE	0.00
HEXANES	0.00	STYRENE	0.00
HEPTANES	0.00	TOTAL	99.96

INSTITUTE OF GAS TECHNOLOGY
MASS SPECTROMETER LABORATORY

PROJECT NO. 65045-00 RUN NO. 7915
REQUESTED BY PAGANESSI DATE OF RUN 11-6-80
SAMPLE DATE ON
DATE OFF 11-5-80 TIME OFF 0.00
RUN WC-1 PROD 165 MIN

	MOLE %		MOLE %
AIR (FREE)	0.0	ETHYLENE	0.01
HYDROGEN SULFIDE	0.0	PROPYLENE	0.01
NITROGEN	54.6	BUTENES	0.00
CARBON MONOXIDE	0.7	PENTENES	0.00
OXYGEN	0.0	HEXENES	0.00
CARBON DIOXIDE	0.2	HEPTENES	0.00
HYDROGEN	44.0	BUTADIENE	0.00
ARGON	0.00	PENTADIENE	0.00
HELIUM	0.00	CYCLOPENTADIENE	0.00
METHANE	0.35	ACETYLENE	0.00
ETHANE	0.11	M.ACET./PROPADIENE	0.00
PROPANE	0.04	BENZENE	0.00
N-BUTANE	0.01	TOLUENE	0.00
I-BUTANE	0.00	XYLENE	0.00
PENTANES	0.00	ETHYL BENZENE	0.00
HEXANES	0.00	STYRENE	0.00
HEPTANES	0.00	TOTAL	100.04

APPENDIX E, Cont.

LIQUID ANALYSIS - RUN WC-1

The following analyses are included:

1. ASTM distillation of total oil simulated by chromatography.
2. Phase separation of liquid knockout, and distillation and ultimate analysis of oil phase.
3. Simulated ASTM distillation (by chromatography) of plus 306°F heavy oil.
4. Component analysis of minus 306°F light oil.
5. Major organic components of water phase.
6. Volatile organics extracted from char by methylene chloride.
7. Total dissolved solids (organics) in water phase.

44563

INSTITUTE OF GAS TECHNOLOGY
CHROMATOGRAPHY LABORATORY
SIMULATED DISTILLATION REPORT

PROJECT NO.: 65045 00 LAB. NO.: 81-1233
DATE: 2-2-81
SAMPLE: 65045 00 WC-1 STRAIGHT OIL
(TOTAL)

% RECOVERED	DEG F	DEG C
I.B.P.	255	123
5% (WT.%)	337	169
10%	370	187
15%	408	208
20%	435	223
30%	555	290
40%	688	364
50%	880	471

% RECOVERED BY 1018 F: 55
% UNRECOVERED: 45

ANALYST: EM

29 : 1 299 H 100

INSTITUTE OF GAS TECHNOLOGY PAGE 1
PETROLEUM - ANALYTICAL REPORT

PROJECT NO. 65045-00 LAB. NO. 44563
REQUESTED BY DUNCAN DATE RECEIVED 11- 7-80
SAMPLE: DATE ON
DATE OFF
WC-1 LIQUID KNOCKOUT, 11-6-80

PHASE SEPARATION

LIQUID PROCESSED	729 G	
OIL RECOVERED	19 G	~~2.6%~~
WATER BY DIFF.	708 G	97.2%
SOLIDS RECOVERED	2 G	0.2%

FRACTIONAL DISTILLATION--ASTM D285

VAPOR TRAP	0.6%
C5-306 F	31.9%
RESIDUE: + 306 F	63.3%
LOSS BY DIFF.	4.2%

PROJECT NO. 65045-00 LAB. NO. 44563
REQUESTED BY DUNCAN DATE RECEIVED 11- 7-80
SAMPLE: DATE ON
DATE OFF
WC-1 LIQUID KNOCKOUT, 11-6-80

PHASE SEPARATION

LIQUID PROCESSED	729 G	
OIL RECOVERED	19 G	2.6%
WATER BY DIFF.	708 G	97.2%
SOLIDS RECOVERED	2 G	0.2%

FRACTIONAL DISTILLATION--ASTM D285

VAPOR TRAP	0.6%
C5-306 F	31.9%
RESIDUE: + 306 F	63.3%
LOSS BY DIFF.	4.2%

ULTIMATE ANALYSIS DRY BASIS WT %

CARBON	~~80.47~~
HYDROGEN	~~6.59~~
SULFUR	
NITROGEN	
ASH	~~0.0~~
TOTAL	~~97.~~

FROM CARBON-HYDRO

C/H WEIGHT RATIO ~~11.69~~

3-5-81 AGS

INSTITUTE OF GAS TECHNOLOGY
CHROMATOGRAPHY LABORATORY
SIMULATED DISTILLATION REPORT

PROJECT NO.: 65045-00
DATE: 1-28-81
SAMPLE: PLUS 306 F

LAB. NO.: 80-1235

% RECOVERED	DEG F	DEG C
I.B.P.	390	198
5% (WT.%)	480	248
10%	537	280
15%	587	308
20%	630	332
30%	772	411

% RECOVERED BY 1018 F: 36
% UNRECOVERED: 64

ANALYST: EM

29 : 1
299 H 100

IGT
EDUCATION RESEARCH

ANALYTICAL REPORT

CHROMATOGRAPHY LABORATORY

Project No. 650Y5.00 Date 11-24-80 Requested by D DUNCAN
Lab. No. 80-1234 (VVSB) Sample OIL -306° F

COMPONENT ANALYSIS, weight per cent:

I. Aromatic Hydrocarbons	
BENZENE	0.44
Toluene	4.14
Ethylbenzene	2.95
M-, P-Xylenes	2.34
O-Xylene	1.49
C_3 Benzenes	4.15
C_4 Benzenes	0.44
C_5 Benzenes	0.12
STYRENE	-
Methyl Styrenes	-
C_2 Styrenes	-
INDAN	1.32
Methyl Indans	0.81
C_2 Indans	-
C_3 Indans	-
INDENE	2.49
Methyl Indenes	1.05
C_2 Indenes	0.25
NAPHTHALENE	17.9
Methyl Naphthalenes	1.08
C_2 Naphthalenes	0.04
BIPHENYL	0.03
Methyl Biphenyls	
ACENAPHTHENE	

II. N Containing Compounds	
PYRIDINE	
PYRROLE	
BENZONITRILE	
ACETONITRILE	

III. O-Containing Compounds	
PHENOL	13.7
O-Cresol	5.82
M-, P-Cresols	15.1
C_2 Phenols	15.4
C_3 Phenols	3.17
BENZOFURAN	0.79
Methyl Benzofurans	1.96
C_2 Benzofurans	0.48
ACETONE	-
Methyl Ethyl Ketone	-

IV. S-Containing Compounds	
H_2S	0.03
THIOPHENE	0.01
Methyl Thiophenes	0.03
C_2 Thiophenes	0.07
C_3 Thiophenes	0.03
C_4 Thiophenes	-
C_5 Thiophenes	-
BENZOTHIOPHENE	0.04
Methyl Benzothiophene	0.03
Other S-Cont. Cpds	0.03

V. Other

VI. Unidentified 1.57

41563-1

IGT

Chromatography Laboratory
Analytical Report

ject: 65045-00 Date: 11-14-80

le WC-1 Aqueous phase Lab No. 80-1221

Major volatile organic components:

	Component	Wt. %
I. Phenolics		
	Phenol	0.15
	Σ C_1-phenols	0.07
	Σ C_2-phenols	0.01
II. Acids		
	Acetic	0.12
	Propionic	0.04
	Σ C_4-acids	0.02
III. Others		
	Acetaldehyde	0.2
	$CH_3-CH=C(CH_3)-CHO$	0.02 (id. probable)
	Acetone	0.5
	Acetonitrile	0.01
	Acetamide	0.03
	Propionamide	0.005
	Indole	0.004
	Pyridine	0.006
	Naphthalene	0.001
IV. Unidentified		
	ca 20 cmpds	0.05

B.A.K.

44563

IGT
EDUCATION RESEARCH

Chromatography Laboratory
Analytical Report

ect: 65045-00 Date: 11-20-80

le: MeCl2 Extract of WC-1 Solids Lab No. 80-1222

Major identified volatile organics as wt.% of methylene chloride

Naphthalene	0.006%	Phenol	0.022%
Σ C1- "	0.002%	Σ C1- "	0.016%
Σ C2- "	0.0013%	Σ C2- "	0.007%
Indan	0.002%		
Indene	0.002%		
Benzofuran	0.0015%		
Acenaphthene	0.001%		
Dibenzofuran	0.001%		
Fluorene	0.0007%		
Phen./Anthracene	0.002%		

plus appx. 30 unid. cmpds above .0005% totalling 0.078%

B.W.

INSTITUTE OF GAS TECHNOLOGY

ANALYTICAL REPORT - MISCELLANEOUS

CHEMICAL AND PHYSICAL TESTING LABORATORY

...ject No. 65045-00 Requested by Paganessi Lab. No. 44563

...imple

LAB NO.	SAMPLE DESCRIPTION	Total* Dissolved Solids		
44563	WC-1 liquid receiver			
	Trial #1	12,000	ppm	
	Trial #2	12,400	ppm	
	* via ASTM			

...nalyst K. Peterson

...ate 11/14/80

Supervisor

APPENDIX E

OPERATING CONDITIONS AND DATA REDUCTION - RUN WC-1

Run Number	WC-1					
Run Duration, min	178					
Steady State, min	163					

Operating Conditions

Feed Gas, M%						
Hydrogen	41.66					
Nitrogen	58.34					
Steam	-					
Carbon Monoxide	-					
Carbon Dioxide	-					
Methane	-					
Pressure, psia	250					
Reactor Temp, °F						
Inlet, 0 ft	1129					
10½ ft						
21 ft	1161					
31½ ft	1153					
42 ft	1184					
49 ft	1204					
56 ft	1224					
63 ft	1234					
70 ft	1225					
Outlet, 77 ft	1175					
Average Reactor Temp	1181					
Feed Gas Rate, SCF/hr	1027					
Solids Feed Rate, lb/hr	11.306					

Operating Results

Product Gas Rate, SCF/hr	1040					
Gas Velocity, ft/sec	14.81					
Residence Time, sec	5.20					
LIQUID Product, lb/hr						
oil						
water						
total	0.542					
Char Residue lb/hr	8.912					

LIQUID	Oils lbs	Solids	Water	Total lbs
CARBON				
HYDROGEN				
OXYGEN				
NITROGEN				
SULFUR				
ASH				
TOTAL				

Product Yield, % C

Elemental Material Balance:

	Feed Mat'l lbs	Feed Gas	Total lbs	Total lbs	Product Gas, lbs	Residue lbs	Liquid lbs	% Recovery
CARBON	4.290		4.290		1.531	1.479		
HYDROGEN	0.459	6.761	7.220		6.955	0.045		
OXYGEN	6.213		6.213		1.104	2.119		
NITROGEN	0.029	131.560	131.890		131.920	—		
SULFUR	0.033		0.033		—	0.018		
ASH	22.515		22.515		—	22.014		
					—			
TOTAL	33.540	138.321	171.861	1.0 55	141.550	26.445	1.61	96.66

46.94 lb. Wood chips & Sand

11.80 lb woodchips 35.14 sand

35.17 12.12 wood

used

10.40 lb remaining.

