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DATE PUBLISHED — DECEMBER 1975

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IDAHO NATIONAL ENGINEERING LABORATORY

CONCEPTUAL DESIGN AND COST EVALUATION
OF ORGANIC RANKINE CYCLE ELECTRIC
GENERATING PLANT POWERED BY MEDIUM
TEMPERATURE GEOTHERMAL WATER

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Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161
Price: Printed Copy \$6.00; Microfiche \$2.25

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CONCEPTUAL DESIGN AND COST
EVALUATION OF ORGANIC RANKINE
CYCLE ELECTRIC GENERATING
PLANT POWERED BY MEDIUM
TEMPERATURE GEOTHERMAL WATER

R. H. Dart
D. T. Neill
J. F. Whitbeck

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PREFACE

The potential for geothermal energy in making a sizable contribution toward supplying the nation's electrical energy lies largely in the more abundant medium temperature reservoirs. To date, commercial geothermal power plants are being planned only for reservoirs above 350°F. Yet these high temperature reservoirs are definitely limited in number and quantity. The lower the industry aims the desired temperature limit, the larger the geothermal resource becomes. One needs only to consider that the largest quantities of ground water (as a quantity per unit of temperature) occur in the 50° to 70°F range, and a smooth natural distribution to much lower quantities of water occurs as higher temperatures are considered.

To harness the medium temperature resources in the range of 300°F, an efficient power cycle is needed, probably adopting principles different from those traditional in the nuclear and coal power plant industries. The most commonly discussed power cycle for such applications is the binary organic cycle in which the geothermal fluid heat is transferred to a more appropriate organic working fluid such as freon or isobutane.

This document discusses the design and cost results of the most efficient technically and economically practical binary cycle envisioned to date for the 300 °F resource. This result is compared in cost to the conventional methods of producing electricity. The document then proceeds to discuss methods by which the costs might be further reduced, using techniques that take special advantage of the peculiarities of the low pressure, medium temperature resource. However, most of these advanced techniques have as yet unproven technical and/or economic feasibility, and hence their effects on costs is not extrapolated in this document.

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Engineering Laboratory

It needs to be stressed that the results in this document are for reference purposes, and should not be construed as establishing the economic potential of medium temperature geothermal energy (except in the very present context, using established present-day technology). What the reader should conclude is that the potential for improvement in the economics of the binary cycle is great, offering future economic feasibility not just for 300°F resources, but for lower temperatures as well. The achievement of such lower costs for these resources is the goal of the Idaho National Engineering Laboratory Geothermal Program, a goal which can only be achieved with the co-operation and assistance of the industries who will subsequently manufacture, build, and operate these power plants. This document is intended to serve as a guide to those areas where the most promise and benefit for cost reductions could be achieved through research, development and demonstration.

J.F. Kunze, Manager
Advanced Programs and Geothermal Projects
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ABSTRACT

The economic production of electrical power from high temperature steam and liquid dominated geothermal resources has been demonstrated. Large quantities of geothermal energy are considered to exist at moderate temperatures, however, the economics of converting this energy into electricity has not been established. This paper presents the design concept of a dual boiler isobutane cycle selected for use with the moderate temperature hydrothermal resource and presents a cost estimate for a 10 and 50 MW power plant. Cost of electrical power from these plants is estimated and compared with that from coal, oil and nuclear plants, the impact of selling a portion of the residual heat in the geothermal effluent is assessed.

SUMMARY

The generation of electrical power from a moderate temperature heat source (about 300°F) is a very non-conventional method of producing electrical power. It is even less conventional when this source of heat is a geothermal liquid. However, a vast supply of energy apparently exists in moderate temperature hydrothermal resources and thus an appraisal of the cost of electricity that can be produced from this resource is needed. The approach of this study was to estimate the cost of power based upon using reasonably conventional equipment and technology, recognizing that further refinements, advances in technology and experience would result in lower costs.

The energy conversion system considered in this cost evaluation uses isobutane to drive the turbine generators. Two similar but different size plants were considered. A 10MW(net) and a 50MW(net) plant. The capital costs of the energy conversion systems for these plants were \$1066/kW for a 10MW system and \$640/kW for a 50MW system. The cost of the energy supply and disposal system was essentially constant at \$540/kW and resulted primarily from well costs. The above costs are in 1975 dollars without contingency and reservoir discovery and analysis costs. Reduction in energy supply and disposal system costs are possible with a better understanding of well performance optimization and development of flow enhancement techniques. Energy supply and disposal system costs in the order of \$375/kW may be possible through a combination of favorable developments. Energy conversion system costs can also be reduced as a result of the application of new technology such as the use of direct contact heat exchangers and organic mixtures as a working fluid, and further optimizations such as increased heat rejection efficiency by taking advantage of daily temperature variations, cool surface water aquifers, etc.

The chart below contains the electrical power costs derived from the power plant cost estimates. For comparison are estimates of the cost of fossil and nuclear produced power. An attempt was made to place all costs

on the same basis (1975 dollars) to obtain a relative position for the geothermal produced power. This chart shows that geothermal energy powering a 50 MW plant, by rather conventional technology could produce electricity for about the same price as that from oil but somewhat higher than from coal or nuclear. The potential improvements that can be derived through further engineering development promises to lower the cost of power to the point

where it would be competitive with coal. It is expected that through these developments, the cost of power from these geothermal systems could be reduced to the level of point A shown on the chart. Note also, that the chart assumes present fuel costs for oil, coal, and nuclear.

A characteristic of geothermal power production is that a large quantity of residual heat is contained in the liquid after energy is extracted for power production. This residual energy is marketable to many processes and will appear increasingly attractive as fossil fuel costs increase. When the residual heat is sold, the income can then be prorated against the cost of the energy supply system which may result in a decrease in electrical power cost. Obviously, any income derived from the residual energy of the most efficient electrical plant would be to an advantage, however, it is not evident that a significant advantage exists if the electrical plant effectiveness is decreased to provide more residual energy. Calculations made to determine the impact of selling the residual heat above 130°F show that at prices above about 6¢ per therm (10^5 Btu) the cost of producing electrical power is reduced. The implementation of such an

integrated system would apply particularly to the smaller geothermal power plant (about 10 MW) since it may be difficult to find users for all the residual geothermal heat* of a significantly larger plant. (Note, current wholesale natural gas costs range from 7¢ to 16¢ per therm.)

It is recognized that 300°F represents only an arbitrary design point (which does correspond to the reservoir temperature of the ERDA developmental program in Raft River). Section 4.2 of this report discusses the expected variation in power costs for higher or lower temperatures. At the present temperatures of commercially competitive geothermal power plants (~400°F), power costs in the range of 10 to 15 mills/kW-hr are usually quoted, definitely competitive with nuclear power.

In summary, it has been shown that the use of moderate temperature geothermal energy for electric power production by conventional heat exchangers and turbine drive is marginal at this time compared with most fossil fuels, however, further engineering and the application of technology presently being developed offers the potential of competitive power. Actual operating experience is necessary to verify the potential of 300°F geothermal fluid and if done, vastly increases the total energy available for power production from geothermal energy.

* The use of residual geothermal heat instead of residual condenser heat is a significant distinction between geothermal power plant waste heat usage and that from coal or nuclear plants. The geothermal heat at 130° to 200°F or above from the heat exchanger or flasher discharge represents an inexpensive form of thermal energy by as much as a factor of three compared to gas-fired high temperature steam. The condenser discharge from coal, nuclear, or geothermal plants have similar temperatures, in the range of 100°F. This heat is considered nominally of little practical use, except for nearby space heating.

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1.0 INTRODUCTION

Geothermal fluids are a viable energy resource for the generation of electrical power at fluid enthalpies of 400-1100 Btu/#. The higher value corresponds to a pure steam supply as available at the Geysers in Northern California and Lardarello in Italy. Lower enthalpy (liquid dominated) systems in New Zealand, Mexico and San Salvador are presently being used to produce competitive electric power. However, in terms of total energy it is likely that the vast majority of the geothermal energy is available at lower enthalpies. This lower grade energy appears to have only marginal promise for producing economic electric power.

This paper reports the results of system design studies and cost estimates related to the use of a moderate temperature (280-320°F) liquid dominated geothermal resource to produce electric power by conventional methods. The principle systems evaluated in this report utilizes a dual boiling isobutane cycle. Costs are given for 10 MW and a 50 MW plants. The costs are also representative of a single boiler plant with about 10-15 percent less output. The cost values are used to determine how the cost of a moderate temperature plant would scale as a function of power and to determine the economic impact of selling residual heat from the plant.

The systems and cost estimates presented have been grouped in a way similar to that outlined in the Uniform System of Accounts by the Federal Power Commission. Further information and techniques were taken from the 1970 National Power Survey and the 1972 Supplement of the Power Survey both publications by the Federal Power Commission.

2.0 ENERGY CONVERSION SYSTEM

In the following sections a dual boiling binary system of 10 and 50 MW are described and potential variations which might result in cost reduction are discussed. The energy supply system consisting of both the production and disposal facilities, is discussed in a subsequent section.

2.1 Energy Conversion System Description

The boiling process (rather than a supercritical cycle) was selected because: 1) fluids which would provide a supercritical process for the moderate temperature application generally resulted in high working pressures and resulting higher costs for both the boilers and condensers and required a large amount of pump work, 2) a plant based upon a supercritical condition would be drastically affected with a degradation in geothermal fluid temperature and 3) the dual boiling cycle minimized the heat exchanger pinch point problems and resulted cycle performance approached or exceeded the performance of supercritical systems considered⁽¹⁾.

Fluid selection and cycle state point evaluations⁽¹⁾⁽²⁾ have resulted in selecting isobutane as the working fluid for the dual boiling power cycle, when used with a moderate (300°F) temperature geothermal source.

The thermodynamic cycle is a conventional Rankine cycle. Energy is transferred from a geothermal heat source to the working fluid, isobutane. The isobutane is preheated, vaporized, expanded through a turbine, and then condensed. The dual boiling cycle implies that the isobutane is preheated and vaporized at two different pressures and temperatures. Power cycle evaluations have shown the optimum vaporization temperatures to be 230 and 160°F with a flow split of 70% to the high temperature and 30% to the lower temperature boilers when the geothermal fluid is initially at 300°F⁽³⁾.

The energy conversion system is presented schematically on Figure 1. Liquid isobutane is pumped from the condenser-hotwell by either a turbine or electrically driven feed pump through low pressure (LP)-preheater #2 where it

is heated to approximate vaporization temperature (160°F) of LP-boiler No. 2. Downstream of LP-preheater No. 2 a flow split occurs with a portion (30%) of the isobutane directed to LP-boiler No. 2, where it is vaporized. The remaining isobutane (70%) enters the high pressure HP-preheater No. 1 where it is heated to the approximate vaporization temperature (230°F) of HP-boiler No. 1. The isobutane from HP-preheater No. 1 enters HP-boiler No. 1 where it is vaporized and directed to the high pressure turbine. The geothermal fluid enters the system at HP-boiler No. 1, then passes to HP-preheater No. 1, LP-boiler No. 2 and lastly LP-preheater No. 2. The temperature of the geothermal fluid is successively lowered while passing through each of the heat exchangers.

