MASTER

Engineering and Economic Study Report

VOLUME I

EXECUTIVE SUMMARY

HONEY LAKE HYBRID POWER PLANT PROJECT

Prepared For
GEOPRODUCTS CORPORATION

FG03-79ET27244

By

Morrison-Knudsen Company, Inc.
Boise, Idaho

and

International Engineering Company, Inc.
San Francisco, California

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TABLE OF CONTENTS

	<u>PAGE</u>
SECTION 1: INTRODUCTION	1-1
SECTION 2: SUMMARY OF STUDY CONCLUSIONS AND RECOMMENDATIONS	2-1
SECTION 3: DISCUSSION	3-1
3.1 Fuel Combustion Optimization	3-1
3.2 Plant Capacity Analysis	3-2
3.3 Wood Fuel Handling Design	3-5
3.4 Plant Cycle Optimization	3-8
3.5 Wood Fuel Drying	3-11
3.6 Emission Controls and Water Treatment	3-16
3.7 Ash Handling and Plant Cooling System	3-19
3.8 Wood-Geothermal Energy Budget and Contribution	3-24
3.9 Geothermal Well System and Plant Operating Requirements	3-29
3.10 Economic Analysis and Sensitivity	3-31
SECTION 4: PROJECT SCHEDULE	4-1

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SECTION 1

INTRODUCTION

Morrison-Knudsen Company, Inc. (M-K) and International Engineering Company (IECO) have completed a technical and economic feasibility study of the engineering aspects of a hybrid wood-fired geothermal electrical generating plant. The proposed plant location is in Lassen County, California, approximately 19 miles east of Susanville, near the Wendel Amedee Known Geothermal Resource Area. This is a hybrid power plant which uses moderate temperature geothermal fluid to augment the heat supplied from a wood waste fired boiler. The study was conducted under contract to GeoProducts Corporation and co-sponsored by the U.S.D.A. Forest Service, California Department of Water Resources and the U.S. Department of Energy.

The purpose of this report is to define major plant systems for implementation into the plant conceptual design and to provide sufficient design information for development of budgetary cost estimates. Emphasis is placed on incorporation of geothermal heat into the power generation process. Plant systems are designed and selected based on economic justification and on proven performance. The culminating economic analysis provides the financial information to establish the incentives for construction of the plant.

The study concludes that geothermal energy and energy from wood can be combined in a power generating plant to yield attractive project economics. The study determines that the hybrid project can achieve the following results:

- o Provide a long term source of electrical power at competitive prices.
- o Provide up to 20% of the total heat to the plant through use of geothermal heat.
- o Provide a prudent use of the available wood and geothermal energy in a combined power plant.

Power generation from the hybrid power plant is the utilization of two forms of energy -- wood and geothermal -- in a combined configuration to supply heat to a power generation process. In the system, high pressure steam generated by burning wood in a boiler is expanded through a turbine to low pressure. A generator attached to the turbine produces electrical power. The low pressure steam exhausted from the turbine is condensed in a condenser and subsequently reheated before returning to the boiler for the generation of more steam. Geothermal heat is used to heat the feedwater. Air required by the boiler for the combustion process is preheated using geothermal heat, thus improving the overall combustion efficiency.

Wood arrives at the plant site containing about 50% moisture. Geothermal heat provides heat to wood dryers which reduce the wood moisture content and consequently improve boiler efficiency.

As a result of the savings in wood fuel consumed, geothermal heat offers cost advantages in the production of electricity in a wood-fired power plant. An artist's concept of the hybrid plant is shown in Diagram A-001.

ARTIST'S CONCEPTUAL DRAWING	
HONEY LAKE HYBRID POWER PLANT GEOPRODUCTS CORPORATION
McWATERS ENGINEERING	DRAWING NO. H-100

SECTION 2

SUMMARY OF STUDY CONCLUSIONS AND RECOMMENDATIONS

The hybrid power plant feasibility study incorporates studies and analyses performed in several major work areas to arrive at the preliminary plant design. All the plant systems are defined and necessary data developed to support a detailed cost estimate and financial analysis of the power plant.

The diagram shown on drawing M-011 depicts all the finalized plant systems arrived at through the system analyses. Drawing C-001 is a site plan showing the relative locations of plant equipment and systems.

Technical evaluations show that incorporation of geothermal heat into a wood-fired power plant is economically feasible and technically practical. Study results are summarized below and a discussion of these results is presented in Section 3.

Wood Fuel Combustion Optimization

- o The combustion options examined are stoker firing, suspension firing, fluid bed combustion, and gas firing. Stoker firing offers a proven method of combusting wood fuel. The technology has been proven in service on a large number of units over a period of many years. The stoker-fired conventional wood boiler is the recommended design to achieve the objectives of this project. If the wood is dried prior to combustion, wood fines removed from the drier are conveyed pneumatically to the boiler and burned in suspension.
- o A suspension-fired boiler using wood has a slightly improved efficiency over the stoker-fired boiler; however, the fuel preparation system is substantially more expensive. The 100% suspension-fired boiler has substantial power requirements for hogs, mills, and other equipment in the fuel preparation system. This equipment has high first costs and the hogs, mills, conveyers, feeders, and screens are high maintenance items.

PROCESS FLOW DIAGRAM
HONEY LAKE
HYBRID POWER PLANT
GEOPRODUCTS CORPORATION

MORRISON
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DRAWING NO
M-011

It is therefore recommended that 100% suspension firing not be considered because this type of combustion is neither economic nor technically practical for this project.

- o Fluidized bed combustors (FBC) are proven technology in smaller capacity units up to 120 million Btu's per hour. Units in the medium- to large-capacity range required to provide steam for this project in a single unit or two units are currently unproven technology and have not been built or tested. The main advantages of the FBC units are the ability to combust high moisture fuel and to handle variations in quality and size of fuel. Additionally, sulfur compounds can be removed by limestone in the bed.

Because of the higher cost and lack of proven technology as compared to the stoker fired boiler, the FBC is not a viable selection for this project.

- o Gasification units, particularly in larger capacities, are technically complex and have unproven reliability. Projected costs for gasification systems for capital, operation, and maintenance are substantially higher than for the stoker-fired boiler. There are no apparent benefits to be gained that justify the higher cost and risk involving using this system. The cost of a wood gasifier and a gas-fired boiler is greater than that of a stoker-fired boiler system. The high cost of gasification systems more than offsets the combined stoker-fired boiler and air correction equipment. Additionally, no gasifiers of sufficient capacity for this project have been built or tested; consequently, a cluster of smaller units is required. Because of the gasification problems involved, this alternative is economically and technically unacceptable.

Plant Capacity Analysis

- o An analysis is performed to determine the economic plant size using 50 MW as the maximum size and considering two smaller sizes -- 35 and 20 MW.