3.37 lb wood chips 10.03

(3.78) (9.62)

8.42 lb wood + 25.12 sand = 3

(8.00 lb) 25.54

35.14

Sand

Feed Material: 11.80 lbs (wood chips)

Feed Gas: N_2 131.56 lbs; H_2 6.761 lbs

Run #	WC-1
Pressure :	250 psig
Max Temp :	1234°F
Residence time :	
Feed Gas :	
Hydrogen	41.2 M%
Nitrogen	58.7 M%
(171.81) 98.66	(169.55)

Products: 3025.55 SCF Product Gas; 26.34 lbs Char (0.10); 1.61 lbs Liquid

Elemental Conversions

	FEED MATERIAL wt %	FEED MATERIAL lbs	Residue wt %	Residue lbs	% Conversion	
CARBON	13.0	4.290	5.6	1.479	65.52	
HYDROGEN	1.21	0.399	0.16	0.042	89.47	
OXYGEN	17.38	5.736	10.93	2.861	50.12	
NITROGEN	0.09	0.030	—	—	100.00	
SULFUR	0.10	0.033	0.07	0.018	45.45	
ASH	68.22	22.516	83.34	22.018	2.23	97.77
SUBTOTAL	100.00	33.003	100.00	26.414	19.96	
MOISTURE	1.6	0.537	0.1	0.026	95.16	
TOTAL		33.540		26.440	21.17	

PRODUCT GAS (3.53 moles E 17.355 moles)	M %	Wt %	lbs	lbs C	lbs H	lbs O	% feed C
CARBON MONOXIDE	0.43	1.01	1.429	0.613		0.816	14.29
CARBON DIOXIDE	0.11	0.28	0.396	0.108		0.288	2.52
NITROGEN	57.76	93.23	131.920	-	-	-	
HYDROGEN	41.00	4.77	6.750	-	6.750	-	
METHANE	0.30	0.28	0.396	0.296	0.100	-	6.90
ETHANE	0.11	0.19	0.269	0.215	0.054	-	5.01
ETHYLENE	0.02	0.03	0.042	0.036	0.006	-	0.84
ACETYLENE	-	-	-	-	-	-	
PROPANE	0.03	0.07	0.099	0.081	0.018	-	1.89
PROPYLENE	0.01	0.02	0.028	0.024	0.004		0.56
BUTANE	0.02	0.07	0.099	0.082	0.017		1.91
BUTENE							
BUTADIENE							
PENTANE							
PENTENE							
PENTADIENE							
HEXENE							
BENZENE	0.01	0.05	0.072	0.066	0.006		1.54
TOLUENE							
TOTAL	100.00	100.02	141.50	1.521	6.955	1.104	35.46

	WC-1 Feed	WC-1 * Residue								
Proximate Analyses, wt%										
Moisture	1.6	0.1								
Volatile Matter	29.7	16.7								
Fixed Carbon	1.6	....								
Ash	67.1	83.2								
	100.0	100.0								
Ultimate Analyses, wt%										
Carbon	13.00	5.60								
Hydrogen	1.21	0.16								
Oxygen	17.38	10.83								
Nitrogen	0.09	0.00								
Sulfur	0.10	0.07								
Ash	68.22	83.34								
	100.00	100.00								
Screen Analyses, U.S.S., wt%										
-6+12										
-12+20										
-20+30										
-30+40										
-40+60										
-60+80										
-80+100										
-100+200										
-200+325										
-325										
TOTAL										
Bulk Density, lb/ft³										
Avg. Particle Size, in.										

* ANALYSIS INCLUDES SAND

Product Yields, % feed carbon

Run Number	WC-1				
Hydrocarbon Gases					
Methane	6.90				
Ethane	5.01				
Ethylene	0.94				
Acetylene	-				
Total	12.75				
Carbon Oxides					
Carbon Monoxide	14.29				
Carbon Dioxide	2.52				
Total	16.81				
Heavy Hydrocarbons					
C_3 (gas)	2.45 }				
C_4 (gas)	1.91 }	4.36			
C_5 (gas)	~				
C_6 (gas)	~				
Benzene (gas)	1.54				
Toluene (gas)	~				
Liquids					
C_5-400°F					
400-600°F					
600+					
water phase					
Total					

Product Gas Comp., Mol% (Dry)						
Carbon Monoxide	0.63					
Carbon Dioxide	0.11					
Nitrogen	57.76					
Hydrogen	41.00					
Methane	0.30					
Ethane	0.11					
Ethylene	0.02					
Propane	0.03					
Propylene	0.01					
Benzene	0.01					
Toluene						
Butane	0.02					
TOTAL	100.00					
Component Conversions,[4] % of feed (daf)						
Carbon	65.52					
Hydrogen	89.47					
Oxygen	50.12					
Nitrogen	100.00					
Sulfur	45.45					
Product Yields, % of feed carbon						
Hydrocarbon Gases						
Methane	6.90					
Ethane	5.01					
Ethylene	0.84					
Total						
Carbon Oxides	16.81					
Oils						
Benzene						
Others[8]						
Total						
Material Balance, %						
Carbon						
Hydrogen						
Oxygen						
Nitrogen						
Sulfur						
Ash						

APPENDIX F.

Summary Material Balance Tables for
Eucalyptus Runs E-1 Through E-7 and
Leucaena Run WC-1

COMPONENT QUANTITIES FOR RUN WC-1
(Measured Quantities in Pounds)

INPUT	C	H	O	N	S	Ash	Total
Wood (dry)	3.099	0.399	2.673	0.030	0.033	26.769	33.003
Moisture in Wood		0.060	0.477				0.537
H_2 Added							
Total Input	3.099	0.459	3.150	0.030	0.033	26.769	33.540
OUTPUT							
Gas							
CO	0.613		0.816				1.429
CO_2	0.108		0.288				0.396
CH_4	0.296	0.100					0.396
C_2H_6	0.215	0.054					0.269
C_2H_4	0.036	0.006					0.042
Others	0.066	0.006					0.072
	1.334	0.166	1.104				2.604
LPG	0.187	0.039					0.226
Water		0.172	1.364				1.536
Oil	0.053	0.004	0.008				0.065
Char	0.322	0.042	--	--	0.018	26.036	26.418
Moisture in Char		0.003	0.023				0.026
Total Output	1.896	0.426	2.499	0.000	0.018	26.036	30.875
% Balance (Output/Input)	61.2	92.8	79.3	0.0	54.5	97.3	92.1

COMPONENT QUANTITIES FOR RUN E-1 (grams)
(Measured Quantities)

INPUT	C	H	O	N	S	Ash	Total
Wood (dry)	82.0	9.8	70.5	0.2	0.1	4.7	167.3
Moisture in Wood		0.6	4.9				5.5
H_2 Added							
Total Input	82.0	10.4	75.4	0.2	0.1	4.7	172.8
OUTPUT							
Gas							
CO	9.1		12.2				21.3
CO_2	5.1		13.6				18.7
CH_4	5.1	1.7					6.8
C_2H_6	2.1	0.5					2.6
C_2H_4	0.3	--					0.3
Others							
	21.7	2.2	25.8				49.7
LPG	5.6	0.9					6.5
Water		2.1	16.5				18.6
Oil	7.4	1.0	3.7			0.3	12.4
Char	20.3	1.4	8.5			5.3	35.5
Moisture in Char		0.2	2.0				2.2
Total Output	55.0	7.8	56.5	0.0	0.0	5.6	124.9
% Balance (Output/Input)	67.1	75.0	74.9	0.0	0.0	119.1	72.3

65045

COMPONENT QUANTITIES FOR RUN E-2 (grams)
(Measured Quantities)

INPUT	C	H	O	N	S	Ash	Total
Wood (dry)	136.7	16.4	117.5	0.4	0.2	7.8	279.0
Moisture in Wood		1.1	8.2				9.3
H_2 Added							
Total Input	136.7	17.5	125.7	0.4	0.2	7.8	288.3
OUTPUT							
Gas							
CO	20.2		26.8				47.0
CO_2	7.1		18.8				25.9
CH_4	10.6	3.6					14.2
C_2H_6	3.7	1.0					4.7
C_2H_4	1.1	0.2					1.3
Others	1.7	0.3	0.7				2.7
	44.4	5.1	46.3	—	—	—	95.8
LPG	11.7	1.5					13.2
Water		3.7	29.1				32.8
Oil	13.4	1.6	7.5			0.8	23.3
Char	35.2	2.3	14.5	0.1	0.1	12.3	64.5
Moisture in Char		0.2	1.3				1.5
Total Output	104.7	14.4	98.7	0.1	0.1	13.1	231.1
% Balance (Output/Input)	76.6	82.3	78.5	25.0	50.0	167.9	80.2

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65045

COMPONENT QUANTITIES FOR RUN E-3 (grams)
(Measured Quantities)

INPUT	C	H	O	N	S	Ash	Total
Wood (dry)	136.5	16.4	117.3	0.4	0.2	7.8	278.6
Moisture in Wood		1.0	8.2				9.2
H_2 Added							
Total Input	136.5	17.4	125.5	0.4	0.2	7.8	287.8
OUTPUT							
Gas							
CO	26.4		35.1				61.5
CO_2	6.3		16.7				23.0
CH_4	17.2	5.8					23.0
C_2H_6	12.9	3.3					16.2
C_2H_4	0.9	0.1					1.0
Others	2.3	0.5	2.0				4.8
	66.0	9.7	53.8				129.5
LPG	10.2	1.3					11.5
Water		4.1	32.5				36.6
Oil	7.0	0.9	1.4			1.0	10.3
Char	39.3	1.9	10.2	0.1	0.1	10.6	62.2
Moisture in Char		0.2	1.9				2.1
Total Output	122.5	18.1	99.8	0.1	0.1	11.6	252.2
% Balance (Output/Input)	89.7	104.0	79.5	25.0	50.0	149.0	87.6

6/82

COMPONENT QUANTITIES FOR RUN E-4 (grams)
(Measured Quantities)

INPUT	C	H	O	N	S	Ash	Total
Wood (dry)	106.9	12.8	91.9	0.3	0.2	6.1	218.2
Moisture in Wood		0.8	6.4				7.2
H_2 Added							
Total Input	106.9	13.6	98.3	0.3	0.2	6.1	225.4
OUTPUT							
Gas							
CO	4.3		5.7				10.0
CO_2	2.8		7.5				10.3
CH_4	1.2	0.4					1.6
C_2H_6	0.6	0.1					0.7
C_2H_4	0.3						0.3
Others							
	9.2	0.5	13.2				22.9
LPG	0.8	0.2					1.0
Water		1.8	14.0				15.8
Oil	8.3	1.0	6.5			0.5	16.3
Char	57.1	5.7	38.4	0.2	0.1	8.4	109.9
Moisture in Char		0.2	1.4				1.6
Total Output	75.4	9.4	73.5	0.2	0.1	8.9	167.5
% Balance (Output/Input)	70.5	69.1	74.8	66.7	50.0	145.9	74.3

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COMPONENT QUANTITIES FOR RUN E-5 (grams)
(Measured Quantities)

INPUT	C	H	O	N	S	Ash	Total
Wood (dry)	63.1	7.6	54.2	0.2	0.1	3.6	128.8
Moisture in Wood		0.4	3.8				4.2
H_2 Added							
Total Input	63.1	8.0	58.0	0.2	0.1	3.6	133.0
OUTPUT							
Gas							
CO	8.8		11.7				20.5
CO_2	3.5		9.2				12.7
CH_4	2.7	0.9					3.6
C_2H_6	0.5	0.1					0.6
C_2H_4	1.6	0.3					1.9
Others							
	17.1	1.3	20.9				39.3
LPG	1.7	0.2					1.9
Water		0.4	3.4				3.8
Oil	3.9	0.5	2.2			0.1	6.7
Char	16.4	1.1	6.5	0.1		3.8	27.9
Moisture in Char		0.1	0.6				0.7
Total Output	39.1	3.6	33.6	0.1	0.0	3.9	80.3
% Balance (Output/Input)	62.0	45.0	57.9	50.0	0.0	108.3	60.4

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COMPONENT QUANTITIES FOR RUN E-6 (grams)
(Measured Quantities)