The isobutane vapor from each of the two boilers is directed to the respective turbines where it is expanded. The lower pressure isobutane turbine could be used to drive a feed pump with minor adjustments of the flow split, however, for analysis purposes it was assumed that all power produced would be converted to electricity. The isobutane from the turbines exhausts enters the condensers where it is condensed with conventional cooling tower water. From there the cycle starts over again. The temperature, pressure, and enthalpy of the process points shown on Figure 1 are given in Table I for utilization of a 300°F geothermal supply.

Details of the dual boiling energy conversion system design basis and a detail description of the design upon which plant cost estimates were made are provided in Appendix A. Plant layouts and schematic diagrams are provided in Appendix B.

The components selected for the system are state of the art design. The heat exchangers are conventional shell and tube exchangers. The boilers are kettle type vaporizers. The turbines are single stage radial inflow designs. The cooling tower is a conventional crossflow wet cooling tower. All major components (heat exchangers, turbines, cooling tower, and pumps) were sized by the manufacturers based upon conditions established by system performance analysis.

Figure #1 DUAL BOILER GEOTHERMAL POWER PLANT

TABLE I
SYSTEM DESIGN THERMODYNAMIC STATE POINTS FOR
FIGURE 1

Point No.	Fluid	Phase	Temperature (°F)	Pressure (psia)	Enthalpy (Btu/lbm)
1	Isobutane	Liquid	105	396	-780.
2	Isobutane	Liquid	160	368	-744.1
3	Isobutane	Liquid	230	354	-691.2
4	Isobutane	Vapor	230	347	-615.6
5	Isobutane	Vapor	128	80	-637.9
6	Isobutane	Vapor	120	80	-639.41
7	Isobutane	Liquid	101	77	-780.77
8	Isobutane	Liquid	160	169	-744.1
9	Isobutane	Vapor	160	162	-631.8
10	Isobutane	Vapor	116	80	-643.4
11	Brine	Liquid	300	238	270.03
12	Brine	Liquid	243	213	211.85
13	Brine	Liquid	202	201	170.522
14	Brine	Liquid	170	188	138.41
15	Brine	Liquid	130	138	98.3
16	Cooling Water	Liquid	75	22	43.18
17	Cooling Water	Liquid	95	12	63.1

2.1.1 10 MW Power Plant

The 10 MW system, as shown on Sketch 3 in Appendix B, consists of single heat exchanger units for the preheaters and boiler. Multiple units were required for the condenser to obtain the heat transfer area. The mass flow rates for the various fluids are given in Table II. A summary of parasitic power losses for the plant is given in Table III.

TABLE II

MASS FLOW RATES - 10 MW PLANT	
<u>Circulating Fluid</u>	<u>$\times 10^{-6}$ lb/hr</u>
Geothermal Fluid	2.54
Total Isobutane	2.65
High Pressure Isobutane	1.92
Low Pressure Isobutane	0.73
Cooling Water	19.0

TABLE III

POWER BALANCE - 10 MW PLANT

Gross Power Output	15 MVA
Losses	5
1. Energy Conversion System Losses	
Isobutane Pumping Power	1.4 MW
Cooling Water Pumping and Fan Power	1.47 MW
Miscellaneous Electrical	0.75 MW
Total Energy Conversion Losses	3.62 MW
2. Energy Supply and Disposal	
Geothermal Fluid Pumping Power	1.43 MW
Net Power Output (with power factor = 1)	10 MW

The information in Tables II and III indicates that the nominal effectiveness of the cycle is about 4 MW(net)/million pounds per hour of 300°F brine. This high utilization rate was achieved because a large drop in the geothermal fluid temperature is achieved with the dual boiling cycle while maintaining an average cycle efficiency about that of single boiler or super-critical cycles. In addition, the minimum temperature difference between the geothermal water and isobutane was fixed to 10°F. This limitation was somewhat arbitrary and further trade-off studies in which this value is varied may result in slightly lower costs.

Studies were made to determine the sensitivity of plant output to changes in the geothermal fluid temperature. At a geothermal fluid temperature of a 320°F the plant could produce 11.7 MW(net). If the geothermal fluid temperatures were 280°F, the net output would be 7.2 MW. A detailed sensitivity analysis of the thermodynamic parameters for this plant appears in Reference (3).

One of the most impressive requirements is that of the total heat transfer area. Huge areas are necessary because of large fouling allowances for the geothermal brine, low thermal efficiency and the need to limit heat exchanger pinchpoint temperatures. It follows that the heat exchangers represent a significant portion of the cost of the energy conversion system. The heat transfer surface requirements for the 10 MW system and overall heat transfer coefficients are listed below and represents a total heat transfer area requirement of 22.5 ft²/kW (gross).

	Surface Area, ft ²	Overall Heat Transfer Coefficient (Btu/hr ft ² °F)
1-HP - Preheater #1	38,000	110
1-LP - Preheater #2	60,000	110
1-HP - Boiler #1	36,000	120
1-LP - Boiler #2	36,000	120
2 - Condensers	167,000	
Total heat transfer surface	337,000	

Details of the heat exchangers may be found in Appendix A. The size of the heat exchange units that can be considered is determined by shipping and erection limitations. Single units weighing approximately 300 tons and with a heat transfer surface area of 80,000 ft² have been built by large heat exchanger companies. It is very desirable to limit the number of units so that associated piping and valves are minimized.

The cost estimate summary, Table IV, lists the total cost of the 10 MW energy conversion system, by the various subsystems. The costs shown are in 1975 dollars exclusive of contingencies. They include engineering, program management and contractor fees. The disposal of rejected heat represents a major fraction (31%) of the cost associated with the system. The cost of the total heat transfer surface represents over 30 percent of the system cost. It should be noted that very conservative fouling factors were used in the sizing calculation and that no trade-offs were made between fouling factors and cleaning schedule. When such large areas and high pressures are required it is unlikely that the use of specialized high performance heat exchangers is possible. Fouling resistances assumed on the geothermal fluid heat exchangers represented about forty percent of the total resistance to heat transfer, thus resulting in very low overall heat transfer coefficients. A small reduction in the fouling factor would result in large increases in the overall heat transfer coefficient. Carbon steel shell and tubing was assumed on all heat exchangers to provide a base cost. Further materials evaluations and trade-offs are required to verify the use of carbon steel.

The lower temperature geothermal fluids frequently have the advantage of lower mineralization than high temperature fluids. In addition, where CO_2 content is low calcite scaling can probably be prevented without severe penalty. Under these conditions, a substantial reduction in the assumed fouling may be justified which could result in perhaps a 30 to 40% reduction brine heat exchanger surface requirements. Tests are currently underway to determine the actual scale fouling and associated thermal resistance from the Raft River geothermal water which has proved to have low salinity and CO_2 content. Thus, it is expected that a power plant at Raft River would incorporate the significant reductions in the area noted; however, these savings have not been incorporated in the costs given in Table IV and could be offset if material changes or retubing were required.

TABLE IV

10MW ENERGY CONVERSION COST ESTIMATE

<u>Item</u>	<u>Description</u>	<u>Cost 1975 Thousand \$</u>	<u>%</u>
Land & Land Rights	Leasing & Right of Ways	21.4	0.2
Land Improvements	Clearing,grading,roads,parking	284.7	2.7
Buildings	Pumphouses & Control Room	340.3	3.2
Misc. Structures	Blowdown & Drain Ponds	215.5	2.0
Brine System	Brine-Piping,Valves,Insulation Support	228.8	2.1
Isobutane System	Isobutane-Piping,Valves,In- sulation, Support	457.6	4.3
Isobutane Storage	Pressure Vessels & Piping	153.1	1.4
Preheaters	Shell & Tube Heat Exchangers	912.5	8.6
Boilers	Kettle Type Vaporizers	834.5	7.8
Condensors-Hotwells	Shell & Tube Exchangers,Iso- butane Tank	1585.7	14.9
Cooling Water System	Cooling Tower,Piping, Valves, Support	1726.5	16.2
Turbine-Generator	Turbine Expander & Electrical Generator	1353.1	12.7
Condensate Pump	Turbine Expander & Turbine Pump	212.7	2.0
Electrical System	Inplant Power Distribution	1417.6	13.3
Controls & Instru- mentation	Flow, Pressure & Temperature Measurement	273.6	2.6
Utilities	Fire Protection, Domestic Water, Sewer System	261.	2.4
Testing	Initial System Check-Out	141.5	1.3
Standard Equipment	Furniture, Lab Supplies, Cranes	<u>241.3</u>	2.3
TOTAL		10,661.4	

2.1.2 50 MW System

The basic difference between the 50 MW and the 10 MW system results from increases by a factor of five in the mass flow rates. The mass flow rates for the 50 MW system listed in Table V. The state point pressures and temperatures are the same as the 10 MW system and are listed on Table I.

TABLE V

MASS FLOW RATES - 50 MW

<u>Circulating Fluid</u>	<u>Flow Rate</u> <u>$\times 10^{-6}$ lb/hr</u>
Geothermal Fluid	12.71
Total Isobutane	13.28
High Pressure Isobutane	9.62
Low Pressure Isobutane	3.66
Cooling Water	95.0

A summary of the parasitic losses associated with the 50 MW system is given in Table VI.

TABLE VI
POWER BALANCE - 50 MW

Gross Power Output	75.3 MVA
1. Energy Conversion System Losses	
Isobutane Pumping Power	7.0 MW
Cooling Water Pumping & Fan Power	7.3 MW
Misc. Electrical Losses	<u>3.8 MW</u>
Total Energy Conversion Losses	18.1 MW
2. Energy Supply & Disposal System	
Geothermal Fluid Pumping Power	7.2 MW
Net Power Output (with power factor = 1)	50 MW

As in the 10 MW case, the heat exchangers represent a major portion of the cost of the 50 MW energy conversion system. Although maximum size units were utilized, multiple shells connected in parallel and series were necessary to accommodate the increased heat loads. When the actual scale fouling and associated thermal resistance have been determined, the heat transfer area requirements could be reduced by 30 to 40%.

The heat transfer surface requirements, using conservative fouling resistances, are as follows:

	<u>Surface Area, Total</u>
2 - HP Preheaters in Series	186,000 ft ²
4 - LP Preheaters in Series	296,000 ft ²
4 - HP Boilers in Parallel	166,000 ft ²
4 - LP Boilers in Parallel	178,000 ft ²
7 - Condensers in Parallel	<u>794,000 ft²</u>
Total	1,620,000 ft ²

The cost estimate summary for the 50 MW energy conversion system is given in Table VII , based upon the schematic and layouts contained in Appendix B .

This cost estimate assumed two radial inflow turbines (high pressure and low pressure as in the 10 MW plant); however , with the larger plant a single axial flow turbine with a low pressure admission would probably be the preferred arrangement.