Capital costs in 1984 for the 20, 35, and 50 MW plants are estimated to be \$49,881,000, \$71,481,000, and \$88,191,000 respectively. These costs are approximate and are not intended for use in the final economic analysis where detailed cost estimates are performed. The costs developed are for predicting relative rates of return on investment, allowing comparisons of the plant size alternates.

- o In addition to capital costs, other items included in the analysis are operation, maintenance, and fuel costs. Revenue from power sales is predicted over the plant life, 30 years.

The internal rates of return over the 30-year life for the 20, 35, and 50 MW plants are 22.2%, 25.4%, and 28.0% respectively. A 50 MW plant is therefore recommended for the Honey Lake Project. The rates of return given are for predicting relative differences between plant sizes. The rates of return for the final selected 50 MW plant are presented in Section 3.10.

- o The 50 MW plant is selected because its rate of return is the most favorable; however, there are other considerations such as environmental constraints, shorter project schedule and transmission options favoring smaller plants that may improve the viability of the smaller plants. By client approval, the selection of plant size was based on plant equipment and processes having proven technology and an established experience record for plants of 50 MW.

Wood Fuel Handling Design

- o The fuel demands for a 50 MW plant are about 730 oven-dry tons per day. The system is sized for operation 365 days per year to ensure availability.

- o All fuel deliveries are weighed on the incoming truck scale. A weighmaster is recommended during regular delivery hours. Chip trucks continue to the trailer dumps where they are emptied into the live bottom receiving hopper. Hogged fuel is conveyed to the sizing area where ferrous metals are removed and fuel is sized to less than 2 inches. Fuel is then conveyed to storage.
- o Economic analysis indicates the fully automatic stackout and reclaim system is preferable for this plant. The additional capital expenditure over a semi-automatic system is shown to yield a 29% rate of return over the life of the plant. Since this type of system is not yet in commercial operation, an adequate demonstration of performance and confirmation of costs are necessary before equipment specification is performed in the detailed design phase. If, during the detailed design phase, sufficient confidence in performance and price is not evident, the semi-automatic system should be selected.
- o During the months of active harvesting each year, hogged fuel is reclaimed directly from the hogged fuel storage area and is conveyed to the dryers. During the months when no deliveries are being received, logs and gondola material are reclaimed from storage.
- o It is recommended that the size of fuel delivered be limited. The largest pieces received through the chip trailer dumps should not exceed 4 inches in diameter by 2 feet length. The logs delivered should be of diameters greater than 6 inches and lengths from 6 to 32 feet.

Plant Cycle Optimization

- o An analysis is performed to determine the optimal economic turbine throttle conditions for the plant thermal cycle. A life cycle financial analysis indicates that a non-reheat turbine should be used with throttle conditions of 1450 psig and 950°F.

- o The analysis performed on the arrangement of the feedwater heaters indicates that the optimal arrangement is two-high pressure heaters being fed from a deaerator. This is independent of the geothermal temperature.
- o The alternates based on 340°F and 275°F geothermal water require the use of a geothermal feedwater heater upstream of the deaerator and no low pressure steam extraction heaters. With 225°F water, no geothermal feedwater heating can be justified; therefore, two low-pressure steam extraction heaters are required.

Wood Fuel Drying Design

- o The dryer types analyzed for wood drying are rotary, tower, conveyor, and cascade dryers. The rotary dryer is recommended as the most viable design for application to the Honey Lake Project. It has a proven track record in the American forest products industry for drying hogged fuel.
- o Although the forest products industry has experienced problems with wood drying, it is believed that the use of relatively low temperature air from the geothermal heat source will mitigate these problems.
- o Although conveyor dryers require approximately the same capital expenditure as a rotary system, they are not believed to be as suitable for drying hogged fuel. Unlike the rotary dryer, the conveyor design does not maintain a uniform product moisture. These dryers are used primarily in food processing applications and have not been tested for hogged fuel.
- o Tower dryers are estimated to be more expensive than either the rotary or conveyor dryers. This design depends on the wood fuel to flow through a choke fed, vertical silo. The poor flow characteristics of hog fuel can cause bridging within the dryer structure to be a serious problem.

- o Cascade dryers are being used successfully in hogged fuel applications in Europe. This alternative was not pursued because the manufacturer indicated that the cascade dryer would probably not be suitable for low gas temperature applications.

Wood Fuel Drying Optimization

- o The amount of wood drying that can be economically justified is examined. At a 340°F geothermal water temperature, fuel drying from 50.8% to 45% moisture is the economic optimum. A rate of return on additional expenses associated with drying is approximately 31%, which indicates a justification for geothermal fuel drying.
- o If the geothermal water temperature is 275°F, drying to 45% moisture is marginally recommended since a rate of return on expenses associated with drying is approximately 24%.
- o No fuel drying is economically justified when the geothermal water temperature is as low as 225°F.
- o Further examination of using flue gas for drying may be desirable in the final design phase of the project. Flue gas drying is not incorporated into the conceptual plant design.

Emission Controls and Water Treatment

- o Restrictions on particulate emissions vary from .01 to .05 grains/DSCF. Control equipment design for the Honey Lake Plant is based on an exhaust concentration of .02 grains/DSCF.
- o Gases produced by burning wood fuel are within required limits and no control equipment is required for sulfur dioxide, nitrogen oxides and carbon monoxide.

- o A multiple-tube cyclone collector followed by an electrostatic precipitator is recommended for particulate emissions control.
- o A baghouse is not recommended for final flue gas cleanup because of the fire hazards present in wood-fired boiler applications.
- o Although a wet scrubber has the lowest capital cost, high operating costs make this option for final gas cleanup unfavorable.
- o Plant makeup water requirements are met by geothermal water after it has served its heating purposes. Geothermal water not used as plant makeup water is reinjected.
- o A lined evaporation pond handles plant waste water. The high ground water level precludes surface disposal or percolation as disposal options.

Ash Handling System Analysis

- o Hydraulic, pneumatic, and mechanical drag ash collection systems are analyzed. A damp mechanical ash conveying system is recommended for this plant. This is a cost-competitive alternative which produces a truckable damp ash mixture. Fire hazards and dust problems are minimized.
- o The dry ash handling system is not recommended because of extreme fire hazards and high operating costs.
- o The necessity of lining an ash storage pond makes the hydraulic conveying alternatives uncompetitive. Recovery of the ash for possible sale would also be difficult.
- o The hydraulic system operating with a dewatering system is not cost competitive. The dewatering system is also expected to cause operational problems.