INPUT	C	H	O	N	S	Ash	Total
Wood (dry)	91.2	10.9	78.3	0.2	0.1	5.2	185.9
Moisture in Wood		0.7	5.4				6.1
H_2 Added							
Total Input	91.2	11.6	83.7	0.2	0.1	5.2	192.0
OUTPUT							
Gas							
CO	8.9		11.8				20.7
CO_2	3.1		8.2				11.3
CH_4	4.9	1.6					6.5
C_2H_6	1.4	0.3					1.7
C_2H_4	1.4	0.2					1.6
Others	1.3	0.2	0.6				2.1
	21.0	2.3	20.6	—	—	—	43.9
LPG	2.9	0.4					3.3
Water		1.2	9.5				10.7
Oil	20.1	2.0	10.7				32.8
Char	29.6	2.2	13.0	0.1	0.1	9.9	54.9
Moisture in Char		0.1	1.5				1.6
Total Output	73.6	8.2	55.3	0.1	0.1	9.9	147.2
% Balance (Output/Input)	80.7	70.7	66.1	50.0	100.0	190.4	76.7

6/82

COMPONENT QUANTITIES FOR RUN E-7 (grams)
(Measured Quantities)

INPUT	C	H	O	N	S	Ash	Total
Wood (dry)	368.79	43.94	312.31	1.35	0.38	24.34	751.11
Moisture in Wood		2.87	22.76				25.63
H_2 Added							
Total Input	368.79	46.81	335.07	1.35	0.38	24.34	776.74
OUTPUT							
Gas							
CO	21.20		28.24				49.44
CO_2	14.96		39.87				54.83
CH_4	7.48	2.51					9.99
C_2H_6	2.49	0.63					3.12
C_2H_4	2.49	0.42					2.91
Others	5.61	0.94	2.50				9.05
	54.23	4.50	70.61				129.34
LPG	6.23	1.05					7.28
Water		3.71	29.48				33.19
Oil	110.91	12.26	68.99			0.26	192.42
Char	175.22	13.27	76.61	0.71	0.30	26.27	292.38
Moisture in Char		0.60	4.81				5.41
Total Output	346.59	35.39	250.50	0.71	0.30	26.53	660.02
% Balance (Output/Input)	93.98	75.60	74.65	52.59	78.95	109.00	84.97

E-9

65-45

COMPONENT QUANTITIES FOR RUN E-1 (grams)
(Adjusted Quantities to Balance)

INPUT	C	H	O	N	S	Ash	Total
Wood (dry)	82.0	9.8	70.5	0.2	0.1	4.7	167.3
Moisture in Wood		0.6	4.9				5.5
H_2 Added		1.5					1.5
Total Input	82.0	11.9	75.4	0.2	0.1	4.7	174.3
OUTPUT							
Gas							
CO	9.1		12.2				21.3
CO_2	5.1		13.6				18.7
CH_4	5.1	1.7					6.8
C_2H_6	2.1	0.5					2.6
C_2H_4	0.3						0.3
Others							
	21.7	2.2	25.8				49.7
LPG	5.6	0.9					6.5
Water		2.8	21.9				24.7
Oil	34.4	4.4	17.2			0.3	56.3
Char	20.3	1.4	8.5			5.3	35.5
Moisture in Char		0.2	2.0				2.2
Total Output	82.0	11.9	75.4	0.0	0.0	5.6	174.9
% Balance (Output/Input)	100.0	100.0	100.0	0.0	0.0	119.1	100.3

COMPONENT QUANTITIES FOR RUN E-2 (grams)
(Adjusted Quantities to Balance)

INPUT	C	H	O	N	S	Ash	Total
Wood (dry)	136.7	16.4	117.5	0.4	0.2	7.8	279.0
Moisture in Wood		1.1	8.2				9.3
H_2 Added		1.8					1.8
Total Input	136.7	19.3	125.7	0.4	0.2	7.8	290.1
OUTPUT							
Gas							
CO	20.2		26.8				47.0
CO_2	7.1		18.8				25.9
CH_4	10.6	3.6					14.2
C_2H_6	3.7	1.0					4.7
C_2H_4	1.1	0.2					1.3
Others	1.7	0.3	0.7				2.7
	44.4	5.1	46.3	—	—	—	95.8
LPG	11.7	1.5					13.2
Water		4.8	38.2				43.0
Oil	45.4	5.4	25.4			0.8	77.0
Char	35.2	2.3	14.5	0.1	0.1	12.3	64.5
Moisture in Char		0.2	1.3				1.5
Total Output	136.7	19.3	125.7	0.1	0.1	13.1	295.0
% Balance (Output/Input)	100.0	100.0	100.0	25.0	50.0	167.9	101.7

COMPONENT QUANTITIES FOR RUN E-3 (grams)
(Adjusted Quantities to Balance)

INPUT	C	H	O	N	S	Ash	Total
Wood (dry)	136.5	16.4	117.3	0.4	0.2	7.8	278.6
Moisture in Wood		1.0	8.2				9.2
H_2 Added		5.4					5.4
Total Input	136.5	22.8	125.5	0.4	0.2	7.8	293.2
OUTPUT							
Gas							
CO	26.4		35.1				61.5
CO_2	6.3		16.7				23.0
CH_4	17.2	5.8					23.0
C_2H_6	12.9	3.3					16.2
C_2H_4	0.9	0.1					1.0
Others	2.3	0.5	2.0				4.8
	66.0	9.7	53.8				129.5
LPG	10.2	1.3					11.5
Water		7.0	55.4				62.4
Oil	21.0	2.7	4.2			1.0	28.9
Char	39.3	1.9	10.2	0.1	0.1	10.6	62.2
Moisture in Char		0.2	1.9				2.1
Total Output	136.5	22.8	125.5	0.1	0.1	11.6	296.6
% Balance (Output/Input)	100.0	100.0	100.0	25.0	50.0	149.0	101.2

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COMPONENT QUANTITIES FOR RUN E-4 (grams)
(Adjusted Quantities to Balance)

INPUT	C	H	O	N	S	Ash	Total
Wood (dry)	106.9	12.8	91.9	0.3	0.2	6.1	218.2
Moisture in Wood		0.8	6.4				7.2
H_2 Added							
Total Input	106.9	13.6	98.3	0.3	0.2	6.1	225.4
OUTPUT							
Gas							
CO	4.3		5.7				10.0
CO_2	2.8		7.5				10.3
CH_4	1.2	0.4					1.6
C_2H_6	0.6	0.1					0.7
C_2H_4	0.3						0.3
Others							
	9.2	0.5	13.2				22.9
LPG	0.8	0.2					1.0
Water		1.8	14.1				15.9
Oil	39.8	4.8	31.2			0.5	76.3
Char	57.1	5.7	38.4	0.2	0.1	8.4	109.9
Moisture in Char		0.2	1.4				1.6
Total Output	106.9	13.2	98.3	0.2	0.1	8.9	227.6
% Balance (Output/Input)	100.0	97.1	100.0	66.7	50.0	145.9	101.0

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COMPONENT QUANTITIES FOR RUN [illegible] (grams)
(Adjusted Quantities to Balance)

INPUT	C	H	O	N	S	Ash	Total
Wood (dry)	63.1	7.6	54.2	0.2	0.1	3.6	128.8
Moisture in Wood		0.4	3.8				4.2
H_2 Added							
Total Input	63.1	8.0	58.0	0.2	0.1	3.6	133.0
OUTPUT							
Gas							
CO	8.8		11.7				20.5
CO_2	3.5		9.2				12.7
CH_4	2.7	0.9					3.6
C_2H_6	0.5	0.1					0.6
C_2H_4	1.6	0.3					1.9
Others							
	17.1	1.3	20.9				39.3
LPG	1.7	0.2					1.9
Water		1.7	14.3				16.0
Oil	27.9	3.6	15.7			0.1	47.3
Char	16.4	1.1	6.5	0.1		3.8	27.9
Moisture in Char		0.1	0.6				0.7
Total Output	63.1	8.0	58.0	0.1	0.0	3.9	133.1
% Balance (Output/Input)	100.0	100.0	100.0	50.0	0.0	108.3	100.0

COMPONENT QUANTITIES FOR RUN E-6 (grams)
(Adjusted Quantities to Balance)

INPUT	C	H	O	N	S	Ash	Total
Wood (dry)	91.2	10.9	78.3	0.2	0.1	5.2	185.9
Moisture in Wood		0.7	5.4				6.1
H_2 Added		0.8					0.8
Total Input	91.2	12.4	83.7	0.2	0.1	5.2	192.8
OUTPUT							
Gas							
CO	8.9		11.8				20.7
CO_2	3.1		8.2				11.3
CH_4	4.9	1.6					6.5
C_2H_6	1.4	0.3					1.7
C_2H_4	1.4	0.2					1.6
Others	1.3	0.2	0.6				2.1
	21.0	2.3	20.6				43.9
LPG	2.9	0.4					3.3
Water		3.6	28.5				32.1
Oil	37.7	3.8	20.1				61.6
Char	29.6	2.2	13.0	0.1	0.1	9.9	54.9
Moisture in Char		0.1	1.5				1.6
Total Output	91.2	12.4	83.7	0.1	0.1	9.9	197.4
% Balance (Output/Input)	100.0	100.0	100.0	50.0	100.0	190.4	102.3

(Adjusted Quantities to Balance)

INPUT	C	H	O	N	S	Ash	Total
Wood (dry)	368.79	43.94	312.31	1.35	0.38	24.34	751.11
Moisture in Wood		2.87	22.76				25.63
H_2 Added		−0.05					−0.05
Total Input	368.79	46.76	335.07	1.35	0.38	24.34	776.69
OUTPUT							
Gas							
CO	21.20		28.24				49.44
CO_2	14.96		39.87				54.83
CH_4	7.48	2.51					9.99
C_2H_6	2.49	0.63					3.12
C_2H_4	2.49	0.42					2.91
Others	5.61	0.94	2.50				9.05
	54.23	4.50	70.61				129.34
LPG	6.23	1.05					7.28
Water		12.63	100.24				112.87
Oil	133.11	14.71	82.80			0.26	230.88
Char	175.22	13.27	76.61	0.71	0.30	26.27	292.38
Moisture in Char		0.60	4.81				5.41
Total Output	368.79	46.76	335.07	0.71	0.30	26.53	778.16
% Balance (Output/Input)	100.00	100.00	100.00	52.59	78.95	109.00	100.19

COMPONENT QUANTITIES FOR RUN WC-1
(Adjusted Quantities to Balance in Pounds)

INPUT	C	H	O	N	S	Ash	Total
Wood (dry)	3.099	0.399	2.673	0.030	0.033	26.769	33.003
Moisture in Wood		0.060	0.477				0.537
H_2 Added		0.117					0.117
Total Input	3.099	0.576	3.150	0.030	0.033	26.769	33.657
OUTPUT							
Gas							
CO	0.613		0.816				1.429
CO_2	0.108		0.288				0.396
CH_4	0.296	0.100					0.396
C_2H_6	0.215	0.054					0.269
C_2H_4	0.036	0.006					0.042
Others	0.066	0.006					0.072
	1.334	0.166	1.104				2.604
LPG	0.187	0.039					0.226
Water		0.231	1.833				2.064
Oil	1.256	0.095	0.190				1.541
Char	0.322	0.042	--	--	0.018	26.036	26.418
Moisture in Char		0.003	0.023				0.026
Total Output	3.099	0.576	3.150	0.000	0.018	26.036	32.879
% Balance (Output/Input)	100.0	100.0	100.0	0.0	54.5	97.3	97.7

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APPENDIX G

Correlation of Test Data

INSTITUTE OF GAS TECHNOLOGY

HYDROPYROLYSIS OF BIOMASS AND RELATED MATERIALS
FOR THE PRODUCTION OF LIQUIDS

by

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Paper Presented at

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HYDROPYROLYSIS OF BIOMASS AND RELATED MATERIALS FOR THE PRODUCTION OF LIQUIDS

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ABSTRACT

Test data for the pyrolytic conversion of eucalyptus wood, leucaena wood, and peat to liquid fuel have been analyzed. Charts have been developed to facilitate prediction of the quantity and composition of the various end products as a function of operating conditions such as temperature, pressure, and carrier gas composition.