TABLE VII

50 MW - ENERGY CONVERSION COST ESTIMATE

<u>Item</u>	<u>Description</u>	<u>Cost 1975 Thousand \$</u>	<u>%</u>
Land & Land Rights	Leasing and Right of Ways	35.7	0.1
Land Improvements	Clearing, Grading, Roads, Parking	314.5	1.0
Buildings	Pumphouses & Control Room	408.8	1.3
Misc. Structures	Blowdown and Drain Ponds	471.7	1.5
Brine System	Brine-Piping, Valves, Insulation, Support	942.	2.9
Isobutane System	Isobutane - Piping, Valves, In- sulation, Support	2519.	7.9
Isobutane Storage	Pressure Vessels and Piping	935.7	2.9
Preheaters	Shell and Tube Heat Exchangers	3730.8	11.7
Boilers	Kettle Type Vaporizers	3058.2	9.6
Condensers - Hotwells	Shell and Tube Exchangers, Iso- butane Tank	6917.	21.6
Cooling Water Water	Cooling Tower, Piping, Valves, Support	4817.3	15.1
Turbine - Generator	Turbine Expander and Electrical Generator	3192.1	10.0
Condensate Pump	Turbine Expander and Turbine Pump	460.8	1.4
Electrical System	Inplant Power Distribution	2792.7	8.7
Controls & In- strumentation	Flow, Pressure, & Temperature Measurements	317.6	1.0
Utilities	Fire Protection, Domestic Water, Sewer System	470.2	1.5
Testing	Initial System Check-Out	220.1	0.7
Standard Equipment	Furniture, Lab Supplies, Cranes	<u>358.1</u>	1.1
TOTAL		31,962.3	

2.1.3 Cost Scale Up of the Energy Conversion System

It is common practice to scale costs of components or plants as an exponential of the capacity (4):

$$C_2 = C_1 \left(\frac{Q_2}{Q_1} \right)^n \quad \text{where}$$

C = Cost (Plant, System or Component)

Q = Capacity

n = Exponential Factor

The cost estimates of similar 10 and 50 MW Plants obtained on the same basis (Tables IV and VII) can be used to determine values of the exponent n. Table VIII lists the exponential factor for the components of the energy conversion system. The total plant scales according to $n = 0.68$. This value is typical of process plants which vary from $n = 0.6$ to 0.7 . The values for the individual standard components given in Table VIII compare favorably with typical values given in reference (4) and were calculated using the cost breakdowns in Tables IV and VII.

A curve of the unit capital cost as a function of plant capacity based on $n = 0.68$ is provided in Figure 2. On this basis it is projected that the unit cost of the energy conversion system for a 100 MW plant would be \$512/kW. Also included is the probable cost due to brine temperatures within 20°F of 300°F upon which this analysis is based. The costs have been presented in 1975 dollars without contingency or escalation. Escalation and contingency would result in a multiplier of 1.7 to 2. This factor would place the actual cost of the energy conversion system for a 50 MW plant around \$1020 to \$1200/kW and that for a 100 MW plant in the range of \$870-\$1025/kW.

TABLE VIII

SCALE OR EXPONENTIAL FACTORS

<u>Item</u>	<u>Exponential Factor -n-</u>
Land & Land Rights	0.32
Land Improvements	0.062
Buildings	0.11
Misc. Structures	0.41
Brine System	0.88
Isobutane System	1.06
Isobutane Storage	1.12
Preheaters	0.875
Boilers	0.81
Condensers & Hotwells	0.92
Cooling Water System	0.64
Turbine-Generator	0.53
Condensate Pump	0.48
Electrical System	0.42
Controls & Instrumentation	0.093
Utilities	0.37
Testing	0.28
Standard Equipment	0.25
Total Energy Conversion System (Not an Average of the Above)	0.68

Figure 2 ENERGY CONVERSION SYSTEM INSTALLED COST VS PLANT SIZE 17

2.2 Potential Cost Improvements

The costs of the energy conversion system, particularly for the smaller plant, are quite high. As previously noted, 30% of the base cost is in heat exchangers. An additional 45% results from; cooling water system (~15%), turbine generator (13%) and in-plant power distribution and control (15%). The remainder (25%) of the cost results from a number of small items. The greatest potential for improvement is to reduce the conservatism in heat exchanger design fouling factors and, in areas where abundant fresh water for cooling exists, substitute once through cooling for the cooling tower. In general, however, large quantities of fresh water may not be available at geothermal sites.

A reduction in the overall cost of the plant by about 5% can be achieved by reducing heat exchanger fouling factors on the preheaters and boilers. The condensers represent about 50% of the total heat transfer area, by the use of extended surfaces, increasing the performance, this area and associated cost might be reduced. Development of direct contact condensers offers the potential to reduce this cost. Currently, experimental research is underway on direct contact boilers and this work will likely expand to direct contact condensers in the near future.

The use of a cooling system in which cooling water is stored to take advantage of the cooler portions of the day may also result in additional savings and is currently being evaluated.

Future developments in heat transfer methods, development and selection of better working fluids and further optimization and operating experience should result in somewhat lower costs.

3.0 ENERGY SUPPLY, DISTRIBUTION AND DISPOSAL SYSTEMS

The energy supply, distribution and disposal systems consists of the supply wells, field piping to collect geothermal water from the supply wells and deliver it to the power plant, then collect the geothermal effluent from the plant and deliver it to the reinjection site for disposal into the reinjection wells. All wells, piping, and pumps related to the energy supply and disposal functions are part of this system. The following sections discuss the design of the energy supply, distribution, and disposal system and presents the equipment cost associated with this function.

3.1 Basis for Cost Estimate, Conventional Design

The estimated cost of all well drilling is based upon the drilling costs of the existing Raft River Geothermal wells. The wells were drilled with a standard rotary drilling rig to a depth of about 5000 ft. The wells are cased to a depth just above the production zone (4000-5000 ft) with 13-3/8 inch diameter casing. This size casing was selected in anticipation of eventual well flow rates in the order of 2000 gpm. The production zone is not cased. The power plant design assumes that the wells are pumped at rate of 1250 gpm by a line shaft pump set at a depth of 500 ft. The pumps have a total developed head of 600 ft, which is sufficient to double the current artesian flow of 650 gpm. The pump depth and pressure at the well head is sufficient to keep dissolved gas in solution.

The transmission lines are 8 inch, schedule 40 wrapped steel piping, buried to a depth of 5 feet and containing expansion loops and supports obtained from detailed material take off. Layouts of the piping runs were made for the cost estimate. The average distance between the supply wells and the power plant, was 2000 ft. Details of the plot plan are included in Appendix B.

A single reinjection line runs from the power plant to the reinjection region, where it branches off to each reinjection well. The reinjection lines are steel and are buried. One reinjection well is provided for every two supply wells. A pressure of 300 psi at the reinjection well has been assumed necessary to achieve the reinjection rates. This pressure, which results in large power consumption may be very conservative.

The reinjection wells are assumed to be equivalent to the supply wells for the purpose of this estimate and therefore, have the same unit cost.

The energy supply systems described are typical of conventional geothermal installations. No enhancement of well flow rates has been considered, nor has the use of non-standard materials. Table IX provides a breakdown of the energy supply and reinjection system costs for a 10 MW power plant. In this estimate spare wells have not been considered because they would result in a distorted cost relative to a larger system requiring many more than the four supply wells needed for a 10 MW plant.

Using 10 MW as the net plant output, a capital investment of \$540/kW is required for the energy supply and disposal system. This cost, as is apparent from Table IX, is dominated by the cost of the wells which represent about 70% of the total cost.

A 50 MW plant would require five times the number of wells and longer transmission lines. Table X provides an estimate for the 50 MW plant which results in an investment of \$548/kW; essentially the same as the 10 MW plant. The reason that the 50 MW system does not show a size scale advantage is that the only savings for multiple wells results from spreading the move in and move out costs of the driller over a larger number of wells. The use of common feed lines to the plant are offset by the increased transmission distance. The cost of an energy supply and disposal system then is about constant with plant size at about \$540/kW.

3.2 Potential Improvements and Cost Reductions

The largest potential for improvement in the cost of supplying and disposing of the geothermal fluid is by reducing the well costs. The previous section provided costs based upon a conventional well design typical of those used with high temperature geothermal fluids. Improvements in the cost can result from two primary areas: increased well production and lower cost well design. Each of these areas will be discussed in general terms in an attempt to show the possible impact on energy costs.

TABLE IX

10 MW ENERGY SUPPLY AND DISPOSAL SYSTEM COST

<u>Item</u>	<u>Description</u>	<u>Cost 1975 Thousand \$</u>	<u>%</u>
Supply Wells	Four Wells-Drilled, Cased, Cemented, Etc.	2444.6	45.3
Supply Pumps	Four-1250 gpm - 600 ft TDH	516.6	9.6
Boost Pumps	Two-2500 gpm	50.8	0.9
Manifolds	16" Branching Manifold	1.5	
Supply Piping	Pipe-Insulated, Buried, Installed, 587. Valved		10.9
Reinjection Pumps	Two-2500 gpm-460 ft TDH- Horizontal	63.8	1.2
Reinjection Piping	Pipe, Buried, Installed, Branch Lines, Etc.	513.7	9.5
Reinjection Wells	Two Wells-Drilled, Cased, Cemented, Etc.	<u>1222.3</u>	22.6
TOTAL		5400.3	

TABLE X

50 MW ENERGY SUPPLY AND DISPOSAL SYSTEM COST

<u>Item</u>	<u>Description</u>	<u>Cost 1975 Thousand \$</u>	<u>%</u>
Supply Wells	Twenty Wells-Drilled, Cased, Cemented, Etc.	12,223.1	44.6
Supply Pumps	Twenty-1250 gpm	2,583.	9.4
Boost Pumps	Ten-2500 gpm	286.6	1.0
Manifolds	18" Branching Manifolds	14.7	0.1
Supply Piping	Pipe-Insulated, Buried, Installed, Valved, Etc.	3,522.3	12.8
Reinjection Pumps	Ten-2500 gpm-460 ft TDH-Horizontal	331.6	1.2
Reinjection Piping	Pipe-Buried, Installed, Branch Lines, Etc.	2,348.2	8.6
Reinjection Wells	Ten Wells-Drilled, Cased, Cemented, Etc.	<u>6,111.5</u>	22.3
TOTAL		27,421.	

3.2.1 Increased Productivity

The two methods currently considered most likely to increase well productivity are multiple whipstocking from a central bore and hydraulic fracturing. It is virtually impossible to estimate the potential gain in productivity that can be achieved by these methods without prior experience in the formation.

It is estimated that three additional bores each about 500 ft in depth can be added to an existing well for about \$150,000. Thus, water would enter the well from four locations. If this resulted in an improvement of 50 to 100% in the well flow, a significant reduction in the cost of the energy supply and disposal system would result.

Assuming that this improvement would apply equally to supply and re-injection wells the capital cost of supplying and disposing of the geothermal fluid would be in the range of \$410 to \$480/kW of electrical energy produced, a reduction of up to 25%.

The estimated cost of hydrofracturing is in the order of \$65,000 and would result in a cost of about \$420/kW for a 50% improvement in flow.

3.2.2 Reduced Design Costs

Moderate temperature geothermal liquids contain about half the energy of a high temperature liquid and one fourth the energy of geothermal steam. Saturation pressure of high temperature geothermal liquids is in the order of 65 atmospheres compared with 3.5 atmospheres for moderate temperature liquids considered in this report.