Plant Cooling System Evaluation

- o The alternative cooling systems examined are mechanical draft cooling tower, spray pond with thermal storage, and spray pond without thermal storage. The spray pond with thermal storage capability is not cost competitive against a conventional spray pond. The earth dikes for 20 feet of pond depth are more than twice the costs for the conventional pond dikes.
- o The results of the cost analysis indicate that the total costs of spray pond systems are less than either the thermal storage pond or cooling tower and is therefore the economic choice.
- o Although this preliminary analysis indicates the pond is favored over a cooling tower, the cost differential is not significant, and a detailed analysis during final design may favor the tower.

Wood-Geothermal Energy Budget and Contribution

- o Fuel savings realized by incorporating geothermal heat into the feedwater heater cycle are 2.1, 3.9, and 7.3 percent for geothermal temperatures of 225°, 275° and 340°F, respectively.
- o Using geothermal water to heat combustion air results in fuel savings of 4.6, 6.1, and 7.9 percent for 225°, 275° and 340°F geothermal water, respectively.
- o Fuel savings as a result of geothermal fuel drying varies from 4.7 to 15.1 percent, depending on geothermal temperature and the degree of drying performed.
- o Combining all three methods of utilizing geothermal heat results in fuel savings of 14.3 and 19.0 percent for the geothermal temperatures of 275°

and 340°F and drying to 45 percent moisture in both cases. This can be accomplished by using the flow from two geothermal wells, with an assumed flow rate of 843 gpm each.

- o Considering economic analyses performed in other sections, feedwater heating and fuel drying are not feasible at the lowest geothermal temperature of 225°F. The fuel savings at this temperature using combustion air heating only is 4.3 percent.

Geothermal Gathering and Injection System

- o The direct capital costs of geothermal gathering and injection systems estimated in 1981 dollars are:

\$1,528,400 for 1 production well

\$2,461,600 for 2 production wells

\$3,447,000 for 3 production wells

- o When the geothermal resource temperature has been finalized for its application within the power plant, the most economical number of wells to be developed can be determined. The number of production wells required, as specified for this report, is one for 225°F geothermal water and two for 275°F and 340°F water.

Backup System Evaluation

- o The major plant equipment such as the turbine generator, boiler and condenser do not have backup units.

- o Two full capacity boiler feed pumps are required - one electric and one steam turbine driven.
- o Two half capacity condensate hotwell pumps and circulating water pumps are specified.
- o Forced draft and induced draft fans are single full-capacity fans.
- o Two full capacity fuel distribution air fans are supplied.
- o AC and DC loads which cannot tolerate an interruption of power are backed up by power systems consisting of batteries, chargers, inverters, transfer switches, and distribution panels.
- o Plant freeze protection is accomplished by the building heating systems and the plant freeze protection system.
- o Fire protection systems are provided for plant protection. Two full-capacity fire water pumps are required.

Plant Operating Requirements

- o Approximately 30 people are required to fill staff positions for operating and maintaining the power plant.

Economic Analysis and Sensitivity

- o The estimated capital costs of the 50 MW power plants in 1981 dollars corresponding to the 225°F, 275°F and 340°F geothermal temperatures are \$72,067,000, \$73,203,000, and \$72,611,000.

- o The total escalated investment costs of the power plants to the date of commercial operation are estimated to \$86,220,000, \$87,544,000, and \$86,823,000 corresponding to the 225°F, 275°F and 340°F temperatures. These costs do not include interest during construction.
- o The rates of return assuming 100 percent equity at the three temperatures are 22.4%, 22.2%, and 22.5%. At an 11 percent interest rate and a debt/equity ratio of 75%/25%, the rate of return on the equity portion for the 275°F temperature is 38.8 percent.
- o Expenses for the plants in the year 1985 at an 11 percent interest rate are as follows:

Geothermal Temperature, °F	<u>225</u>	<u>275</u>	<u>340</u>
Expenses, Mills/Kwh (Includes fuel, O&M, Interest, Geo. Heat, Insurance, Property Tax)	58.6	57.8	56.6
Depreciation, Mills/Kwh	21.8	22.4	22.2
Loan Principal, Mills/Kwh	11.0	11.2	11.1

SECTION 3

DISCUSSION

The following is a brief discussion of the salient parts of the feasibility study and its conclusions. The purpose of this discussion is to provide summary background for the study results and conclusions presented in Section 2.0. Complete and detailed information is contained in the feasibility study Engineering and Economic Study Report.

3.1 FUEL COMBUSTION OPTIMIZATION

The purpose of this study is to review and evaluate the various combustion systems which can be used to extract energy from the wood fuel. The systems examined include stoker firing, suspension firing, fluidized bed combustion, and gas firing. Each system is analyzed and the advantages and disadvantages are assessed along with the current status of development and experience.

Sources of information include technical journals, vendors, research papers, government publications, and owner/operators of equipment. Information available is primarily qualitative in nature. Quantitative information is limited in scope or not available.

It is difficult to perform detailed financial comparisons of some of the alternatives, such as those involving gasification, because so much of the work to date has been on research or pilot-plant facilities. Consequently, scaling up to the size and performance required is speculative.

A conventional wood-fired boiler utilizing pneumatic fuel spreaders and a traveling grate stoker to produce steam for driving a steam turbine and an electrostatic precipitator for flue gas cleanup is considered as the base case against which other alternatives are compared. After

consideration of the combustion alternatives, this configuration is selected for the Honey Lake Plant because it utilizes proven techniques, is cost competitive, and is well-suited to burn the type of fuel involved.

Suspension firing is reviewed and considered to be inappropriate. If wood is to be fired in suspension, extensive preparation is required as it must meet stringent requirements for sizing and moisture content. The additional complexity, power consumption, operating and maintenance requirements, as well as the fire/explosion potential of handling wood fuel with low moisture content, render this approach unfavorable.

Fluidized bed combustors (FBC) are proven technology in the range up to 120 million Btu/hour. The Honey Lake project would require the use of more than one combustor. The most likely scenario is routing FBC hot exhaust gas to heat recovery boilers, which produce steam to drive a steam turbine. The system complexity and high cost of utilizing several combustors makes this alternative uncompetitive.

Gasification can be utilized to produce a low- to medium-Btu gas from the wood. The gas can be fired in a gas-fired boiler to produce steam to drive a turbine generator or can be used as fuel for a gas turbine combined cycle power plant. Gasification is in a transition stage from research to commercialization. No units of sufficient capacity to provide the gas for a 50 MW unit have been built or tested. Several modules would be required having capital, operating and maintenance costs which would be unable to compete with the base case system.