HYDROPYROLYSIS OF BIOMASS AND RELATED MATERIALS FOR THE PRODUCTION OF LIQUIDS

INTRODUCTION

Pyrolysis is a technically viable option for conversion of biomass to superior liquid, gaseous, and solid fuels. Tests on lignite and peat have shown that the conversion temperature and the partial pressure of hydrogen in the pyrolysis atmosphere are important factors in both the distribution and composition of products.

A process design to produce principally liquid fuel from Hawaiian biomass has been completed recently. This system (shown in Figure 1) has been previously described(1). Basically, it consists of short residence time pyrolysis of solids, entrained in a hydrogen atmosphere. This technique, which has been extensively developed at IGT for conversion of lignite, is termed HYFLEX®. Following reaction at about 1100°F and 200 psig, char and liquids are separated from the reactor outlet gas. CO_2 and LPG are removed and, since fuel gas is not a desirable product at the location contemplated, the remaining gas is reformed with steam for production of a high hydrogen content gas which is recycled to the HYFLEX reactor.

For processing eucalyptus wood, the distribution and compositions of products from the HYFLEX reactor were initially estimated by extrapolation of data previously obtained with lignite and peat feeds. Work with peat(2) has shown that at a reaction temperature of 1450° to 1500°F oil production increases from 15% to 20% as hydrogen partial pressure is increased from zero to 200 psi. A further increase in hydrogen pressure decreases oil yield because of increased production of hydrocarbon gas. Therefore, process conditions for maximizing oil yield were established to give 100 psi hydrogen partial pressure in the reactor (200 psi with 50 mol % hydrogen). Later, bench-scale experiments were conducted with eucalyptus wood and leucaena wood feeds to confirm the original assumption. This paper describes the results of the wood tests and their comparison with similar data on peat. Analyses of the wood and peat, which were tested, are shown in Table 1.

TEST EQUIPMENT AND PROCEDURES

Entrained flow pyrolysis of eucalyptus wood has been carried out in a 4-foot long, 1.9-inch ID vertical tube. Reactants are heated and maintained at reaction temperature by electric heaters surrounding the tube. Auxiliary equipment consists of a feed hopper, screw feeder, char removal screw, effluent cooler, char and liquids collection vessels, and gas-sampling and metering facilities. Figure 2 is a sketch of the equipment arrangement and Figure 3 is a photograph of the installation. A detailed description of the equipment and operation techniques has been provided elsewhere(3).

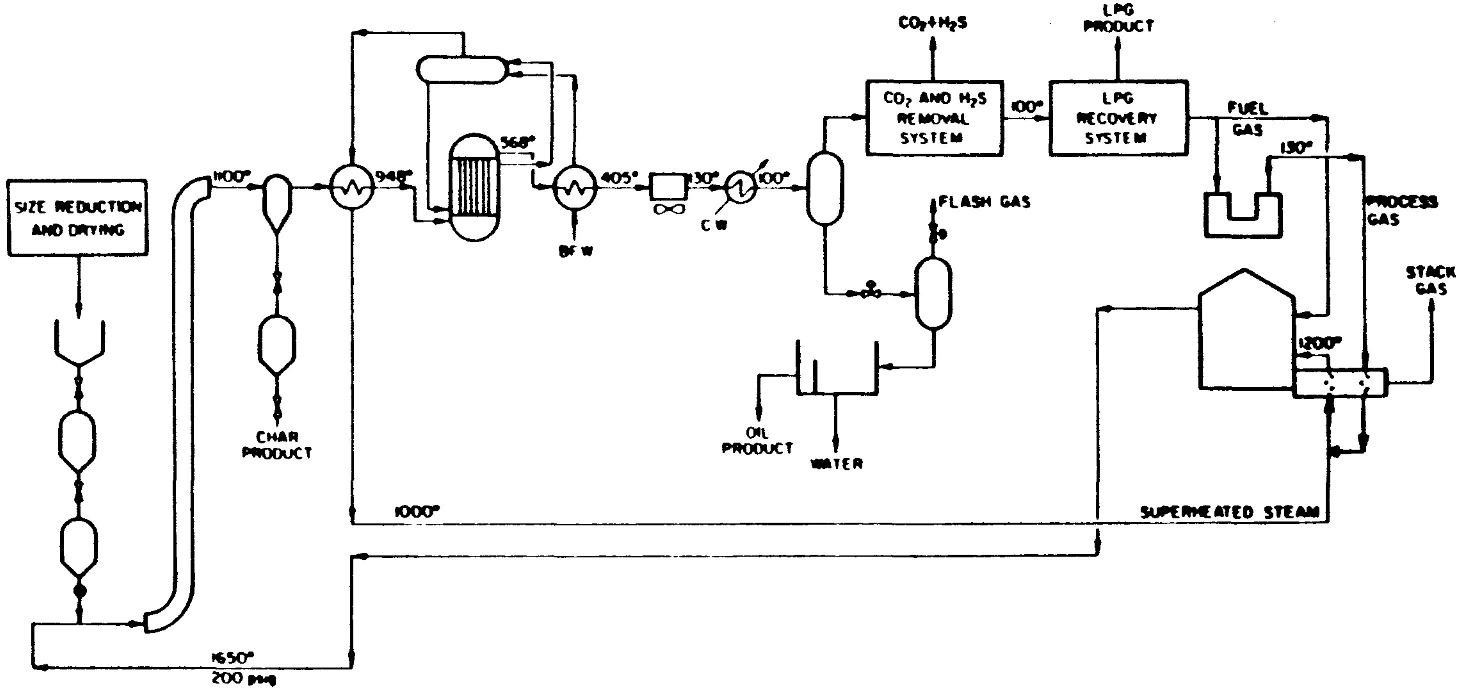

Figure 1. FLOWSHEET FOR BIOMASS TO OIL BY HYFLEX®

Table 1. PROXIMATE AND ULTIMATE ANALYSES OF FEED MATERIALS

	Eucalyptus		Leucaena		Peat*	
	wt %					
Moisture	10.9		8.2		5.2	
Volatile	73.3		74.3		56.3	
Fixed C	14.6		16.1		20.4	
		Ash-free		Ash-free		Ash-free
C	49.0	50.4	49.2	49.9	46.8	57.9
H	5.9	6.1	6.1	6.2	4.8	5.9
O	42.1	43.3	42.7	43.4	26.9	33.3
N	0.1	0.1	0.5	0.5	2.2	2.7
S	0.1	0.1	--	--	0.2	0.2
Ash	2.8	--	1.5	--	19.1	--
	100.0	100.0	100.0	100.0	100.0	100.0
	Screen Analysis, U.S.S. wt %					
-6 + 20					26.6	
-20 + 60					59.9	
-16 + 60	100.0				--	
-60 + 100					11.3	
					2.2	
	100.0				100.0	

* Representative sample.

