FEASIBILITY OF DEVELOPING GEOTHERMAL ENERGY INDUSTRIAL COMPLEXES

C. D. Hornburg

DSS ENGINEERS, INC.
FT. LAUDERDALE, FLA. 33317

Presented in this paper is a summary of a study performed for the Department of Energy under Contract EG-77-C-07-1627.

INTRODUCTION

Purpose and Concept

The overall purpose of this study was to provide economic, technical and other related information on developing industrial complexes to utilize geothermal energy. The basic concept was to select processes of production that may utilize large amounts of moderate temperature energy and group them together at specific geothermal sites for synergic production of products in an optimum economic manner.

Background

The potential for non-electrical utilization of geothermal energy has been investigated by many others.[1,2,3,4] This has been summarized for the ERDA by the Idaho National Engineering Laboratory in the report "National Program Definition Study for Non-Electrical Utilization of Geothermal Energy."[5] The potential for direct industrial utilization of geothermal heat is projected at about 10% of the total potential for direct use of geothermal heat. This would then equate to 2-4% of the total U.S. energy consumption by the year 2000. However, the author of this paper believes that the other potential non-electrical uses of geothermal in the U.S. cannot be obtained without achieving industrial utilization concurrently and that this is a necessary prerequisite.

It is believed that an incentive for developing Geothermal Energy Industrial Complexes (GEICs) must be established and then the concept implemented or realization of the predicted total potential for geothermal utilization in the United States will not be achieved. Also, another premise of the study was that maximum, efficient utilization of geothermal energy can be done best by developing synergistic industrial complexes with companion infrastructures at geothermal resource locations.

Study Plan and Tasks

The study plan consists of executing seven technical tasks in near sequential order to successively screen the alternate possibilities of: products to produce and processes; energy recovery systems and; reservoir types and locations. This was done in such a manner so as to arrive at selection of those products and processes matched to energy recovery systems and sites that offer the highest potential for economical utilization of geothermal energy. A preliminary design was made; capital and operating costs estimated and; the overall possibilities and problems in developing Geothermal Energy Industrial Complexes assessed.

IDENTIFICATION OF POTENTIAL PRODUCTS & PROCESSES

Procedure

The initial screening and selection was done by accomplishing the following steps: determine energy consumption in major industrial groups; analyze energy use in the major energy consuming industries; determine and rank the major steam-energy intensive processes; group products by energy use and raw material/product relationships.

Energy Using Processes

The large energy users in manufacturing are: food and kindred products; paper and allied products; chemicals and allied products; petroleum and coal tar products; stone, clay and glass products; and primary metal industries. An analysis of energy use within these groups revealed that the first four of these were the highest in direct heat use. The processes utilized in these industries were analyzed for steam energy intensiveness and total low pressure steam used. The seven product/processes that are steam energy intensive and are also the major consumers of thermal energy are:

1. Alumina via Bayers Process
2. Bleached Kraft paper in integrated mill
3. Caustic Soda from diaphragm cells
4. Cellulose Acetate
5. MgCl + Soda Ash via Bicarbonate
6. Soda Ash via Sesqui Process
7. Viscose Rayon

The average size plant for production of these products would use from 4.2 to 10.1×10^{12} Btu/yr. Twenty-seven additional products were identified as medium or low consumers of thermal energy but are high in the portion of final product value attributed to cost of steam used to produce them.

Potential Complexes

Based on this energy use analysis, the potential GEICs initially selected were as follows:

1. Forest Products Industries
2. Chlor-Alkali Industries
3. Alumina-Aluminum Products
4. Cellulosic Man-made Fibers
5. Magnesium Compounds and Soda Ash
6. Petro-Chemicals Complex
7. Food and Fermentation Products

The basic raw materials required for these GEICs are wood, NaCl, bauxite, wood pulp, trona ore and magnesium-rich brine, ethylene and grains, soybeans, peanuts, and cottonseeds.

MARKET ANALYSIS
SITES AND COMPLEX SIZES

Market Analysis

A review was made of the trade literature in order to assess the marketing viability of products that were previously identified as having potential for production via geothermal energy. Information obtained included production data, price data, uses, historical and projected growth data, U.S. producers and general economic data. Questionnaires were also sent to major suppliers of most of these products.