3.2 PLANT CAPACITY ANALYSIS

The size or electrical generating capacity of the power plant must be specified in order for the plant systems to be sized, analyzed, and estimated for cost. This section compares various plant sizes on an

economic basis to establish the optimum. The sizes examined are 20, 35, and 50 megawatts, with 50 MW being the maximum as specified by GeoProducts and by the availability of proven equipment for power generation using wood. Pertinent capital costs as well as associated costs for plant performance variations are derived for each plant size so that rate of return calculations can be performed. Performance costs include the effects of cycle efficiency (which are different for each plant size) and resulting variations in fuel consumed. Costs for operations and maintenance are also derived to allow total annual expenses to be predicted. Revenue for the plants, which occurs as a result of power sales, is combined with expenses to yield an annual cash flow upon which the rate of return is predicated.

The average price of fuel depends on the amount required by the plant. Greater consumption causes a higher average fuel cost, which adversely impacts annual expenses. The effect of fuel price variations is incorporated into the analysis.

Some of the more important design bases are:

- o The power generation system consists of a conventional boiler using a traveling grate stoker. Steam from the boiler goes to the turbine generator where it expands to release its energy and subsequently is condensed and returned through the feedwater heaters to the boiler.
- o Revenue from the sale of power in 1985 is 100.26 mills per Kwh.
- o Wood fuel to the plant has a 50.8% moisture content and a heating value of 4502 Btu/lb.

The internal rates of return corresponding to the 20, 35, and 50 MW plants over a 30-year life are 22.2%, 25.4%, and 28.0% respectively, indicating that the largest plant is the most cost-effective. The 50 MW plant is selected because its rate of return is the most favorable; however, there are other considerations such as environmental restraints,

shorter project schedule, and transmission options favoring smaller plants that may improve the viability of the two smaller plants. (The rates of return presented here are for comparative purposes to select the plant size and are not to be compared with rates of return shown elsewhere in the report.) The rates of return for the final selected 50 Mw plant are given in Section 3.10.

The capital costs in this section are produced for the purpose of comparing relative economics of different plant sizes and represent only approximate values. However, the cost differentials are sufficiently accurate to allow good relative values of rates of return to be developed. Given below is a summary of the costs involved in the plant capacity analysis.

TABLE ES-1
COST SUMMARY

Plant Size, Mw	20	35	50
Capital Costs, \$1,000 in 1984	49,881	71,481	88,191
Operating and Maintenance Costs, \$/year in 1985	939,000	1,127,000	1,289,000
Average Fuel Cost, \$(1980)/G.D. Ton			
1980-1989 Period	20.57	21.23	21.97
1990-Remainder of Plant Life	17.00	17.54	18.15
Internal Rate of Return over Plant Life, %	22.2	25.4	28.0

3.3 WOOD FUEL HANDLING DESIGN

The purpose of this section is to develop a conceptual design for the wood handling system that supplies an uninterrupted flow of prepared fuel to the power plant in the most effective manner. Several types of handling systems are examined and several variations of equipment arrangements analyzed to arrive at the most cost effective and operationally suitable system. The final selected wood handling system is shown in Figure ES-1.

Whole tree chips and mill residue are received through trailer dumpers and subsequently screened and hogged as required. Fuel is then stored on a first-in/first-out basis. Logs and gondola material are also received for chipping on site, screening and processing with the hogged fuel. All fuel deliveries are weighed. Fuel is reclaimed automatically from storage to meet boiler requirements and is dried before entering the boiler feed bins.

The estimated fuel demands of the 50 MW power plant are based on the preliminary combustion optimization and cycle analysis. The handling system presented in this report is based on a daily boiler demand of approximately 730 oven-dry (O.D.) tons. The system is sized for a 365-day-per-year operation to ensure availability.

Some of the more important design bases are:

- o Boiler fuel requirements are estimated at 55.3 tons per hour at 45 percent moisture content. A 10% overfeed to the boiler feed bins is required.
- o The hogged fuel receiving system is sized to receive and classify a 7 day supply of fuel in a 40 hour work week.

CONCEPTUAL DESIGN
FOR COST ESTIMATE

CONCEPTUAL FUEL HANDLING
SYSTEM DESIGN FOR
HONEY LAKE HYBRID PLANT

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FIGURE ES-1

- o The hogged fuel storage area is sized to store a 30 day supply of fuel. Fuel is rotated to ensure that no fuel is stored longer than one month.
- o A four month supply of fuel is stored as logs and gondola material.

Harvesting operations in the procurement area are highly seasonal, primarily because heavy snow in the forested areas effectively eliminates access to harvesting sites. The harvesting season normally runs from about May through November or December. The plant must have enough fuel in storage to maintain full operation for the months when no fuel is received. The plant must also have enough surplus to maintain an adequate supply during the early harvesting period while the storage area is being rebuilt. To ensure this supply, the plant must be capable of storing a five-month supply of fuel.

Resource Management Services, Inc., (RMS) in their Fuel Properties report of May 1981 determined that hogged fuel should not be stored for longer than 30 days. This recommendation is based on knowledge of fire hazards and degradation created by spontaneous heating in a hogged fuel storage pile. Based on the recommendations of RMS, a hogged fuel storage area of 30-day capacity is provided. This serves as the fuel supply during the months of active harvesting.

To provide five-month storage capacity, a four-month supply of whole logs and gondola material is required in addition to the 30-day hog fuel pile. Whole logs are the most effective way to store such a large quantity of wood for a long period of time. Large or irregular logs and gondola material which cannot be handled in the field are transported to the plant site for storage and later processing. The whole log and gondola storage area is continually built up during the harvesting season, then during the period without deliveries this fuel is chipped and processed with the hogged fuel.

The system presented is based on certain limitations of the fuel to be received. The disc screen and hammer hog are sized to handle pieces no larger than 2 feet long by 4 inches in diameter. The size of whole logs to be accepted is also limited to a minimum size of 6 inches in diameter by 6 feet long. Smaller pieces can be handled with the gondola material. The largest log which can be chipped without splitting is 52 inches in diameter. Larger logs are handled by using splitting equipment. Gondola material follows the same general size requirements.

Several storage and reclaim systems with varying degrees of automation are examined from economic and operations standpoints. The fully-automatic systems are those that stack and reclaim without the aid of the chip dozer; semi-automatic systems require chip dozers to aid in stacking and reclaiming. The economic analysis indicates that additional capital for the fully-automatic system can be justified, and since this system meets operating criteria, it is selected for use on the Honey Lake project. Since this type of system is not yet in commercial operation, an adequate demonstration of performance and costs are necessary before implementation into the final design phase.

3.4 PLANT CYCLE OPTIMIZATION

Steam produced in the boiler is discharged to the thermal cycle for the generation of electricity. Steam from the boiler expands through the turbine where a portion of the energy in the steam is absorbed for the production of electricity. Steam is exhausted from the turbine to the condenser where cooling water condenses the steam to water before its return trip through the geothermal heater, feedwater heaters, deaerator, and finally to the boiler.