From this point of view, the moderate temperature geothermal well more closely resembles an ordinary irrigation or municipal well. Therefore, the extensive and costly cementing and casing requirements necessary to protect from blow outs around wells tapping high energy sources should not necessarily apply to wells for lower energy sources. Revised well design resulting from

these considerations could cut well costs in the order of 5%. Wells used in the cost estimate are large (13-3/8" casing) for the assumed flow rates. The use of a 9-5/8" casing would be more appropriate if flow cannot be significantly enhanced to 1800-2200 gpm. It has been estimated that a total well cost in the order of \$360,000 (without contingency or escalation) is reasonable for a large number of wells using the smaller casing where move-in and out costs and special logging costs can be distributed. The estimated capital cost of the energy supply system would be reduced to \$397/kW if such charges can be made.

The low pressures and moderate temperatures allow consideration of non-metallic materials for piping and the use of polymers for gasket materials. Currently cement-asbestos pipe is being tested at the Raft River test facility. The use of this material for transmission lines between well and plant could result in a saving of about 25% compared to steel. Coupling this saving with that derived from using smaller wells may further reduce the capital cost of the energy supply and disposal system to about \$370/kW.

The cost estimates have assumed that reinjection wells are essentially the same as the supply wells and that a high pressure (300 psi) is required to achieve reinjection (reinjection pumping power requirements are about 1 MW per 10 MW of net electrical power). Most non-geothermal disposal wells require little or no pressure at the reinjection wellhead. Experience at Raft River site has shown that a potential exists for reinjection at much less depth than the supply wells (about 2000 ft depth). Thus, wells designed specifically for reinjection could reduce the reinjection cost to perhaps 50 percent of supply well costs and, if essentially no reinjection pressure is required, the plant output would be increased by 10 percent.

Many variations are possible when considering the potential in design cost reductions and the potential of enhancement. The purpose of this discussion is to provide a basis for projecting estimates of potential improvements in energy supply costs and thus provide a lower limit on probable costs.

4.0 ESTIMATED COST OF ELECTRICAL POWER

This section provides an estimate of the bus bar electric power cost for the power plants and energy supply systems described in Sections 2 and 3. A cost comparison with nuclear and fossil fueled plants is also provided. All costs are given in terms of 1975 dollars so that current fuel prices may be used thereby eliminating the need to guess at those costs in the future. An additional reason for this approach is the diversity of opinion on the extent of escalation and interest during construction to be applied.

4.1 Basis for Cost Comparison

The power production costs are divided into fixed annual cost, annual fuel cost, and annual operation and maintenance (O&M) costs. Each of these costs will be discussed in detail in the following section.

4.1.1 Fixed Annual Cost

The fixed annual costs are those power costs which are largely dependent on the plant capital investment and working capital. The fixed annual cost contribution to the cost of power is determined by the capital investment, the fixed charge rate, the plant operating factor, and the amortization period or plant lifetime.

The capital investment required for the geothermal energy conversion systems has previously been discussed in Section 2.1. These cost estimates represent an investment of \$1066/kW for the 10 MW system and \$640/kW for the 50 MW system and are exclusive of contingency and escalation. A contingency of 25% applied to these values result in non-escalated 1975 cost of: 1) \$1330/kW for 10 MW and 2) \$800/kW for the 50 MW.

A similar unescalated cost estimate will be published by EPRI⁽⁵⁾, for fossil fueled and nuclear power systems 1000 MW(e) size, in which a contingency of 14% for fossil fueled and 20% for nuclear power system has been included. The cost as reported are; 1) Nuclear-\$544/kW, 2) Coal-\$460/kW, 3) Oil-\$218/kW.

The power costs derived from the nuclear and fossil power plant values given may be compared directly with the cost of power produced by a geothermal system described in this report. Both are based upon the assumption that a plant can be designed and built "overnight" with power production proceeding immediately. Such an approach eliminates complications introduced by escalation and different design - construction times.

To compute the fixed charge cost/kW-hr, the levelized annual fixed charge method was employed, whereby a constant fixed charge rate (which lumps interest, taxes, insurance, etc. into a single rate) over the plant lifetime is applied to the initial investment. The constant fixed charge rate varies according to the type of plant ownership, ranging from 5% for Rural Electrification Administration (REA) financed to as much as 20% for private investor ownership. For this cost comparison, the power plants will be assumed public utility owned with an annual fixed charge rate of 15% (6,7).

The plant operating factor is defined as the ratio of the total gross kW-hr generated in a given time to the total gross installed capacity in kW-hr during that period. The plant operating factor for the geothermal plants is assumed to 85%, for nuclear fueled 85%, and for fossil fueled 80%.

The amortization period for each of the power conversion systems compared below is assumed to be 30 years.

Using the foregoing assumptions, the following lists the annual fixed charges for the various type power systems.

<u>Type of Plant</u>		<u>Fixed Charges</u> <u>[mills/kW-hr]</u>
Geothermal	10 MW	27.27
	50 MW	16.36
Coal		10.0
Fuel Oil		4.74
Nuclear		11.13

4.1.2 Annual Fuel Cost

The fuel costs as of July 1975, to be used in this comparison are summarized below. The fuel cost listed for the geothermal power plant (i.e. wells and pipelines) represents the energy supply, distribution, and disposal system as amortized over a 15 year period at the annual fixed rate of 15%. Thus, the wells would be completely replaced one time during the 30 year plant life, according to this assumption.

<u>Type of Plant</u>		<u>Fuel Cost</u> <u>Mills/kW-hr</u>
Geothermal	10 MW	12.4
	50 MW	12.6
Coal		10.3 *
Fuel Oil		22.2 *
Nuclear		3.0 *

* Energy Finance Week Vol. 1, No. 20, September 17, 1975.

4.1.3 Annual Operating and Maintenance Cost

The operating and maintenance cost includes annual expenses necessary for the operation of the power plant not directly related to the capital investment; such as facility maintenance, office supplies, and shop supplies.

The following table lists the values used for the cost of operation and maintenance.

<u>Type of Plant</u>		<u>O&M</u> <u>mills/kWhr</u>
Geothermal	10 MW	1.2
	50 MW	1.0
Coal		1.0 **
Fuel Oil		1.0 **
Nuclear		1.3 **

** Steam Electric Plant Cost, Federal Power Commission, 1972.

4.2 Power Cost Comparison

Combining the previously discussed fixed annual cost, annual fuel cost, and annual operation and maintenance cost, Table XI lists the calculated power cost for the various type plants.

The power cost presented in Table XI reflect cost on a non-escalated basis of 1975 dollars for the conventional system described in Sections 2 and 3. As can be seen from this table, the cost of producing electrical power from 300°F geothermal fluid is slightly above that of most other generating units. If the source temperature were 320°F, the cost of producing electrical power would be reduced by 7% and 6% for the 10 MW system and 50 MW system respectively. However, a source temperature of 280°F would increase these costs by 16% for the 10 MW system and 13% for the 50 MW system. Improvements are anticipated that will result in a decrease in the cost of power from the 300°F geothermal source.

TABLE XI

POWER PRODUCTION COST COMPARISON

	Binary Organic Geothermal				
	<u>10 MW</u>	<u>50 MW</u>	<u>Nuclear</u>	<u>Coal</u>	<u>Fuel Oil</u>
Fixed Annual mills/kWhr	27.3	16.4	11.1	10.0	4.7
Operating & Maintenance mills/kWhr	1.2	1.0	1.3	1.0	1.0
Fuel Cost mills/kWhr	12.4	12.6	3.0	10.3	22.2
TOTAL mills/kWhr	40.9	30.0	15.4	21.3	27.9

As an example, if the energy supply and disposal system cost were reduced to \$450/kW by whipstock drilling or hydrofracturing the total cost of producing power would be 38.8 mills/kWhr for the 10 MW and 27.7 mills/kWhr for the 50 MW. On the other hand if the casing diameter were reduced as discussed in Section 3.2.2 where the cost of the energy supply and disposal system is reduced to \$370/kW the cost of power would be 37.0 and 25.9 mills/kWhr for the 10 MW and 50 MW respectively. In addition, other innovative concepts such as: direct contact heat exchangers, hybrid cooling towers, phase cooling, the use of mixtures of working fluids are being evaluated and floating power levels may further reduce electricity costs.

Thus far estimating the cost of producing electrical power has not considered the wide variations that exist in all types of power plants. The values as discussed above are representative values expected to be in the range of typical cases. Any particular case in question could be higher or lower than the corresponding value that has been used. This difference is due to the large variation in the actual construction cost as noted in reference (8). Also, existing facilities were constructed when materials, labor, and fuel were not as costly as they currently are. The trend over the past few years has indicated an increase in construction cost of 26% annually. (8, 9, 10) Furthermore, the geographic region under consideration has an impact on the cost. Figure 3 depicts the values listed in Table XI, which include a contingency, of typical or average values. A cost, as indicated by the cross-hatching, was derived by assuming the geothermal and nuclear plants would range between $\pm 20\%$ of the average value, and $\pm 15\%$ for the fossil fueled.

This cost range does not take into account the potential developments that may apply to geothermal systems, resulting in further cost reductions. The costs for the geothermal system were based upon the application of rather conventional and conservative technology and thereby provides a baseline against which improvements can be measured. Continued development, design applications and operating experience is expected to result in both cost reductions and increased power output. The cost reductions that potentially exist have been previously discussed and include: 1) smaller

FIGURE 3 POWER COST COMPARISON (1975 DOLLARS)

diameter wells and/or well flow enhancement, 2) less conservatism in heat exchanger design, 3) improved reinjection well design and 4) lower design costs. Improved power output could result from (1) lower reinjection pressures, (2) improved cooling methods and (3) the use of mixtures of organic fluids as the working fluid and (4) floating power levels.

If these items (some of which may require development of the necessary technology) are incorporated, it is estimated that the median point of the cost range shown on Figure 3 could be reduced to the neighborhood of point A. Thus, a 50 MW power plant using 300°F geothermal water would appear to be capable of producing power competitively with coal-fired plants.

The power cost of medium temperature geothermal power plants in module sizes much larger than 50 MW may be less attractive than those for 50 MW. The reason is because the energy supply system costs will increase due to the need to transport the water greater distances from the wells to the power plant. This cost increase exceeds the unit kW cost reduction advantage of the larger power plant components. Thus, 50 MW appears to be about the optimum sized module for hot water, medium temperature (~300°F) geothermal power plants, for which 20,000 gallons/minute of geothermal water is produced from each square mile.

5.0 INTEGRATED SYSTEM ECONOMIC IMPACT

One of the major features of moderate temperature geothermal power plants is the low conversion efficiency imposed upon them by that temperature. Consequently, a greater amount of fluid must be processed to produce the same electrical energy than is required by a plant operating at higher temperatures. A substantial amount of energy still exists in the geothermal fluid when it is discharged from the power plant. This is in contrast to nuclear and fossil fueled power plants which transfer nearly all of the energy supplied to heat and vaporize a working fluid whose vapors are then expanded through a conventional turbine to produce power. These systems have essentially no residual heat in the energy supply whereas most geothermal resources are liquid dominated and that liquid will retain a large portion of the heat which cannot be transferred to the working fluid without suffering an excessive temperature reduction. Since no effective device yet exists for extracting useful energy directly from hot water, the use of residual heat from geothermal power plants directly in process industries should be a major objective of geothermal research and development.

In this Section the results of an economic analysis, which provides a rough assessment of the value of the income from selling residual heat is presented in terms of the affect on the cost of electricity.