The assembled information was analyzed and the future demand estimated. Based on this, the additional production requirements for 1980-2000 were calculated. This was subsequently used to calculate the number of average size production plants for each product that may be needed during this period.

Siting Considerations

Information given in the U.S. Geological Circular 726 was used to evaluate the western geothermal reservoirs. Only those with an estimated heat capacity of 10×10^{12} Btu/yr for 30 years were considered suitable for developing as industrial complex sites. These were grouped according to temperature and heat capacity for evaluation. There are 29 western reservoirs with fluid temperatures of 200°C or less that have sufficient heat capacity for industrial complexes. These are located in seven different geographical western areas. From a preliminary assessment of other factors, reservoirs rated highest in potential for industrial complexes in each of the designated areas are as follows:

Calestoga, CA	Vale H.S., Ore.
Brawley, CA	Bruneau-Grandview, Ore.
Surprise Valley, CA	Steamboat Springs, Ne.
Lakeview,Ore.	Cove/Ft.Sulphurdale,Ut.

An analysis of the geopressured zones in Texas and Louisiana was made by evaluating the sub-areas designated in Circular 726. The cost and price of the recoverable energy from wells in each sub-area were determined. These areas were then ranked according to economic attractiveness of the energy supply. This indicated that sub-areas AT_1 and BT_1 in South Texas, inland from the coast, would yield the lowest cost geoenergy (methane + thermal). The sub-area through central Louisiana is indiginous to pulp and paper plants and the geoenergy (thermal plus methane) cost is estimated at $.86/MM Btu.

The survey for raw material availability in relation to the geothermal zones revealed the following:

Salt - Texas, Louisiana, Central Utah and South California.

Sodium Carbonate - Southwestern Wyoming, Northwestern Colorado. Brines in Sealres and Owens Lakes.

MG-Rich Brines - Sea water, Great Salt Lake Brines, solid deposits near Gabbs, Nev.

Aluminum Bearing Material - Alunite in Central Utah (near Roosevelt H.S.), shales from Northwest Colorado.

Wood and Wood Wastes - Suitable soft wood in Oregon, Northern California, Texas and Louisiana.

Materials for Food & Fermentation Products - Most promising is corn and grain from Central U.S. to Idaho and potatoes.

The potential industrial complexes were matched to those areas identified with the availability of the raw materials and suitable geothermal resources.

Complex Selection and Sizing

The economical plant size to produce the identified products and the number of these plants needed between 1980 and 2000 to meet the estimated demand was determined. This is shown in Table 1. Product

TABLE 1
NUMBER OF PLANTS REQUIRED

PRODUCT	PLANT SIZE (1000s TONS/YR.) RANGE	AVERAGE	NO. AVERAGE SIZE PLANTS 1980-1990	1990-2000	TOTAL
PAPER MILL PRODUCTS	100-500	350	59	89	148
ALUMINUM	100-200	250	45	81	126
ALUMINA	400-1000	700	16	28	44
CAUSTIC/CHLORINE	300-1000	500	20	36	56
SOYBEAN OIL	25-300	150	21	35	56
CORN SYRUP (HFCS)	25-250	100	18	32	50
ETHYLENE GLYCOL	50-350	200	12	23	35
ETHYLENE OXIDE	100-300	200	12	21	33
BUTYL ALCOHOL	10-75	50	13	41	54
ACETIC ACID	50-250	150	9	16	25
SODIUM CHLORATE	10-50	30	9	17	26
MAGNESIUM	20-100	60	8	18	26
ACETONE	50-150	100	6	9	15

mixes for the main complexes were selected considering this information as well as the interrelationship between processes, raw material requirements and energy use. The three complexes with the highest potential for economic geothermal utilization are as follows:

Forest Products: (Oregon, Northern California or Louisiana)

Kraft Paper Products	- 330,000 tons/yr
Crude Tall Oil	- 14,850 tons/yr
Turpentine	- $1x10^6$ gal/yr

Lumber, plywood and selected wood chemicals

Caustic/Chlorine Products: (Southern California or Texas)

	1000s Tons/yr
Caustic Soda (50% solution)	1000.00
Chlorine	886.50
Sodium Chlorate	30.00
Ammonia	135.25
Oxygen	35.50

Corn Products: (Idaho)

Caustic/Chlorine Complex	1000s Tons/yr
Corn Syrup	150.0
Corn Starch	150.0
Dextrose Sugar	75.5
Syrup for Fermentation	75.0
Corn Oil	24.8
Animal Feeds	343.0

Other "high potential" complexes identified include:

a) Soda ash and allied products from trona deposits in Searles and Owens Lakes

b) Aluminum sulfate, alumina and potassium sulfate from alunite in Central Utah

c) Soda ash, shale oil and alumina in central Utah from ores in western Colorado.