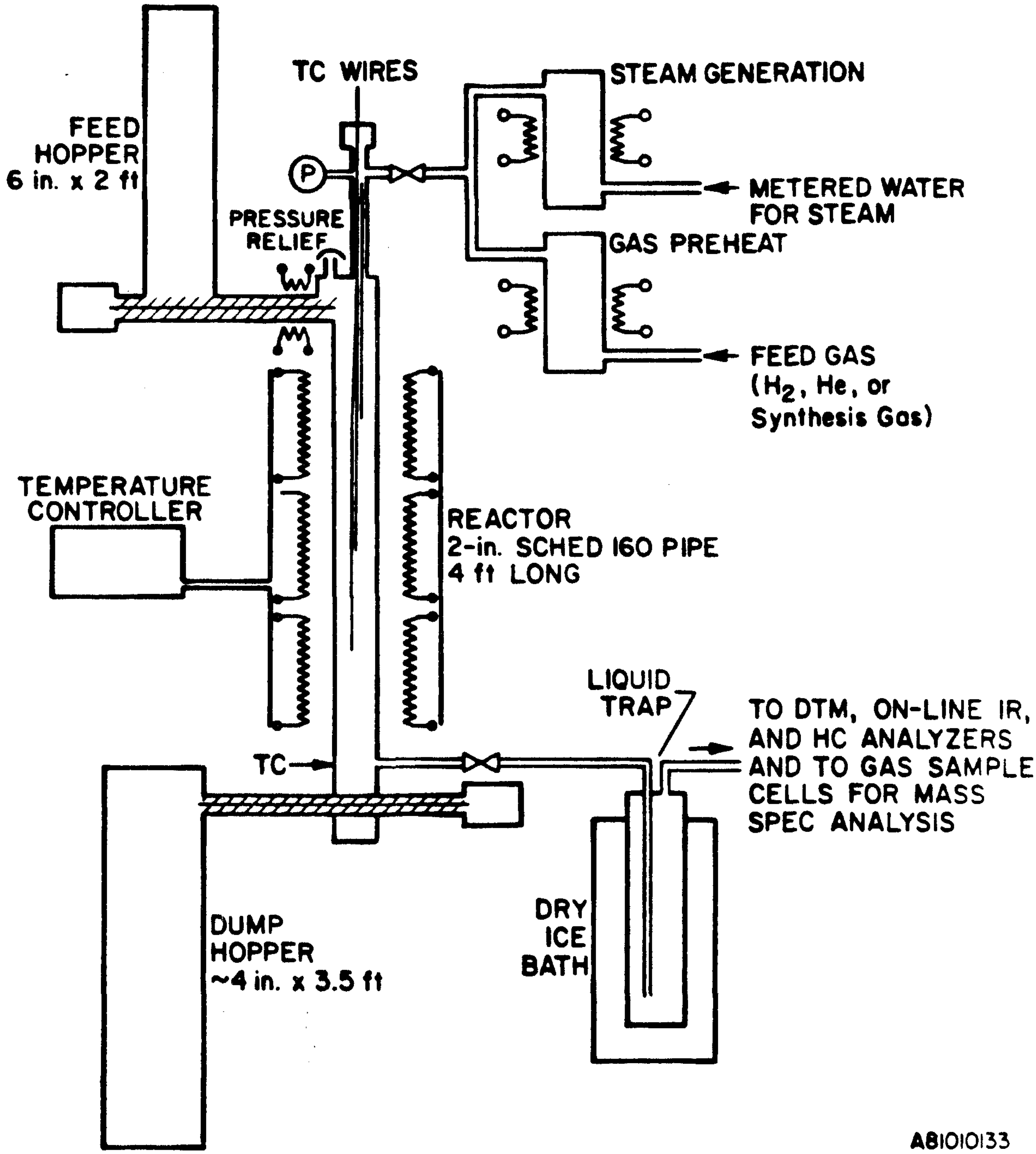

Figure 2. SCHEMATIC OF FREE-FALL DEVOLATILIZATION APPARATUS

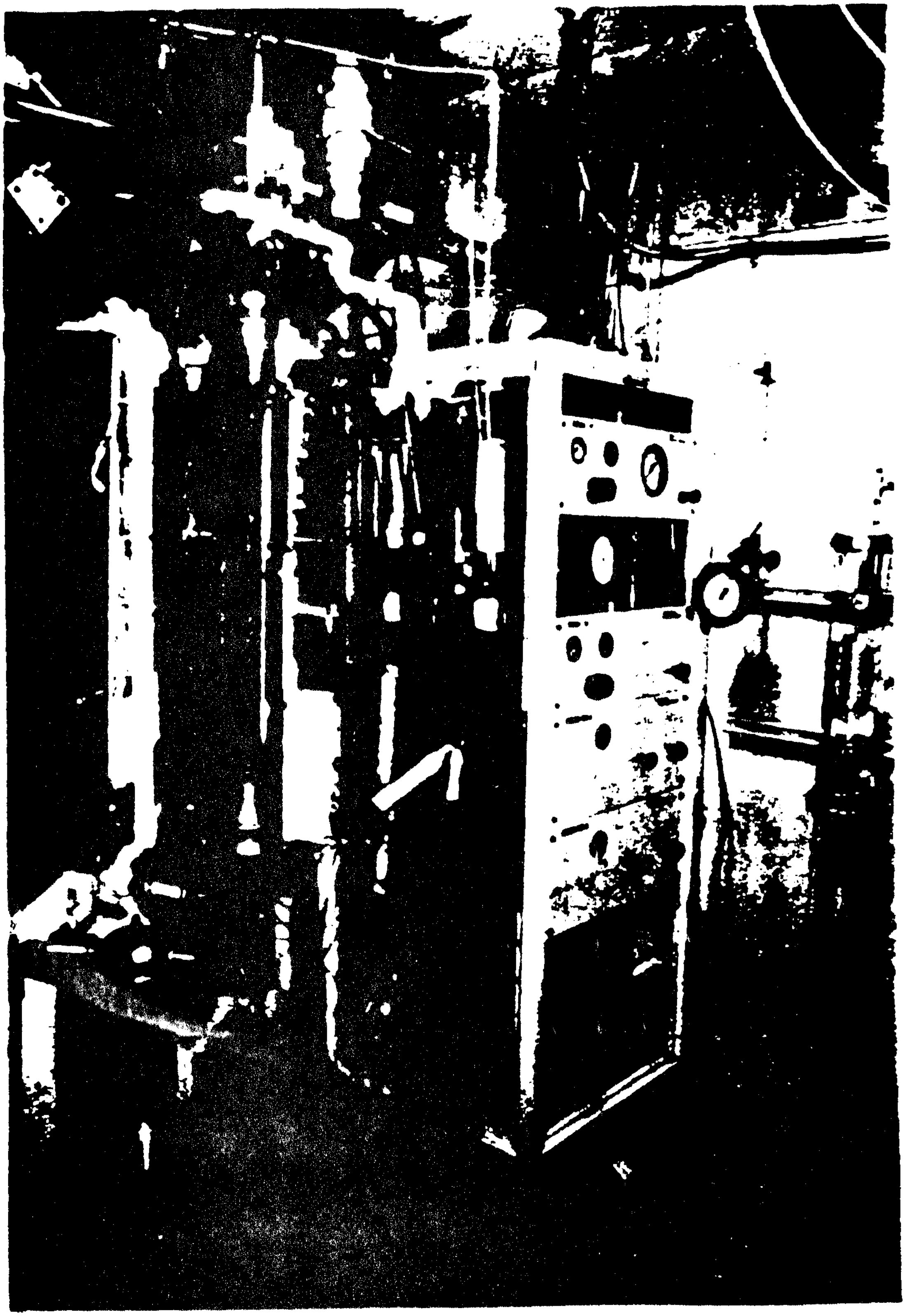

Figure 3. FREE-FALL REACTOR SYSTEM

Entrained flow pyrolysis of peat and leucaena wood was carried out in an 77-foot long, 0.815-inch ID coiled tube. The tube is wound to a 14-inch coil diameter. Heaters and auxiliary equipment, as shown in the sketch (Figure 4), are similar to that for the vertical tube reactor enumerated in the preceding paragraph. Figure 5 is a photograph of several alternate sections of the coil tube. A detailed description of the equipment and operation techniques has been provided elsewhere(2).

Analytical data are developed for each test. The weights of feed material and of char, organic liquid and water produced are recorded. The total gas volume (net gas produced plus carrier gas) is also recorded. The gas is analyzed for individual compounds (CO, CO_2, H_2, CH_4, etc.). From this analysis and the gas volume the weights of the individual compounds in the gas can be determined. Ultimate elemental analyses are carried out on the char, organic liquid, and the water phase to determine the content of C, H, O, S, N, and ash in each.

TEST CONDITIONS AND TEST RESULTS

The operating test conditions and percentages of total feed material converted to various end products are shown in Table 2 for eucalyptus and leucaena wood. Corresponding data for peat are shown in Table 3.

The test conditions for eucalyptus and leucaena are arranged in four groups according to varying conversion atmospheres:

Total Pressure, psia	Carrier Gas Composition	Hydrogen Partial Pressure, psia
250	42% hydrogen/58% nitrogen	105
115	100% hydrogen	115
115	56% hydrogen/44% helium	64
115	100% helium	0

The test conditions for peat are arranged in four groups according to varying conversion atmospheres:

Total Pressure, psia	Carrier Gas Composition	Hydrogen Partial Pressure, psia
500	100% hydrogen	500
250	100% hydrogen	250
100	15% to 84% steam/ 85% to 16% nitrogen	0
30	51% steam/49% nitrogen	0

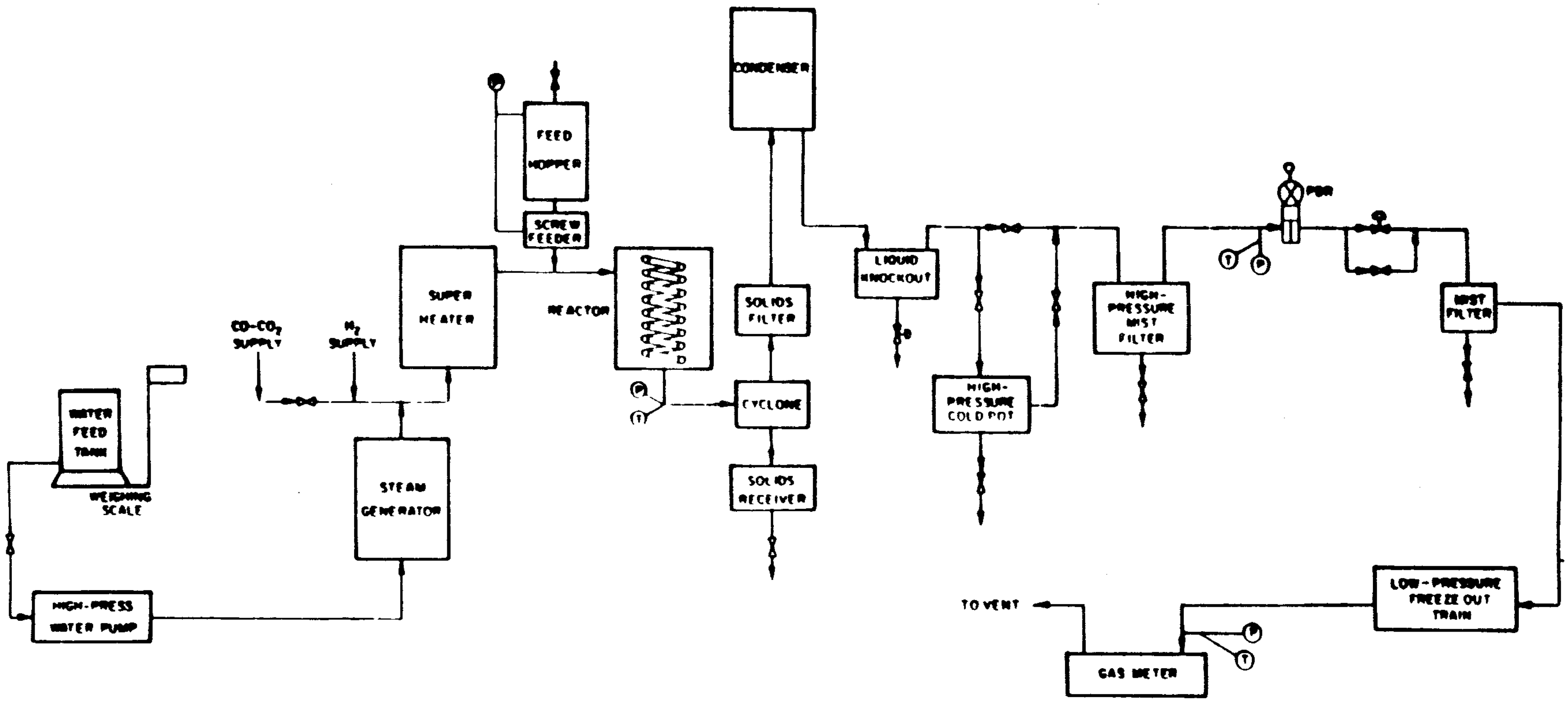

Figure 4. SCHEMATIC OF COIL TUBE REACTOR SYSTEM

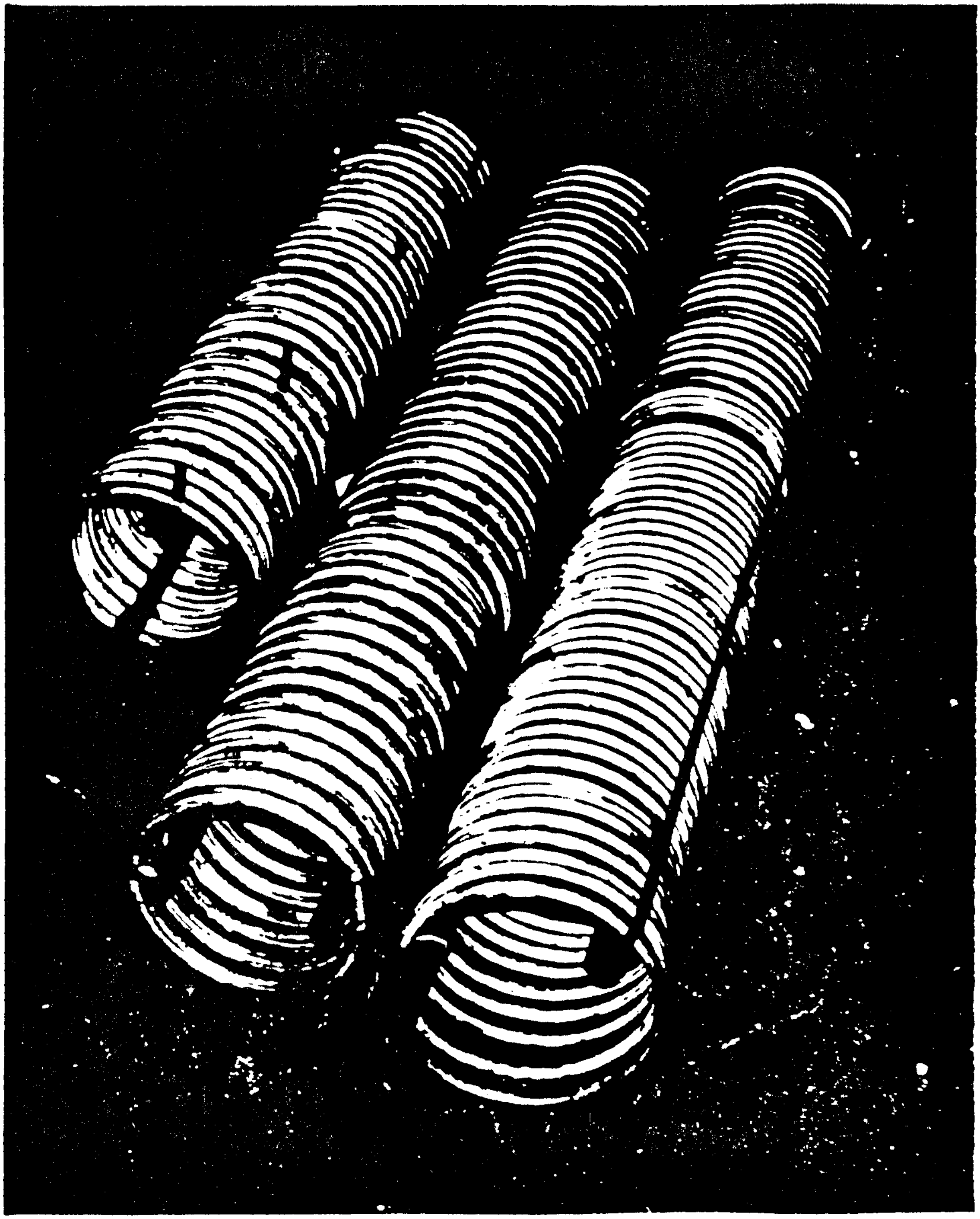

Figure 5. COIL TUBES

Table 2. TEST CONDITIONS AND RESULTS FOR WOOD PYROLYSIS

Feedstock	Leucaena	Eucalyptus						
Gas Atmosphere	Hydrogen/Nitrogen	Hydrogen					Hydrogen/Helium	Helium
Total Pressure, psia	250	115					115	115
Temperature, °F	1234	805	980	1015	1030	1220	990	1040
Solids Feed Rate, lb/hr	11.3	0.31	0.29	0.57	0.34	0.32	0.19	0.29
Gas Feed Rate, SCF/hr	1027	69.3	71.6	71.4	68.6	68.8	69.4	185.6
Gas Residence Time, s	5.20	7.14	6.00	5.90	6.25	5.52	6.00	1.30
Product, wt %*								
Carbon Oxides	28.83	9.30	13.88	23.91	26.13	30.33	17.21	25.78
Organic Liquid	24.34	34.97	30.74	33.65	27.60	10.37	33.14	36.72
Char	7.55	50.37	38.93	21.22	23.12	22.33	29.53	21.66
Hydrocarbon Gas	15.88	1.65	3.92	9.68	12.94	20.28	8.18	6.21
Water	24.53	4.72	12.34	12.79	12.62	19.85	14.85	9.70

* wt % of moisture-free feed.