The economic impact of an integrated system which can sell the residual heat as well as some of the heat which could be used to generate electricity is demonstrated by comparing the calculated breakeven price of electricity if the power plant operation were degraded to provide various amounts of heat for sale at a fixed price. The breakeven price is the value of the electricity which must be realized in order to meet the remaining economic obligations on the entire system after the heat sales.

The breakeven cost calculations were made under the assumption that the power plant costs remained constant even though the power production was reduced. That is, the total dollar cost was held constant, not the dollar per kilowatt cost. However, no additional costs were imposed for any special equipment which might be needed by the heat sales system.

The cost estimates of Sections 2 and 3 provide the basis for these calculations. These costs are given in non-escalated 1975 dollars without a contingency. The number of geothermal wells and the associated energy supply system cost was, of course, held constant. The reduction in electrical power generation was limited to 20 percent because that is about as far as power plant operation can be degraded without significant impact on the system performance. The income from the heat sales was calculated on the basis that all the heat was sold for the assumed price under an 85% on-stream or operating factor.

The quantity of residual heat available for sale was based on a low temperature limit of 130°F which is the geothermal water discharge temperature from the double boiler system. In effect, such a system is assumed to produce no residual heat and represents the base case for this study. Therefore, residual heat for sale must be obtained by either bypassing some geothermal fluid around the power plant or by raising the discharge temperature of the water from the isobutane boilers. No special distinction was made between the different temperatures available by those two methods. No economic credit was taken for the heat content below 130°F, although such heat would surely be used for local space heating and related activities.

The economic impact of selling residual heat (above 130°F) from a single boiler isobutane plant and a double flash steam plant was included in this study. Both plants require a larger capital investment per kilowatt of electricity generated but both discharge geothermal water above 130°F and therefore, provide significant amounts of residual heat before their electrical power generation is reduced.

Table XII is a summary of the capital costs of all three types of power plants and the major operating parameters of interest here. The costs for the 10 MW single boiler isobutane and double flash steam plants were obtained under the same rules as the costs for the double boiler isobutane plant and are well suited for comparison analysis between the three systems. The costs of the 50 MW single boiler isobutane plant were obtained by applying the cost exponential factor obtained from the double boiler isobutane plant cost estimates to the 10 MW single boiler isobutane plant cost estimate.

The calculated breakeven prices of electricity for each of the plant types is given in Table XIII and plotted on Figures 4, 5, 6, 7, and 8. The breakeven prices are plotted against the fraction of the total heat from the geothermal wells (above 130°F) for different assumed selling prices of the heat. The economic model used yields a straight line between each pair of points for a given plant and heat sale price. The dashed extrapolation to the right of the right hand points just indicates the trend. Reducing the power production more than 20 percent would probably cause non-linear effects to become significant and generally increase the breakeven electrical prices above those indicated by the linear extrapolations.

Figure 4 shows that if the residual heat from the double boiler isobutane plant is not sold for more than 7 to 8¢/therm, then no improvement can be made in the breakeven electrical price by reducing the electrical power generation. Such minimum worthwhile heat prices are evident on the other figures with the lowest heat price which would warrant reducing electrical power generation being about 5¢/therm. Table XIV lists some typical heat prices for different fuel sources. Obviously, heat prices of under 10¢ per therm should be economically attractive to process industries which can use the residual heat.

The 20 percent power reduction was not applied to the double flash steam system, shown on Figure 8, because it has so much residual heat even when operating at full power. Consequently, each heat sale price has only one calculated breakeven electrical price. The maximum temperature of that residual heat would be only 206°F rather than the full 300°F which would be available if some of the geothermal fluid were bypassed around the power plant.

The lowest breakeven electrical price of 12.6 mills/kWhr occurs with the 50 MW single boiler isobutane plant for heat sales at 10¢/therm as shown on Figure 6. As can be seen in Table XII, such a plant would produce some (8450 therms/hr) and 40 MWs of electrical power. That is a lot of heat to sell from a single facility. The double flash steam system, Figure 7 shows the next lowest breakeven electrical price of

TABLE XII

COSTS AND OPERATING PARAMETERS FOR THREE TYPES OF GEOTHERMAL POWER PLANTS

Plant Type	Electrical Power Generation (MW)	Geothermal Flow (lb/hr 10^{-6})	Fluid Discharge Temperature ($^{\circ}$ F)	Capital Costs *		Residual Heat Production	
				Energy Supply (\$/kW)	Power Plant (\$/kW)	Full Power (Btu/hr $\times 10^{-6}$)	80% Power (Btu/hr $\times 10^{-6}$)
Double Boiler Isobutane	10	2.5	130	540	1065	0	86
	50	12.5	130	550	640	0	430
Single Boiler Isobutane	10	2.8	156	560	1050	72.8	169
	50	14.0	156	570	630	364	845
Double Flash Steam	10	5.1	206	1440	1040	388	- -

* Capital cost excluding escalation and contingency.

TABLE XIII
CALCULATED BREAKEVEN ELECTRICAL PRICES

Plant Type	Rated Electrical Power (MW)	Electrical Power Production (MW)	Fraction Of Geothermal Heat Source	Heat Selling Price (¢/therm)	Breakeven Electrical Price * (mills/kWhr)	
Double Boiler Isobutane	10	10	0	- -	35.4	
	10	8	0.20	0	44.2	
				5	38.9	
				10	33.5	
	50	50	0	- -	26.7	
	50	40	0.20	0	33.4	
				5	28.3	
				10	23.0	
	Single Boiler Isobutane	10	10	0.15	0	35.5
		10	8	0.35	5	31.9
10					28.3	
0					44.4	
10		50	0.15	5	33.9	
				10	23.3	
				0	27.0	
50		40	0.35	5	23.3	
				10	19.7	
				0	33.7	
50	10	0.44	5	23.1		
			10	12.6		
			0	55.5		
Double Flash Steam	10	10	0.44	0	36.1	
				5	16.7	
				10		

* 1975 cost not including contingency.

Figure 4 IMPACT OF HEAT SALES ON 10 MW DOUBLE BOILER ISOBUTANE PLANT

Figure 5 IMPACT OF HEAT SALES ON 50 MW DOUBLE BOILER ISOBUTANE PLANT

Figure 6 IMPACT OF HEAT SALES ON 10 MW SINGLE BOILER ISOBUTANE PLANT

Figure 7 IMPACT OF HEAT SALES ON 50 MW SINGLE BOILER ISOBUTANE PLANT 41

Figure 8 IMPACT OF HEAT SALES ON 10 MW DOUBLE FLASH STEAM PLANT

TABLE XIV

COMPARATIVE COSTS OF SEVERAL HEAT SOURCES
FOR INDUSTRIAL USE IN THE INTERMOUNTAIN WEST
(July 1975 Costs)

	<u>¢/therm @ 10³ therms/ day</u>	<u>¢/therm @ 10⁴ therms/ day</u>
Coal	14.	14 (\$35/ton)
Oil	23.2	23.2 (32.9¢/gal)
Natural Gas	13.2	11.8
Electricity	45.1	44.8 (15.3 mills/ kWhr)

16.7 mills/kW-hr for heat sales at 10¢/therm. The double flash steam plant produces 10 MW of electricity and some 3880 therms/hr of residual heat. This is also a lot of heat to sell. The general point is that low temperature geothermal plants can produce electricity at competitive prices by selling their residual heat rather than wasting it.

Of course a suitable customer for that residual heat must be found. Such a customer must require rather large quantities of low to moderate temperature heat and the customer's plant must be built very close to the geothermal resource. Those conditions are stiff but not really impossible restrictions. Many industrial processes, particularly in the food processing industry, require substantial amounts of low to moderate temperature heat. At the same time most process plants require relatively small amounts of high temperature heat. If that temperature is below 500°F it can be economically supplied from a 300°F geothermal resource by a high temperature heat pump system as described in Reference 11. Development of such a system would increase the number of potential customers for the residual heat from a geothermal power plant.

These results give rise to the question of whether any electricity should be generated from the low temperature geothermal resource. Why not just sell only heat and import all the electricity? Of course that is the proper plan if the combined system cannot produce both electricity and heat at an overall attractive cost and if there are no other considerations. One important such consideration is to have local control over some electric power generating capability in order to have a guaranteed supply. Also, only a few geothermal wells could supply much more heat than even a large processing plant could use. So balancing the heat production and electrical power production for a particular application may provide the most attractive way to develop the low temperature geothermal resource.

6.0 CONCLUSIONS

The power plant and energy supply system design for use of 300°F low salinity geothermal water has been defined. Cost estimates have been presented, based upon this design for a 10 MW and 50 MW electric power plant. It was found that the power plant capital cost scaled exponentially with power level to the 0.68 power. The cost of the energy supply system, however, was essentially constant on a per kW basis.

The median cost of power from the conventional 50 MW geothermal plant was about 7% above an oil fired plant and 43% above a coal fired plant. However, the further application of existing technology and the development of new technology applied to the energy supply system and binary type power plant offers the potential for moderate temperature geothermal fluid to provide electrical power at prices which are competitive with coal at today's prices. Thus, it appears that the lower temperature limit for economic production of power can be reduced to about 300°F from the present 400°F competitive range. This reduction increases tremendously the amount of geothermal energy available since the largest quantities exist at the lower temperature.

The geothermal liquid leaving a geothermal plant contains a significant amount of residual energy at usable temperatures. It has been shown that the income obtained from selling this energy at about one half the price of natural gas has the potential to further reduce the cost of electrical power, thus, further increasing the competitive position of 300°F geothermal fluid.

The conclusions given above clearly show a viable potential for the moderate temperature resource. However, only through actual experience in the plant design, construction and operation and from experience in reservoir management can these estimates be confirmed. Such confirmation would vastly increase the geothermal potential of the nation.

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APPENDIX A

1.0 INTRODUCTION

This appendix provides a more detailed account of the requirements and description of the 10 MW facility.

Included are the basis for the proposed design and the philosophy involved in selecting, detailing, and estimating the system. This section provides detailed information on the practices and procedures employed in the design effort.

2.0 DESIGN REQUIREMENTS

The system designs and cost estimated presented in this report are based upon the following design bases and assumptions.