PRODUCTION PROCESSES

Pulp and Paper Products

There are presently several methods to produce pulp from wood. The alkaline sulfate, or Kraft process accounts for about 70% of the pulp production in the U.S. This process was selected as the basic process to analyze for the forest products complex in this study. Other promising processes under development and in the pilot plant stage are the alkaline-oxygen (A-O) pulping process and the Rapson Effluent-Free Kraft process. The making of paper and paperboard from pulp is fairly standardized. Large quantities of heat are used to dry a deposit on a fine screen in forming paper.

Wood Chemicals

The three main routes to chemical production from wood are pyrolysis, direct hydrogenation and hydrolyzing. Analysis of these revealed that only hydrolysis could beneficially use geothermal energy. Of the various hydrolysis processes tested, or under development, the Madison Dilute Sulfuric Acid Process was selected as the basis of evaluation in the study. This process produces sugars and lignin from wood wastes using dilute sulfuric acid and heat. Then, there are a large number of products that can be produced from these by many different processes. Considering the factors important in the study, the products and annual production rates selected were as follows:

Product	1000s tons/yr
Ethanol (190 proof)	101.40
Acetic Acid	120.20
Phenol	55.80
Benzene	53.20
Furfural	6.51
Methanol	5.43
Yeast	29.90

Caustic/Chlorine Complex

For caustic and chlorine production, the diaphragm cell for electrolysis would be used in lieu of a mercury cell. Sodium Chlorate would be made using a similar cell without the diaphragm. Liquor from these cells is concentrated in double effect evaporators. Nitrogen, obtained from air liquefaction and rectification is mixed with hydrogen from the electrolysis operations, under pressure, in a reactor to produce ammonia. An average of 395 MWe and 880,000 #/hr steam are required by the basic caustic/chlorine products complex selected.

Corn Products

For the corn products complex, the sulfurous acid method of refining is employed using shelled corn as raw material. It undergoes physical changes followed by chemical conversion of starch to dextrines, syrups, and dextrose. All the thermal energy required for the operation can be supplied by steam at 35 psia or less. The annual thermal requirement to meet the production rates selected would be about $3.02x10^{12}$ Btu/yr.

Alumina and Related Products

An alunite processing complex planned for Utah would produce 500,000 t/yr alumina, 370,000 t/yr potassium sulfate, 1.1 MM t/yr phosphate fertilizers, 605,000 t/yr ammonia phosphates, and 20,000 t/yr aluminum fluoride. It will require approximately $3.94x10^{12}$ Btu/yr of heat as low pressure process steam. However, it appears that this complex will be implemented before energy from the geothermal resource in this area can be made commercially available.

Nahcolite-Dawsonite Complex

A Nahcolite-Dawsonite processing complex could be developed in northwest Colorado. Such a complex could use about 40×10^{12} Btu/yr of heat from low pressure steam. The white nahcolite and nahcolite-rich fines could be transported to the Cove-Ft. Sulfurdale geothermal area for producing soda ash. To produce 10,000 tons per day of soda ash would require 14.5×10^{12} Btu/yr of low temperature heat.

Trona Brine Complex

A complex to process brine from Searles or Owens Lakes could be established at, or near, Coso Hot Springs. This complex could produce soda ash, sodium sulfate, lithium carbonate, potassium chloride, borax and, possibly sodium chloride. Caustic/chlorine could also be produced here using the sodium chloride brine.

ENERGY SUPPLY ANALYSIS

Introduction

This work involved primarily the design and analysis of systems to upgrade the thermal energy in the available geothermal fluids to fit the requirements of the selected processes. Other potential problems in utilizing geothermal fluids such as scaling, corrosion and non-condensable gases were investigated.