Table 3. TEST CONDITIONS AND RESULTS FOR PEAT PYROLYSIS

Feedstock	Peat												
Gas Atmosphere	Hydrogen									Steam/Nitrogen			
Total Pressure, psia	500				250					100			30
Temperature, °F	1110	1220	1340	1510	1000	1110	1220	1315	1405	1230	1335	1515	1285
Solids Feed Rate, lb/hr	8.5	10.7	23.1	11.6	10.3	9.7	9.4	14.6	14.0	7.3	6.1	9.3	72.1
Gas Feed Rate, SCF/hr	2126	2121	2233	1815	1096	941	985	965	1065	337	478	370	177
Gas Residence Time, s	5.3	4.9	3.9	4.9	4.7	5.2	4.8	5.2	4.6	5.3	4.1	4.0	1.0
Products, wt %*													
Carbon Oxides	16.92	17.42	17.78	16.92	11.09	13.99	14.24	18.00	21.71	21.08	24.46	31.98	16.14
Organic Liquid	15.96	13.62	16.42	6.39	20.17	17.93	19.90	11.79	6.78	14.43	13.86	11.41	8.96
Char	38.79	38.38	45.29	39.82	53.36	48.48	39.82	48.25	45.05	47.80	43.14	40.80	51.06
Hydrocarbon Gas	15.03	16.75	10.53	21.83	3.18	7.74	10.90	14.02	18.64	7.64	10.63	10.88	6.79
Water	14.76	14.31	10.28	16.88	12.47	11.43	16.45	13.64	12.77	8.27	7.70	2.99	14.20

* wt % of moisture-free feed.

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DISCUSSION

Design of a system to convert biomass to superior fuels requires not only a knowledge of the quantities of the various end products - char, organic liquid, water, hydrocarbon gases and carbon oxide gases - but also requires a knowledge of their compositions. Both quantities and compositions will depend on the specific conditions of temperature, pressure, residence time, and composition of the gas atmosphere employed during conversion.

Figure 6 is a diagram showing the elemental composition of some of the feed materials and end products of interest. Superior fuels are obtained by removal of oxygen. Removal of carbon or the addition of hydrogen may also be necessary to attain the specific carbon-to-hydrogen ratio desired. Oxygen may be removed from the system as carbon oxides (CO_2 and CO) or as water (H_2O). Removal as CO_2 is preferable since it removes more oxygen without removing any hydrogen. For example, Line a, b, c of Figure 6 shows that removal of sufficient CO_2 alone from eucalyptus or leucaena wood will produce liquid hydrocarbons with a composition close to hexane. Since production of carbon oxides is an important consideration in the conversion process and also because it is one of the most reliably measured quantities in the experimental work, we have chosen to employ it as the principal measure of the extent of conversion in predicting conversion to end products.

The elemental composition and the quantity of the various end products from conversion will depend on the percentage of each element from the feed converted to each product. These percentages are derived from the experimental measurements of elemental compositions and quantities of each end product relative to the elemental composition of the feed material. Comparing the percentages of each feed element converted to each end product against the extent of conversion (percent of feed carbon to carbon oxides), shows the effect of feed type (wood or peat), of the reaction pressure, and of the reaction atmosphere composition (carrier gas composition). This is the purpose of the following discussion.

Figure 7 shows that the extent of conversion, as evidenced by carbon oxide formation, increases linearly with increasing temperature. For peat, conversion is slightly higher in a steam-nitrogen atmosphere at 30 to 100 psia than in a 100% hydrogen atmosphere at 250 to 500 psia. Conversion of wood is not affected at all by gas atmosphere and at equivalent temperature is higher than conversion of peat. It appears that there is insignificant conversion below 650^oF for either wood or peat.

Figure 8 shows the effect of the pyrolysis gas atmosphere on the total amount of hydrogen going to end products. With carrier gas containing no hydrogen, the amount of hydrogen contained in products is either less than or about