2.1 System Requirements and Design Bases

2.1.1 Energy Supply and Re-Injection

A. Brine Conditions

Temperature

(a)	Design temperature °F	350
(b)	Normal operating temperature °F	300
(c)	Minimum brine temperature for
plant operation °F	280
(d)	Maximum brine temperature	320

B. Flow

(a)	Design minimum pumped rate/well, #/hr	6.2×10^5
(b)	Design natural flow rate/well, #/hr	3×10^5
(c)	Total brine flow rate maximum, #/hr	3.1×10^6
	nominal, #/hr	2.5×10^6

C. Pressures

(a)	Deep well pump suction	90 psia
(b)	Re-injection pressure	300 psia
(c)	Minimum pressure in plant	98 psia

D. Brine Composition

<u>Cations</u>	ppm	<u>Anions</u>	ppm
Boron	0.3	Chloride	667
Barium	0.4	Bromide	2.5
Calcium	56	Iodide	0.032
Iron	3.4	Fluoride	6.3
Potassium	26	Phosphorus	0.007
Lithium	1.2	Sulfate	0.06
Magnesium	0.64	Sulfide	0.2
Sodium	403	Bicarbonate	48.8
Nickel	2.1	Carbonate	14
Strontium	1.4	Hydrated Silical	51
Silicon	45-70	Ammonia	1.53

Gases	<u>stp cc's of gas per liter of brine</u>	<u>g of gas per kg of brine</u>	<u>mole % in the gas phase (not including water)</u>
H ₂	0.53	.00005	1.4
He	<.1	.00002	<.1
N ₂	32.0	.040	81.8
O ₂	.1	.00014	.25
Ar	.7	.001	1.7
CO ₂	5.8	.011	14.8
SO ₂	-	-	<.1
TOTAL	39.1	.052	100

E. Brine Corrosion and Scaling

Brine Side Fouling Factor for Heat Exchangers $0.003 \frac{\text{hr-ft}^2\text{-}^\circ\text{F}}{\text{BTU}}$

Typical U's (Btu/hr-ft ² -°F)	Fouled	Clean
Preheaters	110	200
Boilers	120	230
Condensers	130	170

F. Locations of Brine Wells

(a)	Average distance between supply well and power house, ft	2000
(b)	Elevation difference, power house minus well, maximum, ft	50
(c)	Number of supply wells, min. required	4
(d)	Number of re-injection wells, min. required	2
(e)	Average distance between power house and re-injection wells, ft	5000
(f)	Elevation difference, re-injection well, minus power house, ft	50

2.1.2 Cooling Water Base Case is Cooling Tower Heat Sink

(a)	Air maximum wet bulb temperature	65°F
(b)	Air dry bulb temperature	-30°F to 100°F
(c)	Off-tower temperature design	75°F
(d)	Cooling tower range	20°F
(e)	Condenser outlet water temperature	95°F
(f)	Makeup water required	1000 gpm
(g)	Average distance from make-up well to power house	2000
(h)	Average distance from power house to re-injection well	5000
(i)	Number of supply wells, minimum	1
(j)	Number of re-injection wells, minimum	1

2.2

Codes and Standards

The geothermal power plant cost estimate, design, and fabrication are in accordance with the following Codes and Standards:

American Institute of Steel Construction
American National Standards Institute, B 31.1
American Society of Mechanical Engineers, Section VIII
American Society for Testing and Materials
American Welding Society
Institute of Electrical & Electronic Engineers
Instrument Society of America
National Electrical Manufacturers Association
National Fire Protection Association
Occupational Safety & Health Act
Tubular Exchanger Manufacturers Association Class "C"
Uniform Building Code

3.0 SYSTEM AND COMPONENT DESCRIPTION

3.1 Overall Facility Description

The total facility consists of supply and reinjection wells and associated transmission lines to convey the geothermal fluid to the power plant site. The arrangement of the wells relative to the power plant is shown on sketch No. 1 (Appendix B). At the power plant, the geothermal fluid is directed from a common header to the sequence of heat exchangers shown in Figure 1. The layout of this equipment is given in Appendix B. The isobutane is expanded in a turbine which discharges to condenser. The condenser is cooled by a conventional wet cooling tower.

The geothermal fluid leaving the low temperature preheater (preheater No. 2) is transferred about one mile to the general location of the reinjection wells where it then branched to the individual reinjection wells.

The performance and description of the individual systems is presented in the following sections.

3.2 System Performance

A series of analyses were conducted to determine the system configuration and design parameters for the 10MW geothermal binary cycle power demonstration plant. A simplified digital computer model of a geothermal binary cycle system was developed based on the design requirements set forth in Section 2.0 of this appendix.

From previous studies on various working fluids, isobutane was chosen as the working fluid for this application. Based on in-depth studies of supercritical and boiling cycles, the boiling cycle was selected since the pumping power required for the supercritical cycle severely penalized the system performance.

A double boiler system was chosen with the higher pressure boiler operating at 230°F and the low pressure boiler operating at 160°F. At 230°F, the saturated vapor is at the highest entropy point and expansion through the turbine to any given low pressure state will give maximum power output per pound of flow without expanding through a two phase region. The pinch point occurs in the low pressure boiler and, therefore, the boiling temperature has a primary effect on the brine discharge temperature. At 160°F, the utilization of the brine is maximized, the size of the preheaters is reduced, the system pressure is reduced, and the overall system becomes less sensitive to fluctuations in brine supply temperatures,

The temperature and pressure of the condenser significantly influences system performance due to the back pressure effects on the turbine. Turbine output power is maximized with low condensing pressures, however, then conditions cause the condenser size to increase significantly. This problem becomes more prominent with the utilization of a cooling tower since the cooling water temperature can drop no lower than 75°F to insure that the plant output will never drop below 10 MW. The minimum temperature across the condenser was set at 20°F which results in the optimum condensing temperature of the working fluid is 105°F.

3.3 Facility Description

3.3.1 Energy Supply and ReInjection System

The 10 MW Binary Cycle Demonstration Plant requires four supply wells. The wells are approximately 5000 feet deep and spaced about 1600 feet apart along a fault line.

The geothermal brine supply pumps are set at a depth of 500 feet which will eliminate any flashing in the pump bowls. The pumps are capable of supplying 1,250 gpm at 150 psi to the brine supply lines.

The supply lines to the plant are ASTM A 105 Grade B, the inside diameter of 8 inches. The supply piping is buried at a minimum depth of five feet with expansion loops at 200 foot intervals.

The four supply lines will be collected into a 16" diameter header just outside the plant boundary and dispersed to two boost pumps through two 8 inch diameter, ASTM A 105 Grade B, Schedule 40 pipes.

The boost pumps boost the incoming brine to 238 psi which enters the plant system through a 16 inch line.

The entire brine supply system is insulated by a "spray on" method, using an industrial insulation similar to Isocyanurate. The insulation has a K-factor equal to or less than .10 and has a compressive strength of at least 25 psi. The insulation will stand temperatures up to 350°F with no degradation and be applied at least 2 inches thick.

The spent brine is piped from the plant through a 16 inch pipe. The flow is then split and distributed to the two reinjection wells through 8 inch diameter pipe. Both pipes are of standard wall thickness and are fabricated from ASTM A 105 Grade B steel. The reinjection piping is buried at a minimum depth of 3 feet and left uninsulated.

The reinjection pumps are located at each reinjection well site and increase the brine pressure from 120 psi to 300 psi for reinjection.

The reinjection wells are drilled to an approximate depth of 5,000 feet. They are cased and cemented to the reinjection depth to prevent reinjecting the brine into a strata of cooler water. The reinjection wells are located geologically downhill and 4,000 ft from the supply wells to insure recirculation past the geothermal heat source. The proposed energy transmission system is shown in Appendix B.

3.3.2 Geothermal Fluid Heat Exchange System

The Geothermal Fluid Heat Exchange System is defined as the brine piping from the inlet header to the outlet header, but not including either header, the isobutane piping from the inlet of the first low pressure preheater to the flanges on the generator and pump turbines, and the low and high pressure preheaters and boilers.

The in-plant brine piping is 16 inch standard pipe. The incoming fluid flows through the high pressure boiler. The fluid is then circulated through the high pressure preheater before entering the low pressure boiler. Before reinjection the geothermal brine flows through the low pressure preheater. Isolation valves are provided for each heat exchanger. The piping, valves, and fittings are supported to avoid overstressing the piping system. Expansion loops are provided where long straight lengths of pipe are required.

The isobutane enters the heat exchanger system through a 16 inch line from the feed pump. The liquid flows through the low pressure preheater. The flow is then split through the use of a control valve which reduces the pressure of the flow to the low pressure boiler. The remainder of the flow passes through the high pressure preheater and onto the high pressure boiler. From the respective boilers, the isobutane vapor flows through 20 in. diameter lines to the high and low pressure turbines. A fast acting shut-off valve is provided at the turbine inlet. The pipe, valves, and fittings are supported to avoid overstressing the piping system and expansion loops will be provided where long straight lengths of pipe are encountered.

The details of the low pressure preheater are provided in Figure 2. The high pressure preheater design is contained in Figure 3 and the boiler design details are shown in Figure 4.

Unit Name
1) Low Pressure Preheater

Designation
PH-2A

Unit Description - Carbon Steel Construction

Tube bundle -

5100 tubes - 0.75-inch OD - 16 B.W.G. - 0.9375 inch triangular pitch
60 ft. long - 60,000 sq. ft. surface area - 4 tube passes

Shell - 75 inch inside dia x 0.75 inch wall

- 16 inch dia. Brine inlet and outlet
- 2 14-inch dia Isobutane Inlets and Outlets
- 3-inch thick tubesheet

TEMA type - BHM

Approximate weight - 200,000 lb

Figure #2 Low Pressure Preheater

Unit Name Designation
 1) High Pressure Preheater PH-1A

Unit Description - Carbon Steel Construction

Tube Bundle -

3400 tubes - 0.75 inch OD - 16 B.W.G. - 0.9375 inch triangular pitch

60 ft long - 38,000 sq. ft. surface area - 2 tube passes

Shell - 60-inch inside diameter 0.75-inch wall

- 16-inch dia Brine Inlet and Outlet

- 2- 14-inch dia Isobutane Inlets and Outlets

- 3-inch thick tubesheets

TEMA type - BHM

Approximate Weight - 190,000 lb

Figure #3 High Pressure Preheater

Unit Name	Designation
1) High Pressure Boiler	B-1
2) Low Pressure Boiler	B-2

Unit Description - Carbon Steel Construction

Tube Bundle-

4564 tubes - 0.75 inch OD - 16 B.W.G. - 0.9375 inch triangular pitch
 40 ft long - 35,846 sq. ft. surface area 4 tube passes

Shell - 69/120 inch inside diameter x 2-inch wall

16 inch dia Brine Inlet and Outlet

2 16-inch dia Isobutane Outlets

3-inch thick tubesheet

Tema Type - BKT

Approximate weight - 244,000 lb

Figure #4 Boilers

3.3.3 Power Conversion System

The Raft River 10 MW Geothermal Binary Power Demonstration Plant will employ a 15 MW turbine driven generator. The generator will be incorporated into a power generating package including a lubrication system, a controls package with safety shutdown logic, and an instrumentation package.

The generator turbine is a single stage radial inflow machine incorporating variable area inlet nozzles which provide full emission flow to the turbine wheel. The variable nozzle concept allows higher turbine efficiencies over a wider range of operating conditions as well as providing flow control to the unit. The design parameters for the turbine are shown in Table 3.3.3 - 1.

The turbine is driven exclusively by the high pressure flow and is directly coupled to the generator shaft.

The generator is a 3600 rpm, 15 MW, 13,800 volts AC generator. It is totally enclosed with an air to water cooling system. The heat exchangers are supplied with the unit and require approximately 300 gpm of cooling water. The generator itself is air cooled from a closed loop air system. This allows the unit to operate in a clean air environment eliminating the potential hazards created by dust and other foreign particles.

The unit will be self-contained. It will be a brushless, permanent magnet generator containing a built-in voltage regulator. The appropriate switch-gear will be matched to the generator.

A typical turbine generator system is shown in Figure 5 .