Heat can be extracted from the geothermal fluid for process use by direct heat exchange to the process fluid; production of steam for process heating; production of steam for generating shaft power or; production of a secondary vapor (from isobutane, etc.) for electricity generation, shaft power or process heating. Since steam is the most widely used process heating media, alternate systems to supply process steam at required pressures from low temperature geothermal fluids were analyzed. These systems incorporate compression for upgrading, or beneficiation, of the available energy.

Steam Compression

Compression can be accomplished via steam jets or mechanical means. Electric motors, engines, steam turbines or isobutane turbines can be used as drives for mechanical compression. In the case of steam jets or steam turbines, high pressure steam would have to be generated from fossil fuel or waste heat. The effective utilization of this high pressure steam is quite low in a steam jet but 98% effective with a back pressure steam turbine driving a compressor. However, the jet compressor is very low in cost compared to a steam turbine and does have application for small quantities of process steam.

An analysis of mechanical compression modes indicated that a multi-effect compression with desuperheating between effects would give reasonable efficiency coupled with simplicity. The effects chosen correspond to the process steam pressures of 25, 45, 75 and 135 psia which are commonly used. Of the alternate compressors that should be used for this duty, the centrifugal machine is most appropriate to supply process steam for large industrial complexes. These could efficiently compress steam in a flow range from 50,000 #/hr. to 200,000 #/hr with a single unit. For those applications where less than 50,000 #/hr is needed it would be more economical, and technically correct, to use a screw machine and wet vapor at the inlet.

Of the alternate drives for the compressor, the choice is usually between a steam turbine and an isobutane turbine. The choice depends on the amount of electricity needed in the plant when "in-house" generation is accomplished. In those cases where more electricity than needed in the plant can be generated via waste heat produced steam, some of this high pressure steam should be used to beneficiate low pressure steam produced from geothermal fluid. However, additional steam should not be generated via fossil fuel for a turbine driven compressor.

Self-Beneficiated System

A system using a turbine operating on a hydrocarbon or fluorcarbon fluid offers the advantage of being able to extract further low grade heat from the geothermal fluid and convert this to mechanical power for compression. This is done at low temperature and pressure, but a high turbine efficiency, small turbine size and low initial cost is attained.

A simplified geothermal energy self-beneficiation system is shown in Figure 1. This uses only geothermal fluid after flashing to heat and evaporate isobutane which passes through a turbine driving the steam compressors. For this to be done, the compressor work required must be such that the total geothermal fluid needed to produce the flashed steam is equal to the amount of brine needed (at the temperature after flashing) to produce work required by the isobutane turbine for compression.

The optimum operating conditions vary with geothermal fluid temperature and process steam temperature required. A computer program was developed and utilized to determine the optimum operating conditions. The resulting minimum pounds of geothermal fluid per pound of process steam at various fluid temperatures and process steam pressures is shown in Figure 2.