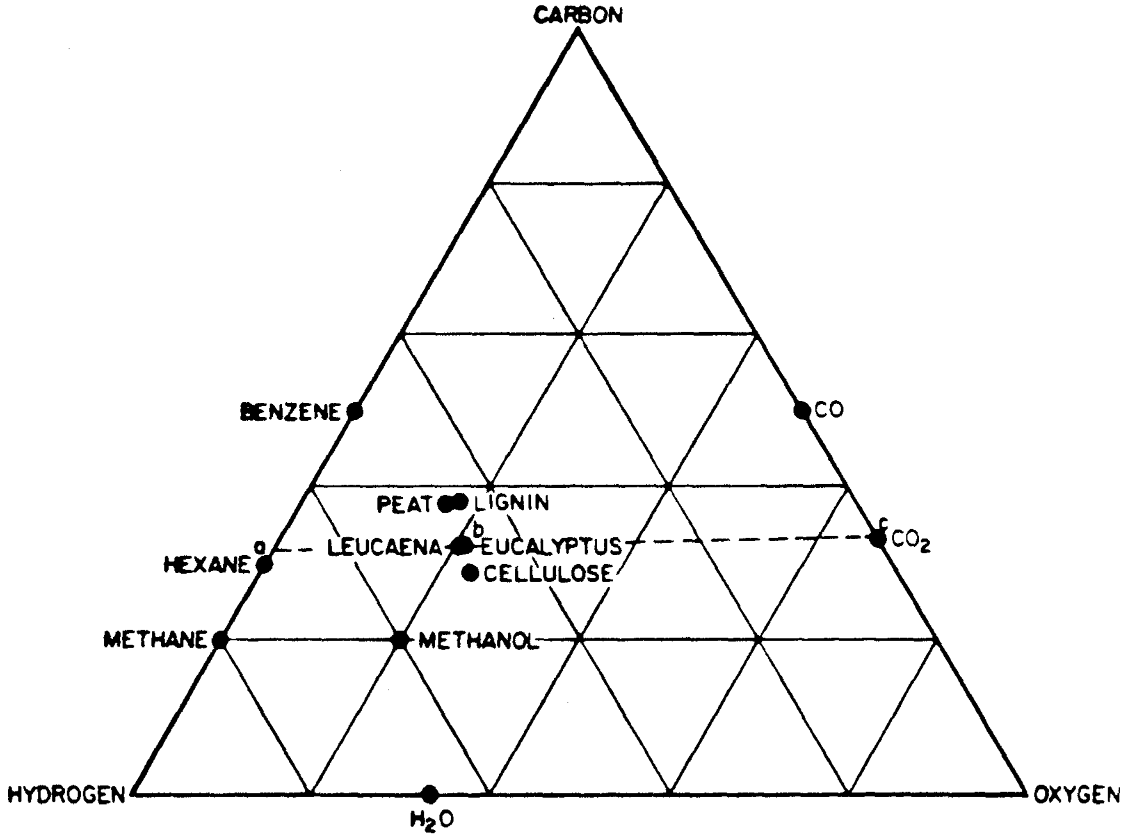

Figure 6. ELEMENTAL ANALYSES OF BIOMASS, PEAT, AND END PRODUCTS

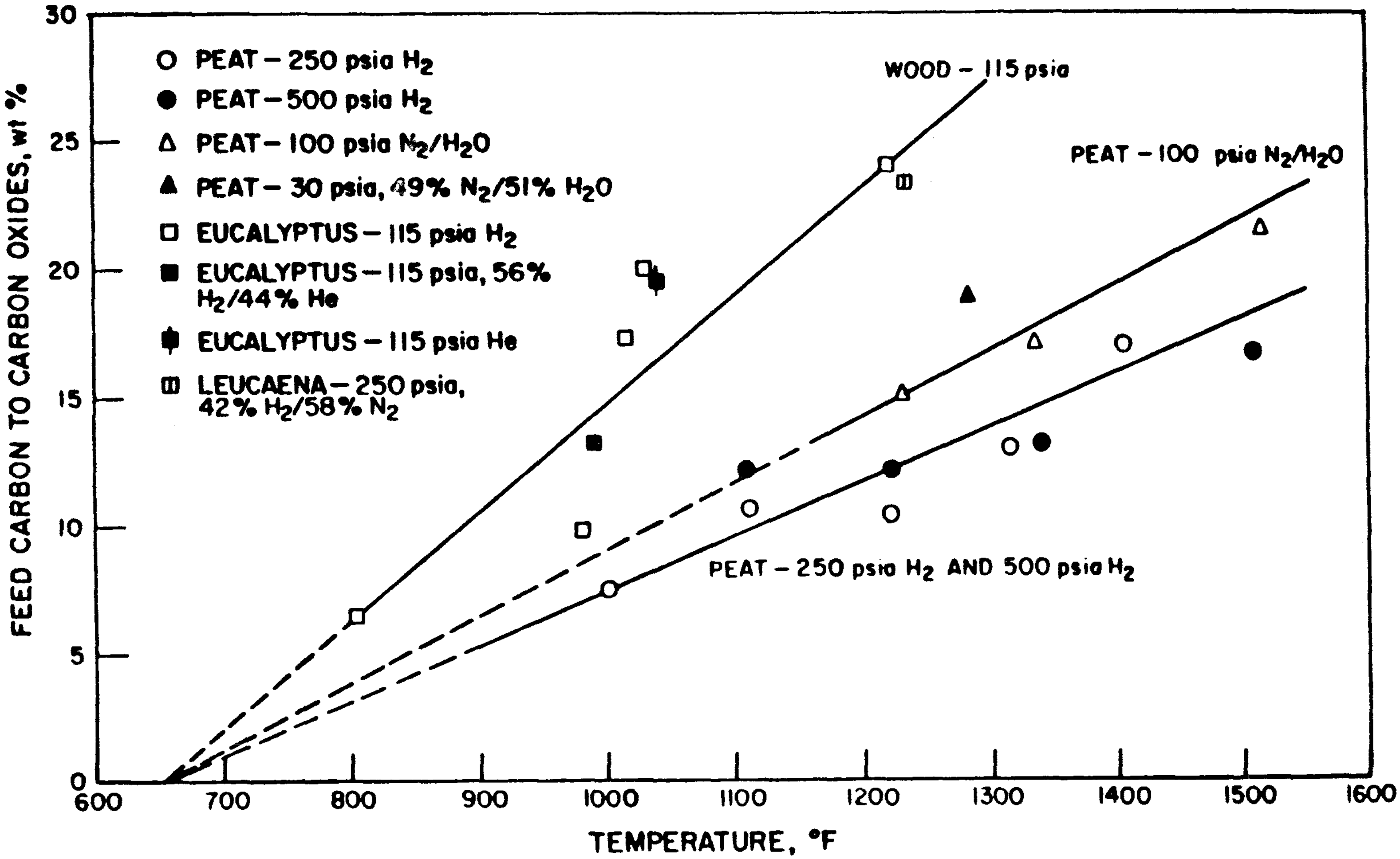

Figure 7. CONVERSION TO CARBON OXIDES VERSUS PYROLYSIS TEMPERATURE

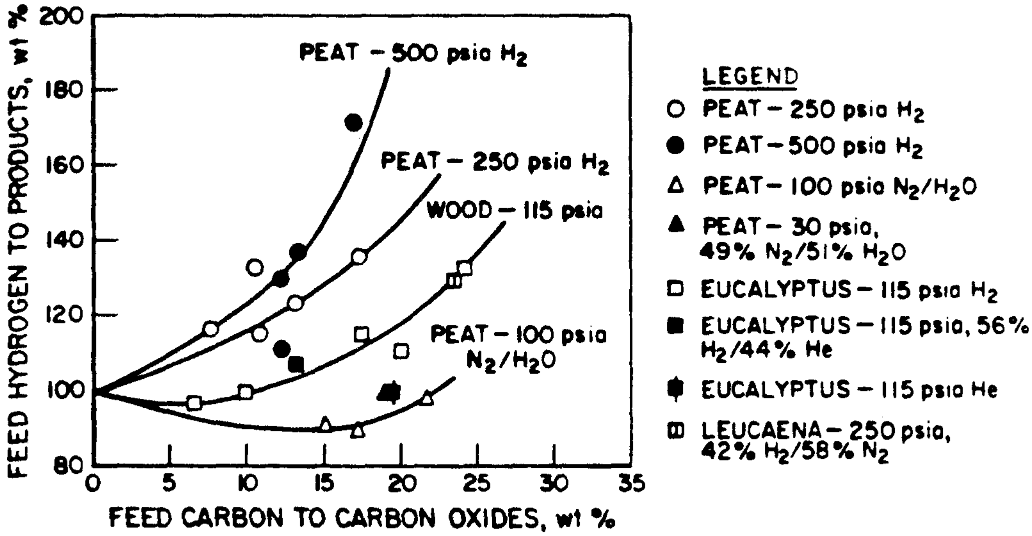

Figure 8. TOTAL FEED HYDROGEN TO PRODUCTS

equal to hydrogen contained in the solid feed. "Less than" means that hydrogen will be produced as gas which is not counted as a product. Increasing hydrogen partial pressure in the carrier gas increases the quantity of hydrogen going to products to make it considerably more than the hydrogen in the solid feed. That is, hydrogen from the gas becomes part of either organic liquid, char, hydrocarbon gas, or water.

Figure 9 shows the disposition of carbon, hydrogen, and oxygen individually from the feed into organic liquid. The percentage of each element to organic liquid reaches a maximum at between 10% and 15% carbon to carbon oxides and then decreases rather rapidly at higher extents of conversion. It is interesting to note the similarity between the percentages of carbon and hydrogen going to oil, suggesting that there are groups of hydrogen to carbon bonded radicals remaining intact. On the other hand, the percentage of feed oxygen going to organic liquid is lower than the percentage of both carbon and hydrogen. This is desirable for improving the fuel value of the organic liquid as compared with the feed. The percentage of oxygen going to organic liquid is much less for peat than for wood. The organic liquid produced from peat is thereby of higher quality as a fuel (lower oxygen) both because there is originally less oxygen in the peat and also a lesser percentage of oxygen is converted to organic liquid.

Figure 10 shows the disposition of carbon, hydrogen, and oxygen from the feed into char. At low conversions, the amount of each element remaining in the char decreases rapidly as conversion increases. At higher conversions the amount tends to reach a constant value. Here, the hydrogen and oxygen show similar percentages reporting to char while carbon to char is considerably higher. Increasing hydrogen pressure has a marked effect in decreasing the amount of each element remaining in the char.

Figure 11 shows the considerable effect of increased hydrogen pressure to increase both carbon and hydrogen going to hydrocarbon gases.

Figure 12 shows that there is little effect of hydrogen pressure on the quantity of oxygen going to carbon oxides. The percentage of oxygen to carbon oxides is higher in the case of peat than in the case of wood. It turns out that, because the percentage of oxygen in the peat feed is lower than in the wood feed, the ratio of oxygen to carbon in the carbon oxides produced is very nearly the same for peat and wood conversion.

Figure 13 shows that, for peat, the percentage of elements converted to water reaches a maximum at between 5% and 10% of carbon to carbon oxides. On the other hand, for wood, water formation increases continuously over the full range of conversion investigated.