TABLE 3.3.3 - 1

HIGH PRESSURE TURBINE DESIGN PARAMETERS

Parameter	Generator Turbine
Turbine Specific Speed	1,175
Tip Diameter (in)	44.6
Enthalpy (Btu/lb)	26.23
Efficiency	.84
Turbine Shaft Horsepower (hp)	16,459
Turbine Speed (RPM)	3,600
Tip Speed (ft/sec)	702
Inlet Pressure (psia)	346
Inlet Temperature (°F)	230
Exhaust Pressure (psia)	80
Exhaust Temperature (°F)	129
Turbine Flowrate (lb/sec)	528
Inlet Flange Dia (in)	20
Exhaust Flange Dia (in)	42

A-14

Figure #5 TURBINE - GENERATOR SYSTEM

The systems analysis computer program model has assumed that the isobutane condensate pump was an electrically driven centrifugal pump. Therefore, the low pressure vapor is expanded through a turbine which is used to drive a generator. The low pressure turbine design parameters are shown in Table 3.3.3-2.

With a minor adjustment in the flow split, the low pressure flow could be matched to the flow required by the system condensate pump.

The system condensate pump would then be a turbine driven centrifugal pump supply liquid isobutane the heat exchange system. The pump impeller is of conventional design with the addition of an inducer to lessen the NPSH requirements.

The pump turbine concept is similar to that of the generator turbine. The pump is driven exclusively by the low pressure flow. It is a single stage radial inflow machine with variable area inlet nozzles providing full emission flow to the turbine wheel.

The isobutane start up pump was sized to provide start-up capability. This pump is vertically mounted, taking suction from the hot well, and has a capacity of 1500 gpm at 150 ft head and requires 75 horsepower.

TABLE 3.3.3-2

LOW PRESSURE TURBINE DESIGN PARAMETER

<u>Parameter</u>	<u>Feed Pump Turbine</u>
Turbine Specific Speed	1,300
Tip Diameter (in.)	31.5
Enthalpy (Btu/lb)	13.6
Efficiency	.85
Turbine Shaft Horsepower (hp)	3,634
Turbine Speed (rpm)	3,600
Tip Speed (ft/sec)	495
Inlet Pressure (psia)	161
Inlet Temperature (°F)	160
Exhaust Pressure (psig)	80
Exhaust Temperature (°F)	118
Turbine Flowrate (lb/sec)	222.2
Inlet Flange Diameter (in.)	18
Exhaust Flange Diameter (in.)	30

3.3.4 Condensing and Cooling System

The Condensing and Cooling System consists of the following components.

- a) Isobutane Piping - from the turbine exhaust header to the inlet of the first Low Pressure Preheater
- b) Cooling Water Piping - from the cooling water pumps through the system to the top of the cooling tower
- c) Shell and Tube Heat Exchangers
- d) Hot Well
- e) Cooling Tower
- f) Cooling Water Treatment System
- g) Pumps
 - 1) Cooling Water Circulating Pumps
 - 2) Isobutane Start-up Pump

The isobutane vapor from the turbines exhausts into a 36 inch diameter header. From this header, a 36 inch diameter line directs the flow to the condenser. After condensing, the liquid isobutane flows through 12 inch diameter line from the condenser into the hot well which is located directly beneath the condenser. From the hot well, through 20 inch diameter lines, the flow can be valved into the turbine feed pump or to the isobutane startup pump. The flow bypasses the system feed pump and flows into a 20 inch diameter line which includes a control valve, check valves, relief valves, and filter. The pipe, valves, and fittings are supported so as to not overstress the system. Expansion loops will be provided where long straight lengths of pipe are encountered.

The cooling water pumps take suction from the cooling tower sump. The flow leaves each pump through an 16 inch diameter line connected to a 36 inch diameter header. The flow then continues through the 36 inch diameter pipe for approximately 60 ft to the condenser unit. The flow passes through the condenser into a 36 inch diameter return line header. This 36 inch line continues for approximately 100 ft returning to the cooling tower.

The pipe, valves, and fittings are supported so as to not overstress the piping system.

The condenser is described in detail in Figure 6.

The hotwell provides a holding capacity for the isobutane from the condensers, and also a tank from which the feed pump takes suction. It is located directly underneath the condensers with nozzles for pump suction being on the bottom.

The size of the hotwell was determined by a flow holding time of approximately 2 minutes. The tank is 12 ft inside diameter by 20 ft high. The wall thickness is 0.5 inch. The vessel is constructed of carbon steel and is supported from grade level.

The cooling tower was sized to cool 38,000 gpm from 95°F to 75°F a design wet bulb of 65°F. The tower selected is a set cross-flow type. The cooling tower is approximately 50 ft high, 80 ft wide and 300 ft long. The unit would consist of 4 cells each having 200 H.P. fan motors.

The cooling water will have a treatment facility to inhibit scale formation on the condenser tubes. The unit will be installed so as to comply with the EPA guidelines.

The cooling water circulating pumps were selected to provide 38,000 gpm with 125 ft of head. Selection was made to use five pumps with a capacity of 8000 gpm each. These are vertical sump pumps and take suction from the cooling tower sump. Each pump would require 300 H.P. motors.

Number of Units Required - 2

Unit Name	and	Designation
1) Condenser		C-1
2) Condenser		C-2

Unit Description - Carbon Steel Construction

Tube Bundle

7070 tubes - 0.75-inch OD 16 B.W.G. 0.9375-inch triangular pitch
60 ft long - 80,000 sq ft surface area - 2 tube passes

Shell - 85-inch inside dia x 0.75 inch wall
 - 24-inch dia cooling water inlet and outlet
 - 2 16-inch dia Isobutane Inlets
 - 12-inch dia Isobutane Outlet
 - 2-inch thick tubesheet
 TEMA type - BJM

Approximate Weight - 230,000

Fig. 6 Condenser

3.3.5 Control and Instrumentation System Description

Plant operating controls and instrumentation are provided to permit remote manual start-up of the plant and essentially automatic operation, with operator surveillance, from the power plant control room.

The automatic control loops consist of a turbine speed controller with an overspeed shut down provision, and liquid level controls for each boiler, the hotwell, and the cooling tower water reservoir. The turbine speed controller will be procured as an integral package with each turbine. Since the generator output frequency must precisely match the control frequency of the Bonneville Power network, the turbine control will be designed to maintain a constant generator frequency. A frequency sensor will monitor the generator output and input this information to the controller. The controller then actuates the turbine inlet valve by means of a pneumatic power system. The turbine controller can also be operated manually for start-up, synchronization, and establishment of base load output. The controller incorporates a turbine overspeed trip that immediately shuts off the turbine inlet valve in the event that the turbine speed exceeds a pre-established value.

Conventional 3-element controls will satisfy the needs for control of the boiler liquid levels. The controller will sense the inlet (liquid) flow rate, the outlet (vapor) flow rate, and the boiler liquid level to control the liquid flow control valve. Either venturi or orifice-type devices may be used for sensing the liquid and vapor flow rates. Liquid level sensing can be readily accomplished by use of a conventional combination external reference level standpipe and differential pressure transmitter.

The liquid level in the hotwell and cooling tower reservoirs are controlled through the use of a simple, single-element controller. When the liquid level drops to a pre-established low level, the controller opens an appropriate valve and starts the makeup pump. When the liquid level reaches the required upper level, the valve and pump are shut-off. The controller will be provided with a remote-manual switch for on-off and automatic operation.

Process instrumentation, such as fluid pressures, temperatures, flow rates, differential temperatures and pressures, and liquid levels can be provided by means of locally-mounted indicators throughout the plant. Similarly, controls for pump motors and isolation-type valves are provided locally. However, controls and instrumentation pertinent to plant operation are located in the power plant control room so that the operator can detect operational discrepancies and take remedial action. To facilitate operation, the power plant operating controls and instrumentation are displayed on a graphic control panel. A conceptual design of such a graphic control panel is shown in Figure 7. The display is presented in the form of a simplified flow diagram. Control switches are located adjacent to the pictorial representation of the item being controlled. Instrumentation data are presented on recorders. Those parameters that can vary fairly rapidly, such as pressure and flow, are recorded continuously. Parameters such as temperatures that are expected to change relatively slowly, are recorded on multi-point recorders. This recorded data not only permits the operator to see the immediate selection, but provides trend conditions to assist in pin-pointing causes of irregularities.

LEGEND:

- CONTROL SWITCH WITH INDICATOR LIGHT
- REMOTE-MANUAL CONTROL VALVE
- AUTO-CONTROL VALVE WITH MANUAL OVER-RIDE

FIGURE 7

GRAPHIC CONTROL PANEL

3.3.6 Electric Power System

The electric power system not only transmits the power generated by the geothermal power plant to the Bridge substation and hence to the Raft River Electrical Co-op power distribution system, but also brings in electrical power from the substation to power the pumps, lights, convenience outlets, and the power plant instrumentation and controls. The nominal gross electrical power output of the turbine-driven generator is 15 MW, while the nominal plant power requirement is 5 MW resulting in a net electrical power output of approximately 10 MW based upon a system power factor of 1.0.

The electrically driven brine pump at each of the four supply wells and two reinjection wells are powered from a 12.5 kv power line installed to each well during the well-drilling operation. The 12.5 kv power is converted to 480 v, 3-phase power by means of pad-mounted 500 kva transformers located at each well. The brine pump motor is controlled through a control panel located at the well-head pump house. Control cables will be provided from each well to the power plant to permit control of the pumps from the main control room. A 480 v - 240 v/120v transformer, protective panel, light system, and convenience power for maintenance will be provided at each pump house. Power is also provided for the temperature, pressure, and flow rate indicators which are installed at the pump house, as well as panel-mounted recording instruments located at the main control room.

Other than the 12.5 kv power line to each well, the electrical power will be brought in from or provided to the new Bridge substation, located approximately two miles from the power plant, through a 34.5 kv, 60 Hz distribution line. This power line connects to a 13.8 kv bus via a 12 Mva, 13.8 kv - 34.5 kv transformer with appropriate switch gear, synchronization device and overcurrent and differential protective relays. Two primary power take-offs from the 13.8 kv bus supply electrical power to the cooling tower pumps, fans, and associated pump house lighting, and the three brine boost pumps,

the isobutane boost pump, cold well water pump and power plant lighting, convenience power, and controls. Electrical power to these two major circuits is supplied through separate 2000 kva, 13.8 kv - 480 v transformers and fusible 480 v motor control centers. The turbine-driven generator is also connected to the 13.8 kv bus through protective relays and a synchronization device. Thus, during and prior to plant start-up, electrical power, as required, will flow from the new Bridge Substation distribution line to the two primary circuits indicated above. After the turbine-generator is brought up to speed and synchronized with the power system control frequency, electrical power generated by the turbine-generator will supply electrical power directly to the two primary circuits indicated above, as well as feed power to the Bridge Substation via the 13.8 kv bus. The 13.8 kv bus will also power the generator control and excitation unit. A 125 vdc battery bank is provided to supply dc power for the switch gear so that power for the controls will be available in the event that ac power is inadvertently interrupted.

In-out metering, relaying, and supervisory functions are provided as required by the Bonneville Power Administration (BPA). A communication link will be installed to connect the plant into the BPA system.

Lighting is provided throughout the facility in accordance with Illumination Engineering Society Standards. A ground grid system will be installed and bonded to all metallic structures such as the preheaters, boilers, condensers, and piping. A cathodic protection anode bed is installed to provide protection against electro-chemical deterioration of the plant as well as supply and reinjection piping.