SIMPLIFIED GEOTHERMAL ENERGY SELF BENEFICIATION SYSTEM

FIGURE 1

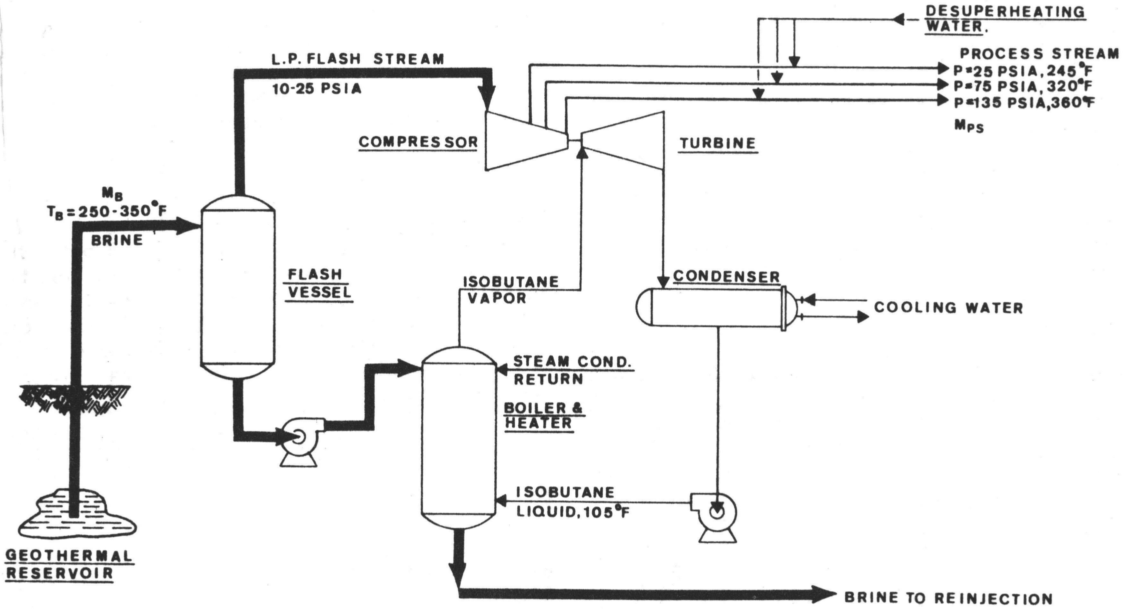
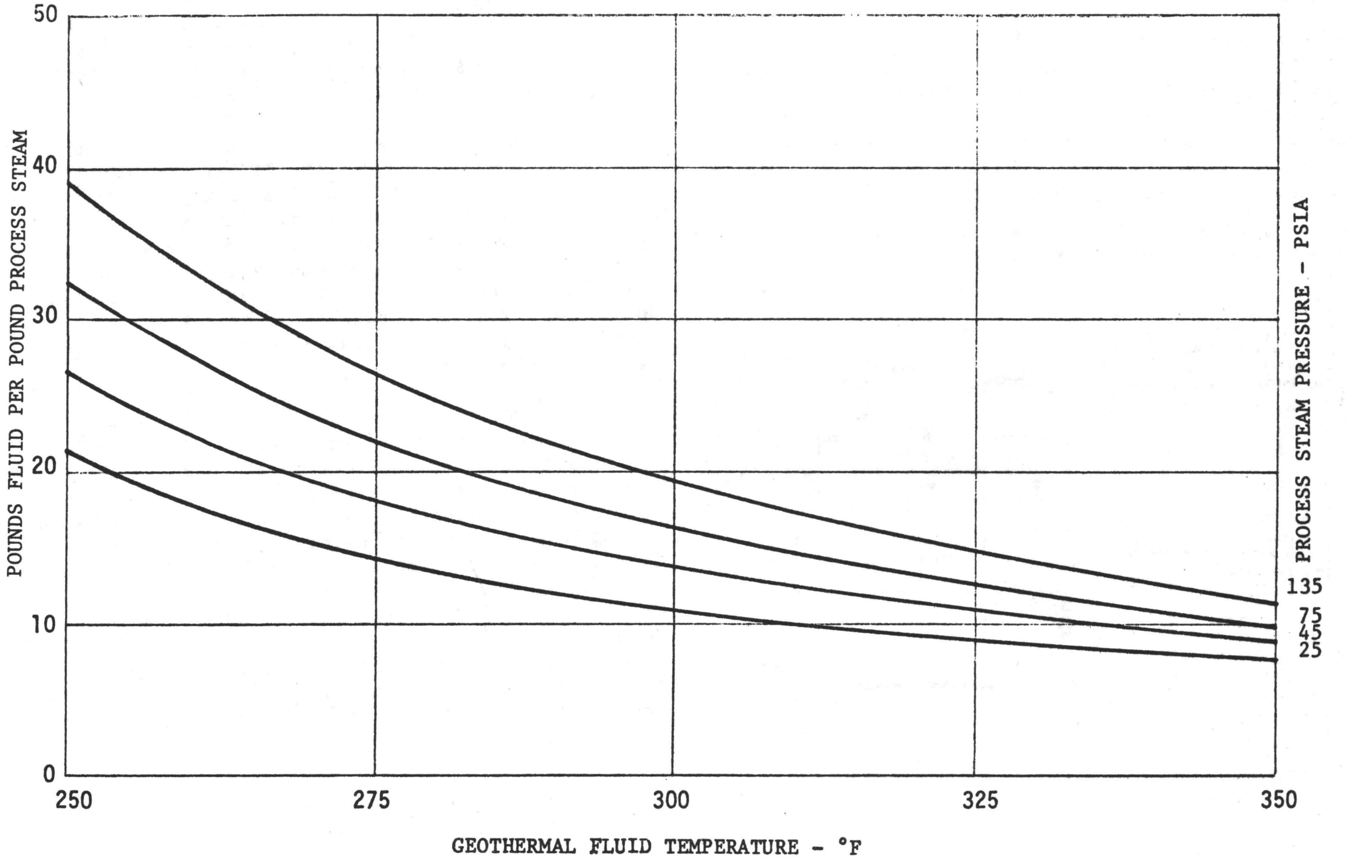