Variations in the thermal cycle cause changes in the cost of the equipment and cycle efficiency resulting in changes in the amount of fuel consumed. The variations in the cycle that are analyzed to produce the

overall optimum cycle are: (1) turbine throttle (or main steam conditions) and (2) number and arrangement of the regenerative feedwater heaters. The analysis of main steam conditions considers turbine size (bucket length) and reheat and non-reheat variations.

The thermal cycle alternate selected as the optimum delivers the required electrical generation over its operating life at the highest internal rate of return. The rate of return is developed for each of the cycle configurations examined and includes the effects of initial capital cost, fuel cost, and cost for operations and maintenance.

The turbine throttle conditions examined include the following:

Throttle Temp., °F	950	950	950	950	950	900
Throttle Pressure, psig	1800	1450	1800	1450	1250	850
Reheat Temp., °F	950	950	N/A	N/A	N/A	N/A

The cycle selected has 950°F, 1450 psig throttle conditions and no reheat.

As feedwater returns from the condenser to the boiler, it travels through heaters supplied with turbine extraction steam for heating the feedwater. Geothermal water is also supplied to a heater for feedwater heating.

Variations in the feedwater heater arrangement and location of the geothermal feedwater heater are analyzed to determine the number of high- and low-pressure heaters as well as justification for the geothermal heater. The final arrangement selected is shown in Figure ES-2. Economic justification for a geothermal heater is analyzed at geothermal temperatures of 225°F, 275°F, and 340°F. At 225°F geothermal water, no geothermal feedwater heater can be economically justified and the geothermal heater is replaced by two extraction heaters.

3-10

W- LBS/HR
F- TEMPERATURE, °F
H- ENTHALPY, BTU/LB
P- PRESSURE, PSIA

TURBINE HEAT RATE = 8529 BTU/KWH

HEAT BALANCE DIAGRAM
950 F/1450 P @ THROTTLE NONREHEAT
MAXIMUM GUARANTEED LOAD
HONEY LAKE HYBRID PLANT PROJECT

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FIGURE ES-2
CASE 4

OPTIMUM CYCLE CONFIGURATION

3.5 WOOD FUEL DRYING

The moisture content of wood fuel usually affects the design of the boiler more than any other property. Reduction of fuel moisture content results in a significant increase in boiler efficiency and a decrease in capital cost of the boiler and its auxiliaries. Drying wood fuel also reduces boiler particulate emissions.

The objective of this task is to develop the conceptual design for a wood-fuel drying system and then to determine the amount of drying that can be economically justified. Geothermal hot water is used as the heat source for drying.

Several types of dryers are examined to determine the most suitable system for this application. The three basic types manufactured in the United States are: rotary dryers, tower dryers, and conveyor dryers. A cascade dryer of Swedish design is also considered.

In the comparative analysis of the different types of dryers, common problems related to drying wood wastes are assessed. These include pollution problems from dryer exhaust, increased fines, increased fire and explosion hazards, and high operation and maintenance costs. The rotary dryer best minimizes these common problems.

Capital costs for a typical case are examined for the three types of dryers manufactured in the United States. Tower dryers are estimated to require 2-3 times as much capital expenditure as conveyor or rotary dryers. For the typical case, conveyor and rotary dryers require approximately the same capital. Therefore, the rotary dryer is chosen over the conveyor design for technical reasons. The Table ES-2 shows a comparison of dryer costs.

TABLE ES-2
 DRYER COST SUMMARY
 (1981 DOLLARS)

<u>COST ITEM</u>	<u>ROTARY DRYER</u>	<u>CONVEYOR DRYER</u>
Scope	3-14 ft. diameter dryers cyclone collectors drive motor fans and motors ducting within system installation	7 conveyor units 5 ft x 40 ft each dust collection equipment fans and motors ducting within system installation
Capital costs	\$1,950,000	\$1,890,000
Power required	975 Hp	1750 Hp

Air is heated in a shell-and-tube or plate-type heat exchanger which uses geothermal hot water as the heat source. The temperature of the geothermal resource is estimated to be between 225°F and 340°F. Heated air from the heat exchanger is admitted directly into the dryer.

Wood chips are admitted to the rotary dryer at an average of 50.8% moisture content and are conveyed pneumatically through the dryer. The wetter particles have a longer retention time in the dryer due to their higher density. This allows fairly good control of the degree of drying and uniformity of the product moisture content. Exhaust air from the dryer is passed through cyclone separators for recovery of fines. These fines are suitable for suspension firing in the boiler. A schematic of the rotary dryer system is shown in Figure ES-3.

FIGURE ES-3
ROTARY DRYER

Following selection of the type of dryer, an analysis is performed to determine the extent to which the wood can be economically dried. Three geothermal temperatures are examined: 225°, 275°, and 340°F. To find the optimum fuel moisture at each temperature, drying from the delivered moisture content of 50.8 percent to 45, 30, and 15 percent moisture is analyzed. The additional capital expenditure associated with drying the fuel is calculated for each case. Fuel savings are also calculated. Using the capital costs, annual operation and maintenance costs along with the annual fuel savings, a rate of return analysis is performed for each case. This analysis shows that by using 275° or 340°F geothermal water, drying to 45% moisture is the economic optimum. If the geothermal water temperature is only 225°F, no drying is economically feasible. Figure ES-4 shows the amount of fuel saved as a result of wood drying.

Another design option, flue gas drying is also analyzed. Because of the uncertainties involved, it has not been incorporated in the plant design. During the final design phase of the project a detailed investigation of using flue gases for drying may be warranted.

FIGURE ES-4
FUEL SAVINGS
FROM GEOTHERMAL DRYING

3.6 EMISSION CONTROLS AND WATER TREATMENT

Emissions from the Honey Lake Plant include pollutants in the flue gases and waste water from various sources. The purpose of this task is to define plant emissions and respective sources and to specify control systems to meet all federal, state, and local environmental requirements. The Identification of Environmental Issues report by Gennis and Associates was reviewed and is used as a basis for control system designs.

Combustion products of wood fuel are examined to determine potential air pollutants in the flue gases. Gaseous emissions from the hogged fuel boiler are minimal. Sulfur and nitrogen oxides and carbon monoxide emissions are within environmental guidelines and require no control. However, particulates entrained in the flue gases are substantial. Particulates include unburned carbon and hydrocarbons, unburned wood particles, and sand or dirt carried into the boiler with the fuel.