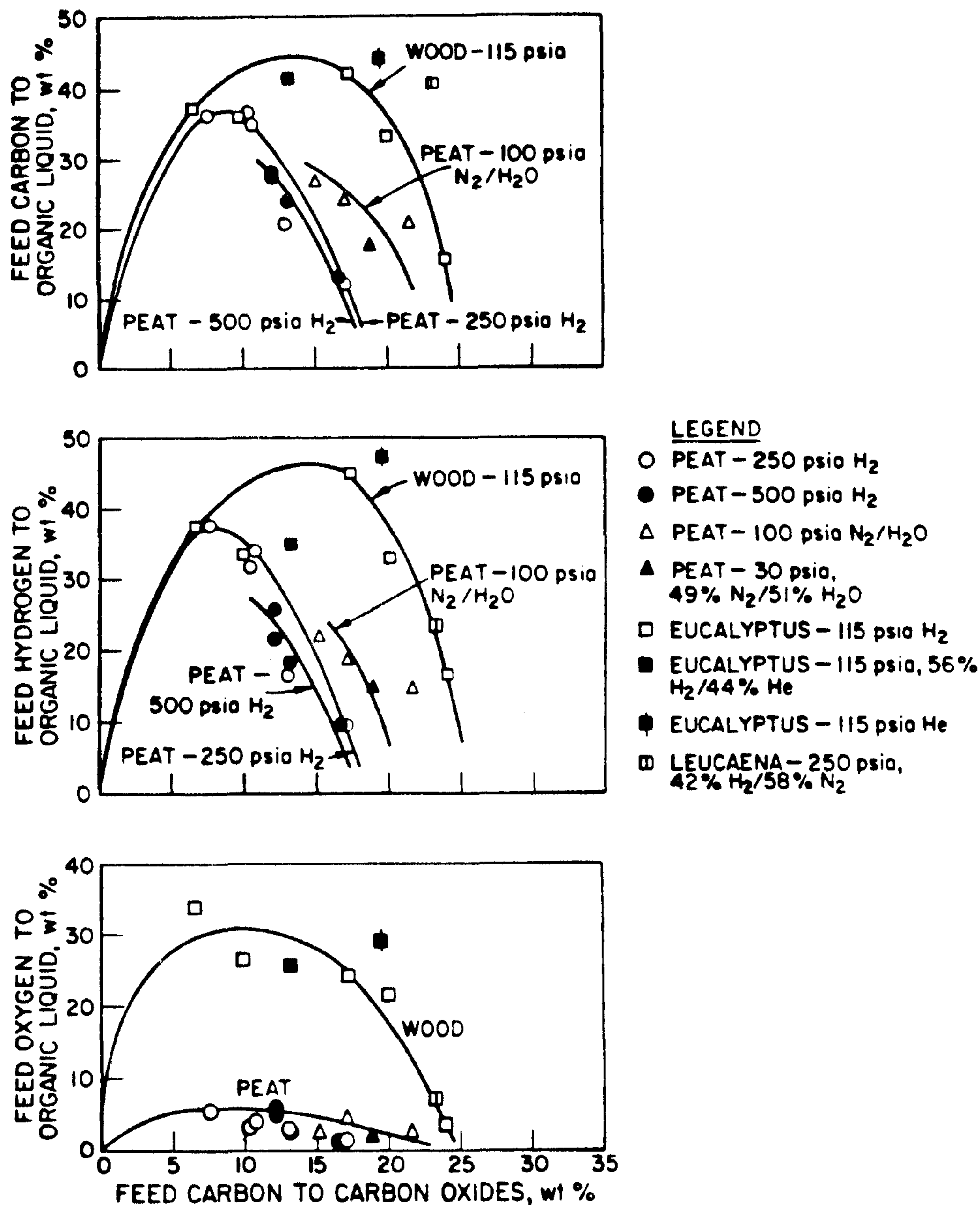

Figure 9. CONVERSION OF FEED ELEMENTS TO ORGANIC LIQUID

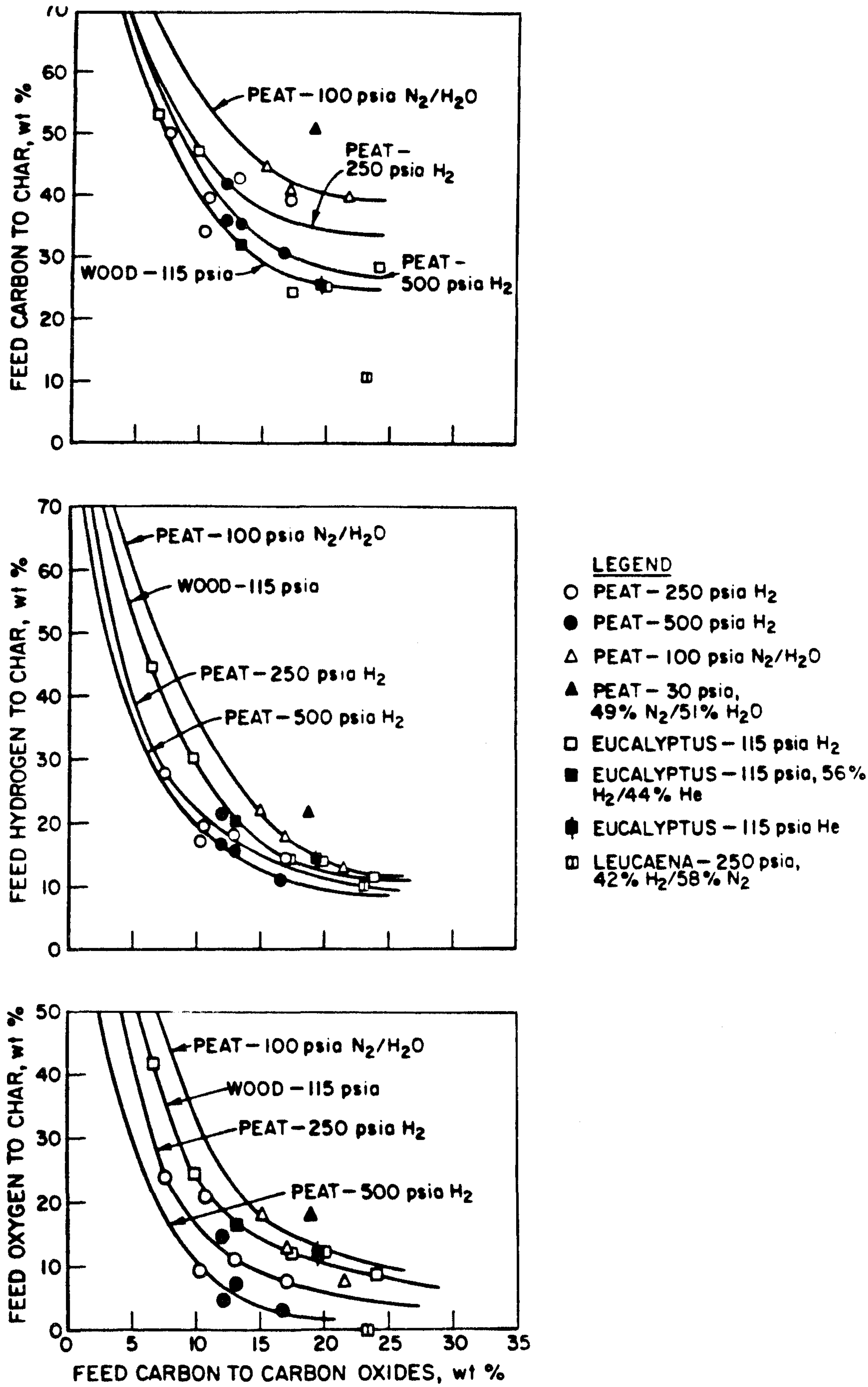

Figure 10. CONVERSION OF FEED ELEMENTS TO CHAR

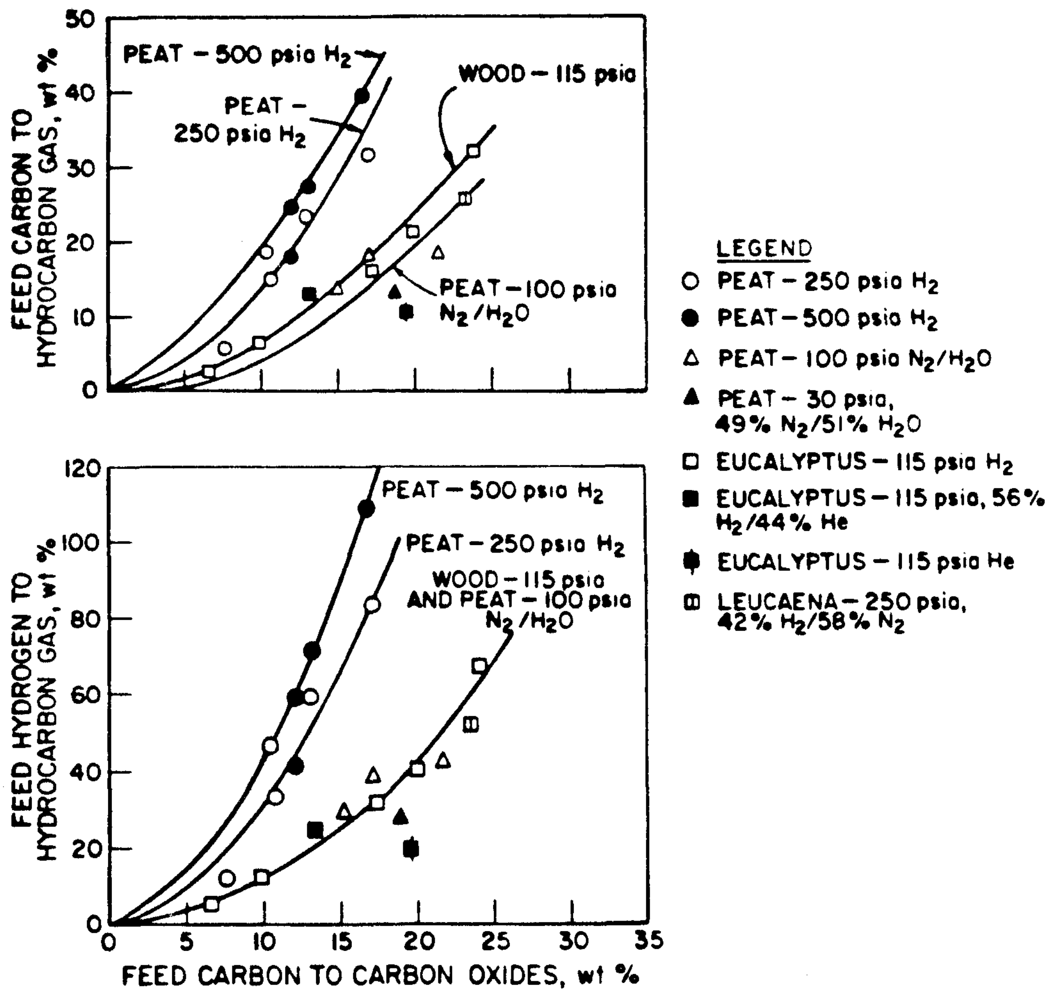

Figure 11. CONVERSION OF FEED ELEMENTS TO HYDROCARBON GASES

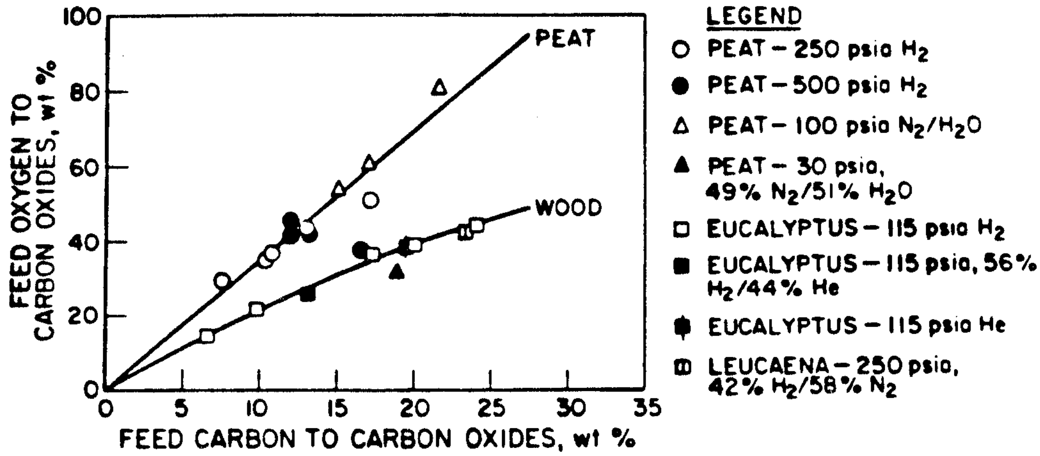

Figure 12. CONVERSION OF FEED OXYGEN TO CARBON OXIDES

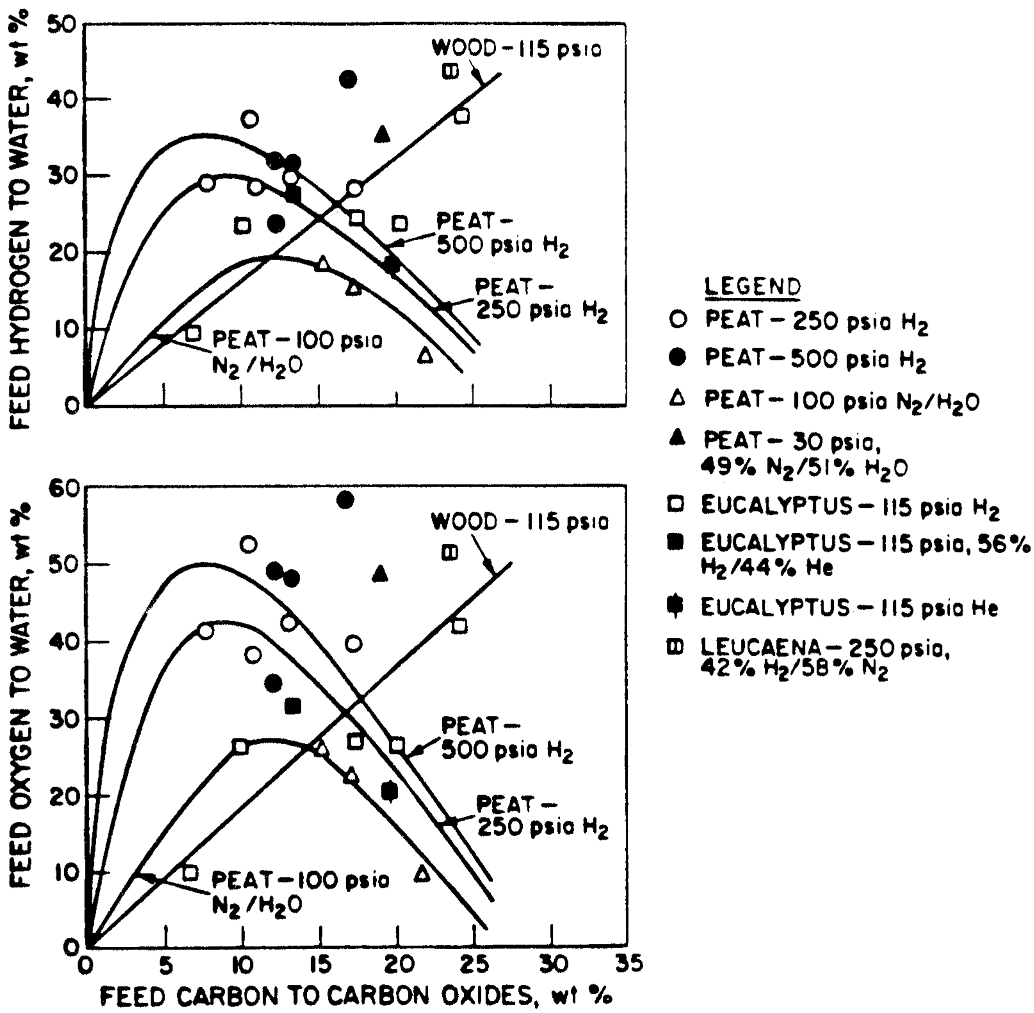

Figure 13. CONVERSION OF FEED ELEMENTS TO WATER

Mainly, the conversions by pyrolysis of wood and peat show decided similarity. There are some very notable exceptions. In the region of substantial liquid production important differences are as follows:

- Conversion of peat requires 200° to 400°F higher temperature
- Organic liquid produced from wood contains much more oxygen than organic liquid produced from peat. The oxygen not appearing in the liquid from peat appears mainly in carbon oxide gases or as water.
- Increasing hydrogen partial pressure in the pyrolysis gas atmosphere markedly increases the amount of hydrogen converted to total end products. In the case of peat, the proportion of hydrogen going to oil is decreased by increasing hydrogen pressure. In the case of wood, the proportion of hydrogen going to oil is generally higher than in the case of peat and is not affected appreciably by varying hydrogen pressure.

The charts presented here for predicting the percentage of feed elements going to various end products can be used to calculate the quantities and compositions of each of the products. Table 4 shows how this may be done for one specific condition with eucalyptus wood.

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Table 4. PRODUCTS FROM EUCALYPTUS PYROLYSIS

Condition: 15% of Feed Carbon to Carbon Oxides
Hydrogen Carrier Gas at 115 psia

	Conversion			
	% of Feed Element X	% in Feed =	% of Total Feed	Composition, wt %
C to Organic Liquid	43	49.0	21.1	59.3
H to Organic Liquid	46	5.9	2.7	7.6
O to Organic Liquid	28	42.1	11.8	33.1
TOTAL TO ORGANIC LIQUID			35.6	100.0
C to Char	29	49.0	14.2	59.1
H to Char	18	5.9	1.1	4.6
O to Char	14	42.1	5.9	24.6
Ash to Char	100	2.8	2.8	11.7
TOTAL TO CHAR			24.0	100.0
C to Hydrocarbon Gas	15	49.0	7.4	83.1
H to Hydrocarbon Gas	25	5.9	1.5	16.9
TOTAL TO HYDROCARBON GAS			8.9	100.0
C to Carbon Oxides	15	49.0	7.4	37.0
O to Carbon Oxides	30	42.1	12.6	63.0
TOTAL TO CARBON OXIDES			20.0	100.0
H to Water	25	5.9	1.5	11.2
O to Water	27	42.1	11.4	88.9
TOTAL TO WATER			12.9	100.0