3.3.7 Fresh Water System

One fresh water well approximately 400 feet deep will supply water for the fire protection system, make-up water for the cooling tower, and all necessary potable water for the office and generator building. The capacity for the well pump is 1,000 gpm.

The system is designed so that all systems will be shut off except the fire protection system should a fire be detected.

The system is backed up by a 100,000 gallon above ground insulated tank. The auxilliary tank pressure is maintained by a boost pump.

3.3.8 Supply, Storage, Fill and Drain - Tanks, Piping, Valves, etc.

The brine system vents are valved 1 in. diameter pipe, and are located on the top of the tube bundle head on the boilers, and on the top of the brine outlet piping on the preheaters.

The brine system drains are valved 2 in. dia outlets in the bottom of the boiler tube bundle heads, and the bottom of the brine inlet piping at the preheaters. These outlets are enlarged to four inches before connection to an underground drain that flows to the brine leaching basin.

The isobutane vent system is connected to the top of the outlet piping on the boilers and preheaters, and consists of a valved 2 in. pipe with a valved 1 in. atmospheric vent connection adjacent to each unit. Each unit vent is connected to a 2 in. diameter header that collects all of the heat exchangers. A 2 in. diameter line from the header conducts gas to the inlet header of the condensers. This line is valved in the same manner as the unit vents with a 1 in. diameter vent to the atmosphere with connections for pressure gauges.

The isobutane drain system consists of a valved 2 in. diameter connection at the bottom of the inlet piping to the boilers and preheaters. These join a 4 in. diameter header from all units, and a 4 in. diameter pipe conducts the isobutane to the drain pump, which delivers the isobutane to the storage tanks, hot-well, or to the isobutane supply line on either side of the turbine driven feed pump. Valved connecting lines are also provided from the isobutane piping on either side of the generator turbine, pump turbine, the suction side of the turbine pump, the inlet header of the condensers, or the outlet pipe of the hot-well.

The isobutane storage tanks have outlet piping connected to a 12" diameter pipe header that feeds the transfer pump. A 4 in. diameter valved connection between the suction side of the transfer pump will by-pass isobutane to the suction line of the drain pump.

A 12 in. diameter pipe connects the transfer pump to the hotwell with an alternate line connected to the discharge side of the drain pump.

The hotwell outlet to the boost pump supplies the turbine pump through a 20 in. diameter pipe. A by-pass allows the boost pump to be shut down during operation.

3.4 Buildings, Roads, and Foundations

A 44' x 104' power house building will house the turbine generator system, the control room, laboratory, and offices.

The building has concrete footings and foundation walls. The exterior walls are constructed of concrete block, reinforced by placing reinforcing bars and concrete in the cores for seismic loading. The partition separating the generator room is also constructed of concrete block. It acts as a shear wall for seismic loading and fire wall between the office area and the generator room.

The roof structure is constructed of structural steel joist with steel decking and cane fiber board insulation. A 3 ply 20 year built-up asbestos fiber asphalt impregnated roofing material is applied over the insulation using a low temp bonded asphalt.

The interior office partitions are constructed of frame material using nailed and taped sheetrock for the finished wall surface. The interior wall surfaces are painted and the building is protected by the use of a wet sprinkler system.

The pump houses are metal Butler type buildings protecting the pump and its associated electrical wiring and switching. Each building is set on a concrete foundation and is provided with adequate lighting for maintenance.

Access roads are provided to the power plant site as well as each of the well sites. The access roads to the various wells are **directly over** the supply and reinjection lines. The roads are all weather gravel surface roads capable of supporting heavy loads. The proposed area plan and plant layouts are shown in Appendix B, Sketches 2 and 3 respectively.

Three leaching ponds are constructed adjacent to the plant site. Two of the ponds are for cooling tower blowdown while the third is used to drain the entire plant brine system if necessary. Each pond has a capacity of 75,000 gallons. An additional smaller leaching pond is located at the low end or low point of each supply and reinjection line for draining these lines if necessary.

Concrete foundations are provided for the boilers, preheaters, pumps, turbine-generator skid, storage tanks, condensers, hotwell, and piping supports. All of these foundations have steel bearing plates where necessary. They are precision leveled and dry pack grouted to support the amount of designed weight.

3.5 Operational Considerations

The prerequisites for plant start-up should include the brine system operating in the by-pass mode, the domestic water system operating with the storage tank filled, the cooling tower operating with cooling water circulating through the condensers, and the system filled with isobutane. The shut-off valves to the turbines should be closed.

The isobutane system should be pressurized before brine circulation through the heat exchangers commences. Once the boiler outlet temperature reaches a preselected value, the turbine shut-off valves can be opened and the turbine generator and turbo pump can be brought to rated speed and the auxiliary pump can be dropped off line.

Once the system has stabilized and the generator frequency synchronized with the power grid the automatic switchgear should transfer the power to the grid.

Predetermined critical parameters are monitored automatically during normal plant operation and in the event of abnormal conditions, an alarm sounds and the system is automatically shutdown. Other selected operating parameters are monitored and only the alarm sounds in case of abnormalities. The operator has the decision to shut the plant down.

PLAN
SCALE 1/8"=1'-0"

REVISIONS			
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REVISIONS			
NO.	DATE	DESCRIPTION	APPROVED
1			

PARTY OF RECORD		PARTY OF IDENTIFYING NO.		NOMENCLATURE OR DESCRIPTION		MATERIAL SPECIFICATION		ITEM NO.	
UNLESS OTHERWISE SPECIFIED		DRAWN		DATE		PARTS LIST		ABROSET NEELEK COMPANY	
DIMENSIONING AND SYMBOLS ARE AMERICAN NATIONAL STANDARD		DESIGN						TITLE	
DIMENSIONS AND TOLERANCES ARE IN INCHES		DESIGN REVIEW						RGPF	
TOLERANCES:		STAMP						COMMERCIAL POWER PLANT	
DECIMALS: .125 = .1		WAVES						BRINE SUPPLY & REINJECTION	
FRACTIONS: 1/16 = .0625		SHEET						SYSTEM SCHEMATIC	
ANGULAR: 1/2° = .0087		DRAWING NUMBER						10 MW	
DO NOT SCALE DRAWING		SHEET						E 020020400 SKETCH #3	
QUALITY ASSURANCE		DRAWING FORM						RELEASE DATE	
ESSENTIALITY LEVEL								SHEET

AERJET NUCLEAR QUALITY ASSURANCE ESSENTIALITY LEVEL:

INDEX CODE NUMBER				SCALE: 1" = 20'				DATE ISSUED:			
AREA	DWG. TYPE	CL.	ORIG.	REV.	DATE	BY	DATE	NO.	DATE	BY	DATE

DESIGNED		BY		DATE		REVISIONS		APPROVED		DATE	
DRAWN		BY		DATE		APPROVED		APPROVED		DATE	
CHECKED		BY		DATE		APPROVED		APPROVED		DATE	
APPROVED		BY		DATE		APPROVED		APPROVED		DATE	
ORIGIN		BY		DATE		APPROVED		APPROVED		DATE	
AND		BY		DATE		APPROVED		APPROVED		DATE	
ASC		BY		DATE		APPROVED		APPROVED		DATE	
ASC		BY		DATE		APPROVED		APPROVED		DATE	
ASC HAS		BY		DATE		APPROVED		APPROVED		DATE	
ASC ESC		BY		DATE		APPROVED		APPROVED		DATE	

AERJET NUCLEAR COMPANY		INCORPORATED		IDAHO FALLS, IDAHO	
U. S. ATOMIC ENERGY COMMISSION		IDAHO OPERATIONS OFFICE		IDAHO FALLS, IDAHO	
COMMERCIAL		GEOTHERMAL		10 MW POWER PLANT	
PROPOSAL AREA PLAN		DWG. NO.		SKETCH #2	
PROJECT NO.		DATE		BY

AEROJET NUCLEAR QUALITY ASSURANCE ESSENTIALITY LEVEL:

INDEX CODE NUMBER				
AREA	DWG	TYPE	CL	SERIAL

NO.	DATE	REVISIONS	APPROV. AEC	APPROV. AEC	APPROV. AEC	APPROV. AEC	APPROV. AEC	APPROV. AEC
DESIGNED	BY	DATE	AEROJET NUCLEAR COMPANY					
DRAWN			INCORPORATED					
CHECKED			IDAHO FALLS, IDAHO					
APPROVED			FOR					
APPROVALS			U. S. ATOMIC ENERGY COMMISSION					
ORGAN	BY	DATE	IDAHO OPERATIONS OFFICE					
ANC			IDAHO FALLS, IDAHO					
ANC			COMMERCIAL					
ANC			GEOTHERMAL					
ANC H&B			10 MW POWER PLANT					
ANC E&C			PROPOSAL PLOT PLAN					
SCALE:	1" = 600'		DWG. NO. SKETCH #1					
DATE ISSUED:			K PROJECT NO.					

APPENDIX B

Sketch
Number

Title

1. Commercial Geothermal 10 MW Power Plant Proposal
Plot Plan
2. Commercial Geothermal 10 MW Power Plant Proposal
Area Plan
3. RRGF Commercial Power Plant 10 MW Brine Supply
and Reinjection System Schematic
4. RRGF 10 MW Binary Cycle Commercial Power Plant
Flow Diagram
5. RRGF 10 MW Binary Cycle Commercial Power Plant
Layout
6. RRGF 50 MW Binary Power Plant Piping Diagram
7. Construction Logic Diagram Raft River Project

REVISIONS		DATE	APPROVED
NO.	DESCRIPTION		

LEGEND

- COOLING WATER
- BRINE SOLUTION
- WORKING FLUID
- SHUT-OFF VALVE (NORMALLY CLOSED)
- SHUT-OFF VALVE (NORMALLY OPEN)
- CHECK VALVE
- FLOW CONTROL VALVE
- PUMP

PART OR IDENTIFYING NO.		NOMENCLATURE OR DESCRIPTION		MATERIAL/SPECIFICATION		ITEM NO.
UNLESS OTHERWISE SPECIFIED		PARTS LIST		DATE		
DIMENSIONS AND SYMBOLS ARE AMERICAN NATIONAL STANDARD		DRAWING NO.		REV.		
DIMENSIONS AND TOLERANCES ARE IN INCHES		TOLERANCES		DECIMALS		
				FRACTIONS		
				ANGULAR		
				DO NOT SCALE DRAWING		
PART NEXT FINAL		NEXT ASBY		USED ON		
QUALITY ASSURANCE		DRAWING		FORM		
ESSENTIALITY LEVEL						

AEROSOL NUCLEAR COMPANY		220 GF	
50 MW		BINARY POWER PLANT	
PIPING DIAGRAM		SKETCH #6	
SCALE		RELEASE DATE	
NONE

DISTRIBUTION RECORD FOR ANCR-1226

External

335 - UC-66 - Geothermal Energy - TID-4500, R63

24 - Special External Distribution per Authors List

Internal

1 - Chicago Patent Group - ERDA
9800 South Cass Avenue
Argonne, Illinois 60439

3 - A. T. Morphew, Classification and Technical Information Officer
ERDA-ID
Idaho Falls, Idaho 83401

31 - INEL Technical Library

60 - Authors

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