Three methods of particulate control are evaluated -- electrostatic precipitators (ESP), baghouses, and wet scrubbers. These methods are generally considered to be capable of controlling particulates to within the guidelines specified by governmental agencies. In each of these methods a multiple cyclone collector precedes the secondary cleanup equipment. Technical and economic factors are considered in the evaluation. An electrostatic precipitator is recommended for this plant. Although the capital costs for this option are slightly higher than for the other two, operating costs show the additional capital expenditure to yield an acceptable rate of return. Other factors contributing to selection of the ESP are that the baghouse is prone to fire hazards when used with a wood boiler and the wet scrubber has high operating costs. A cost summary in 1981 dollars is given in Table ES-3 for each of the alternative air correction systems. Figure ES-5 is a schematic of the electrostatic precipitator system.

FIGURE ES-5
ALTERNATE 1
EMISSIONS CONTROL-ELECTROSTATIC PRECIPITATOR

Water effluent from the plant includes geothermal fluid, sanitary waste, runoff from paved areas and the fuel piles, blowdown from plant systems, and chemical waste. Several disposal methods for the waste water are reviewed. Environmental concerns due to the high ground water level in the area coupled with good evaporation potential leads to selection of a lined evaporation pond for waste water disposal. It is assumed that used geothermal fluid not required for plant makeup is reinjected; however other methods of surface disposal may be suitable such as irrigation water or otherwise.

The particulate emissions target is 0.02 grains per dry standard cubic foot leaving the stack. The mechanical collector efficiency is assumed to be 70 percent, requiring 98.6 percent efficiency in the secondary collector.

TABLE ES-3
AIR CORRECTION SYSTEMS - SUMMARY
(1981 DOLLARS)

<u>Alternative</u>	<u>CAPITAL COST</u> <u>\$1,000</u>	<u>ANNUAL O&M</u> <u>\$1,000</u>	<u>POWER</u> <u>(KW)</u>	<u>RATE OF</u> <u>RETURN</u>
Electrostatic Precipitator	2,886	87	766	20%
Baghouse	2,878	124	698	*
Wet Scrubber	2,385	73	1662	Base

*No rate of return is computed for the baghouse because of the possible fire hazard involved coupled with no decided economic advantage.

3.7 ASH HANDLING AND PLANT COOLING SYSTEM

The various types of ash handling systems as well as alternate condenser cooling systems are analyzed and selected based on economics and operation. Boiler ash from the bottom ash, siftings and air hoppers, and fly ash collected by the air correction equipment must be collected for offsite disposal or sale. This analysis examines alternate methods of ash handling and determines the most appropriate system for the Honey Lake project. Both technical and economic factors are considered in the analysis.

Three basic types of ash systems are available -- fully wet systems, dry or pneumatic systems, and damp mechanical systems. Many variations and combinations of these were considered before the five alternates presented in this report were chosen for detailed analysis. These five alternates are:

1. Hydraulic system to an ash disposal pond
2. Hydraulic system to dewatering bins
3. Pneumatic system to a dry storage silo
4. Mechanical drag system to dumpsters
5. Combination mechanical bottom ash and hydraulic fly ash

Common problems associated with handling ash from wood-fired boilers include fire and explosion hazards, dusting problems, and dewatering of ash. Examination of these problems in conjunction with the relative system costs indicates that Alternative 4 (see Figure ES-6), the damp mechanical drag collection system discharging to dumpsters, is the most viable design for this project. Alternates 1 and 5 are not considered for detailed analysis because of inherent operational problems. A cost summary of alternates 2, 3 and 4 is given in Table ES-4

FIGURE ES-6
ALTERNATE 4
MECHANICAL DRAG SYSTEM
TO DUMPSTER DISPOSAL

TABLE ES-4
ASH HANDLING COST SUMMARY
(1981 DOLLARS)

	<u>CAPITAL COSTS</u>	<u>ANNUAL O&M COSTS</u>	<u>ANNUAL POWER REQ'MTS KWH</u>
Alternate 2 - Hydraulic System to Dewatering Bins	\$1,871,900	\$ 56,200	374,162
Alternate 3 - Pneumatic System to a Dry Storage Silo	1,260,000	148,000	1,411,740
Alternate 4 - Mechanical Drag System to Dumpsters	1,545,000	61,800	193,596

Although dump mechanical drag ash handling systems have been used in Europe in the past, the concept has just recently been introduced in the United States. Bottom ash is collected in a dry bottom ash hopper and released onto a submerged mechanical drag conveyor. Ash travels up an incline and drops onto a collection conveyor. All other ash hoppers empty continuously onto their respective dry drag conveyors. These conveyors all transfer ash to a common collection conveyor which subsequently transports the ash to dumpsters for removal from the site.

The type of plant cooling system to serve the power plant main condenser and auxiliary coolers must be selected. The purpose of this task is to compare three alternative plant cooling systems on an economic basis to establish the optimum system and to include an applicable cost estimate. The alternative cooling systems examined are: (1) the conventional induced-draft mechanical cooling tower; (2) a spray pond system; and (3) spray pond with a deep water sump to provide thermal storage cooling capability. Relative capital costs and operating costs for each type of cooling system are estimated and summarized on equalized bases to provide an objective comparison of alternatives.

The cooling tower is a conventional mechanical-draft tower consisting of a two-cell structure mounted on a concrete basin and having two exhaust fans on top of the tower to create an induced air flow. Condenser cooling water is cooled by direct contact with the induced ambient air.

The cooling ponds consist of diked ponds having a liner to prevent seepage to the ground. The water is cooled by being sprayed into the air using spray nozzles located in the pond. The spray pond with thermal storage has a deep water reservoir for storing water cooled during the night for use during the day.

Results of the operational and economic analysis indicate that a pond without storage is the selection for Honey Lake cooling. Figure ES-7 shows a schematic of the pond system. Outlined below in Table ES-5 is a summary of the cooling system costs.

TABLE ES-5
COOLING SYSTEM COST SUMMARY

	<u>COOLING TOWER</u>	<u>SPRAY POND W/O STORAGE</u>	<u>SPRAY POND WITH STORAGE</u>
Differential Turbine Generation, KW	Base	Base	Base
Differential Auxiliary Power, hp	+4 hp	Base	Base
Present Day Capital Costs, \$	587,200	563,000	724,000
Indirects, Escalation (60% of P.D. Costs), \$	<u>352,200</u>	<u>337,800</u>	<u>434,400</u>
Total Capital Costs \$	939,500	900,800	1,158,400
Present Day Operating & Maint. Costs, \$/yr	14,700	14,100	18,100

FIGURE ES-7

SPRAY POND CIRCULATING WATER SYSTEM

3.8 WOOD-GEOTHERMAL ENERGY BUDGET AND CONTRIBUTION

The integration of moderate temperature geothermal heat into a power plant electrical generation processs can cause substantial reductions in the plant fuel consumed. Basically, heat that is normally supplied from plant fuel is augmented with geothermal heat to cause an improvement in power produced in relation to fuel consumed.

The purpose of this section is to investigate the implementation of geothermal heat into a 50 MW wood-fired plant by developing the relative improvements in plant performance and fuel saved. This section emphasizes the thermal effects of geothermal energy utilization. The economics of geothermal utilization are discussed in previous sections and results from these sections are considered in the final combination of geothermal heat usages.

Integration of geothermal heat into the power plant is analyzed for the following applications: (1) feedwater heating, (2) combustion air heating, and (3) wood drying. Geothermal heat used for feedwater heating reduces the amount of steam that must be extracted from the turbine, thereby reducing fuel consumption.

Using geothermal heat for heating boiler combustion air causes air at an elevated temperature to enter the boiler, which saves fuel normally required to heat the air. Geothermal heat for wood drying reduces the moisture content of the wood by evaporating and discharging the moisture before the wood enters the boiler. Boiler efficiency is improved and fuel consumption reduced. Plant performance and fuel consumption are predicted for each of the above alternates for three variations in geothermal water temperature. The alternates are then combined for each geothermal temperature and the associated results analyzed.

The results of the analyses indicate that heating feedwater using geothermal water at 340°F saves up to 7 percent of the fuel required when no geothermal heat is utilized. Similarly, about 8 percent fuel savings is realized when boiler combustion air is preheated with geothermal heat. Geothermal heat can be used to dry the wood fuel to practically any degree of moisture content desired, regardless of geothermal water temperature. Using 340°F water to dry the wood to 45 percent moisture causes a corresponding 5 percent savings in wood. If all three methods of incorporating geothermal heat into the plant are utilized, a total fuel savings of about 19 percent is produced.

Overall plant performance based on theoretical as well as practical applications of geothermal heat are analyzed. Figure ES-8 shows the variation in fuel saved and percent of the total heat supplied to the plant that is geothermal heat. This figure includes all forms of geothermal heat uses at each temperature and therefore shows the theoretical impact of geothermal heat, whereas Table ES-6 shows the impact of geothermal heat from economically feasible geothermal applications. It is noted that at 225°F geothermal water, no feedwater heating or wood drying is justified.

TABLE ES-6
PERFORMANCE GAINS FROM ECONOMICALLY FEASIBLE
GEOTHERMAL APPLICATIONS

Geothermal Temp., °F	225	275	340
Feedwater Heating	No	Yes	Yes
Combustion Air Heating	Yes	Yes	Yes
Wood Fuel Drying	No	Yes	Yes
Fuel Saved, Wet Ton/Yr	22,997	76,917	101,973
% Fuel Saved	4.3	14.3	19.0

FIGURE ES-8
PERFORMANCE GAIN FROM
COMBINED GEOTHERMAL PROJECT

The electrical power production associated with the utilization of geothermal heat is based on the conceptual design as specified in previous sections. In addition, a procedure is derived for predicting the amount of electrical generation attributed to geothermal heat in a constructed power plant. The actual relationship between geothermal heat supplied to a plant and corresponding increase in power generation can only be determined after the actual equipment performance data is specified. The theoretical relationship between the geothermal heat input to the plant and the resulting power generation is shown in Figure ES-9.

FIGURE ES-9

POWER PRODUCTION ATTRIBUTABLE TO GEOTHERMAL HEAT

3.9 GEOHERMAL WELL SYSTEM AND PLANT OPERATING REQUIREMENTS

The geothermal resource at Honey Lake is part of the Wendel-Amedee geothermal reservoir system. Geotechnical specialists have predicted that the Honey Lake wells to be developed will have hydrothermal fluids ranging in temperature from 250°F to 491°F. The hybrid power plant design is based on a compromise hydrothermal fluid temperature at the plant of 275°F. Alternative fluid temperatures are also evaluated for a minimum of 225°F and a maximum of 340°F. The hydrothermal fluid is pumped from the production wells and delivered under pressure through insulated pipelines and connected to heat exchangers for preheating boiler feedwater, combustion air, and air to pre-dry the boiler wood fuel. The hydrothermal fluid is under sufficient pressure throughout its travel to preclude flashing of liquid to vapor within the system. Used geothermal fluid returns through an uninsulated pipeline to the injection well. Because of their proximity to roads and mobile wood handling equipment, geothermal pipelines are buried as a protective measure. Capital cost estimates are prepared for this geothermal gathering and injection system and range from \$1.5-million for a single-well system to \$3.4-million for a three-well system.

The staff required to operate and maintain the Honey Lake Power Plant is based on the plant operating philosophy and a review of existing facilities with similar equipment and capacity. Adjustments are made to the staff to cover variations resulting from the geothermal equipment.

A plant organization chart is presented in Figure ES-10 which defines the projected plant staff including both operations and maintenance personnel. Brief descriptions of the scope of responsibility as well as a typical salary for each position on the chart are included in the main body of the report.

PLANT ORGANIZATION CHART HONEY LAKE HYBRID POWER PLANT

() NUMBER IN PARENTHESIS INDICATES THE NUMBER OF PEOPLE REQUIRED.

* ROTATING SHIFT WORKERS.

** MAY NOT REQUIRE FULL-TIME PERSON.

FIGURE ES-10

3.10 ECONOMIC ANALYSIS AND SENSITIVITY

The conceptual design presented in the previous sections is used as the basis for developing costs associated with the Honey Lake plant investment. The estimates prepared represent costs for the final selected 50 MW power plant and cover costs for the geothermal well system, power plant, land, permitting, wood inventory, and indirects. Annual costs for operation, maintenance, and equipment replacement are developed for input to the financial analysis. Using these cost estimates and costs for fuel and geothermal heat, annual electrical production costs and rate of return are developed for the proposed plant. A sensitivity analysis is performed to establish the relationship between plant costs and geothermal temperatures, and between plant costs and interest rates.

The plant design at the 275°F geothermal temperature is taken as the base case upon which the detailed estimates are performed. To support development of the plant cost estimates, a detailed equipment list is prepared in addition to drawings including fundamental piping and instrument diagrams, general arrangement drawings, electrical one-line diagram, and a site plan. These can be found in the Appendix, Volume II.

The estimated capital costs for the power plant in 1981 dollars are \$72,067,000, \$73,203,000, and \$72,611,000 corresponding to 225°F, 275°F and 340°F geothermal temperatures. To determine the actual capital required to finance the project, these costs are escalated at 9% per year over the three year design and construction period of the project. The total escalated investment costs of the power plants at the date of commercial operation (January 1, 1985) are estimated to be \$86,220,000, \$87,544,000, and \$86,823,000 corresponding to the 225°F, 275°F, and 340°F temperature at 11% interest. These costs do not include interest during construction. Considering a plant generation rating (gross) of 50,000 KW, this results in a total installed cost of about 1750 dollars per KW.

The rates of return corresponding to these cases assuming 100 percent equity financing are 22.4%, 22.2% and 22.5% corresponding to the three geothermal temperatures.

The financial analysis and cost estimate conducted on the wood-fired power plant is predicated upon the following bases:

- o A detailed cost estimate is prepared for the 275°F case and adjustments are made to this estimate to arrive at investments corresponding to the 225°F and 340°F cases.
- o The plant design begins in January of 1982 and commercial operation is set at January 1985. Plant operating life is 30 years.
- o Cost estimates are based on systems and conceptual designs as selected and specified in the previous sections of this report.
- o A wood supply equal to five months of fuel use is included in the initial investment cost for the power plant. Sales taxes and tax credits are applied as required.
- o Twenty-five percent of the capital costs are provided by equity from owners. Seventy-five percent of the capital costs are provided by long-term debt.
- o The plant is assumed to operate at an 85% capacity factor, i.e., gross generation is 50 MW for 7446 hrs/yr.
- o Financing during the construction and production period is calculated at interest rates of 8%, 11%, and 14%.
- o The rate for power sold is 100.26 mills per KWh in 1985. The mill rate escalates at 9% per year commencing in 1986.
- o The rate for geothermal heat expense is 10 mills per KW/hr in 1985. The rate escalates at 9% per year commencing in 1986.

- o Insurance, property taxes, and plant depreciation are incorporated into the financial analysis.

To determine the sensitivity of the analysis to geothermal temperature, plant costs corresponding to each temperature are developed. Table ES-7 shows the plant investment for each temperature as well as the basis for determining wood cost, geothermal heat, operating and maintenance costs, and revenue from power sold.

TABLE ES-7
COST AND OPERATING SENSITIVITY

Geothermal Temp, °F.	225	275	340
<u>Costs, \$1,000</u>			
Direct Investment			
Power Plant	44,164	44,243	43,909
Mobile Equipment	705	705	705
Subtotal	44,869	44,948	44,614
Geothermal Well System	1,528	2,461	2,461
Construction Gen. Exp.,			
Overhead, Fee	8,230	8,409	8,350
Land	80	80	80
Total Direct	54,707	55,898	55,505
Misc. Investment			
Wood Inventory	2,900	2,596	2,456
Sales Tax	1,670	1,706	1,694
Environ. Permitting	637	637	637
Engineering & Fee	5,165	5,231	5,231
General & Administrative	3,073	3,138	3,117
Contingency	3,915	3,997	3,971
Total Misc.	17,360	17,305	17,106
Total Investment	72,067	73,203	72,611
<u>Plant Operations</u>			
Operating & Maint., \$1000	1,377	1,407	1,397
Wood Fuel Required, ODT/YR	253,000	226,500	214,200
Power from Geothermal Heat			
KW	2,016	6,546	8,909
Gigawatts Hrs/Yr	15.0111	48.7415	66.3364
Net Power Sold			
KW	45,825	45,540	45,658
Gigawatts Hrs/Yr	341.2129	339.0908	339.9695

Table ES-8 shows the rates of return corresponding to geothermal temperatures at each of the three interest rates. Rates of return are computed based on the equity portion only as well as for the assumption of 100 percent equity financing.

TABLE ES-8
RATES OF RETURN

Geothermal Temp, °F.	225	275	340
Rate of Return on Equity Portion* (Financial)			
8% interest	42.8	42.3	43.5
11% interest	39.3	38.8	39.9
14% interest	35.8	35.3	36.3
Rate of Return Assuming 100% equity (Internal)	22.4	22.2	22.5

*Debt/Equity Ratio is 75%/25%

Computation of the financial rate of return assumes that the plant is financed by 75% debt and 25% equity and is based on the equity portion only of the financing. The internal rate of return assumes that the plant is financed by 100% equity and no debt financing is involved. The net cash flow corresponding to the respective methods of financing is used to compute the financial and internal rates of return. The rates of return represent the discount rate at which the percent worth of the negative cash flows equals the percent worth of the positive cash flows. In other words, the rate of return (financial or internal) is the interest rate at which the summation of the present worths of all yearly net cash flows is zero.

It is noted from Table ES-8 that an apparent inconsistency occurs since the rate of return at 225°F is higher than at 275°F. This occurs primarily because a geothermal feedwater heater was employed in the 275°F plant whereas the economics as presented in this report do not justify it. The heater was used however, because the 275°F temperature was designated as the base case and it was desirable to show all aspects of geothermal heat used in this case and because the analysis during final design will probably show more favorable economics for the heater when the heater performance is optimized. It is apparent from the table that the rate of return improves with an increase in geothermal temperature.

From Table ES-8 it is noted that the rate of return improves only marginally with increasing geothermal temperatures. Although substantial quantities of wood are saved in going from lower to higher geothermal temperatures, this is partially offset by the increasing cost associated with using more geothermal heat. This cost is 10 mills/KWh in 1985. Additionally, the quantities of investment for the entire plant are quite large and, consequently from the standpoint of rate of return, denigrate the positive impacts of geothermal heat.

Shown in Table ES-9 are expenses, depreciation and loan principal payments in the year 1985 (first year of commercial operation) for a plant designed for 275°F geothermal water. The interest rate is 11%.

TABLE ES-9
EXPENSES

EXPENSES	Mills/KWH
Operating and Maintenance	5.9
Wood Fuel Expense	22.7
Interest	24.7
Geothermal Heat	1.4
Equipment Maintenance	0
Insurance	.5
Property Tax	2.6
Total Expenses	57.8
Depreciation	22.4
Loan Principal	11.2

SECTION 4

PROJECT SCHEDULE

The project schedule provided herein outlines the manner in which an engineer constructor performs engineering, procurement and construction activities for the project. The schedule is arranged to show critical activities in project management, engineering, procurement, and construction of the plant to clarify the relationship between these functions.

At project inception, the project manual, project schedule, technical outline, and design criteria are developed. After completion in the third month, they are the guide for all future work on the project.

In the second month, work on mechanical studies and optimizations, plant general arrangements, and turbine and boiler specifications begin. Subsequently, engineering work to support material and equipment procurement is emphasized. Structural design and the preparation of construction drawings is started in the fifth or sixth month but cannot be completed until vendor drawings for the major equipment have been received. The relationship between vendor drawings and detailed engineering is frequently more important than delivery dates.

If the geothermal wells have not been completed at project inception, they should be completed in the first three months to support final equipment sizing. Site work (construction) begins in the tenth month and continues to completion by the thirty-sixth month. Construction testing begins in the twenty-sixth month.

The overlap between engineering, procurement, and construction and between construction and start-up is common in the power industry. The overall schedule of thirty-six months is aggressive and can be achieved only through a phased or overlapping engineering, procurement, and construction program.