FIGURE 2

SELF BENEFICIATION SYSTEM MINIMUM GEOTHERMAL FLUID/ PROCESS STEAM USING FLASHED BRINE TO DCHX



Also, using a computer program, complete typical self-beneficiation systems to produce 250,000 lbs/hr of steam at 25, 45, 75 and 135 psia pressures from geothermal fluid at 250°F through 350°F (in 25°F increments) were designed. This included all operating temperatures and pressures, vessel sizes; pumps, turbine and compressor sizes and; well field data. This data is tabulated in the final report and was used to estimate costs of beneficiated steam. The systems use a direct contact heat exchanger (DCHX) for heating and evaporating isobutane in a closed loop. The DCHX was designed in accordance with methods developed by DSS Engineers[6,7] from development and test work done under ERDA Contracts.

Non-Condensable Gases

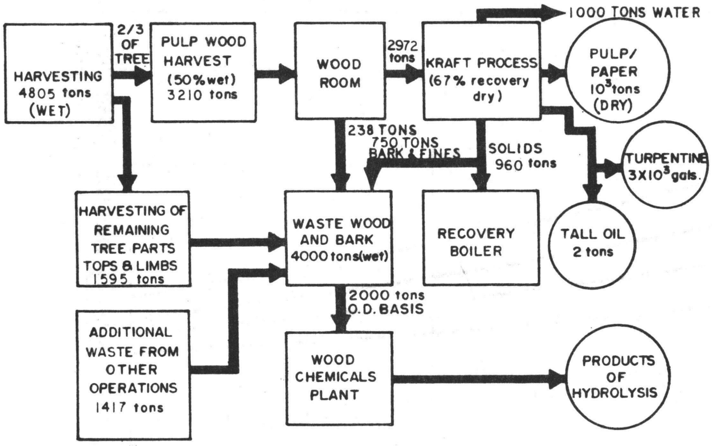
It appears that, in most cases, non-condensible gases will be released from the geothermal fluid if it is flashed to produced steam. By proper care in designing process heating equipment, particularly in material selection, these gases can be tolerated. Care must also be taken concerning environmental and safety aspects. It may be found that in most cases where non-condensible gases, particularly hydrogen sulfide, are present in the geothermal fluid, a steam generator using submerged tubes to produce "clean steam" is the best solution to this problem. The design is simple and costs are small. In this case, the gases would remain with the geothermal fluid to be reinjected into the ground.

FOREST PRODUCTS COMPLEX DESIGN

General

In preparing the designs for utilizing geothermal energy in both pulp and paper mills and in processes producing wood chemicals, the philosophy was to: 1) maximize the use of geothermal energy in each case and; 2) use conventional equipment whenever new or additional equipment was required. Also, plant modifications for geothermal use were minimized.

The overall material flow for the forest products complex is shown in Figure 3.



PRINCIPAL MATERIAL FLOW IN FOREST PRODUCTS COMPLEX

FIG. 3

From this it can be seen that all waste wood from the Kraft process is directed to the wood chemicals plant. Thus, the pulp and paper mill is denied steam generation via bark boilers as is the usual practice. The wood chemicals plant would also receive the balance of the trees harvested for pulp wood plus waste wood from other forest operations in the area.

Pulp and Paper Mill

The pulp and paper plant consists of: 1) Pulping process unit, 2) Bleach Plant and, 3) Paper Mill. Process flow diagrams for a typical 1000 ton/day bleached pulp and paper mill are presented in the final contract report. These were based on the standard Kraft, or sulfate method and show all heat requirements for the processes. The process steam needed for the conventional plant is as follows:

Use	Steam - #/Hr 25 psia	135 psia
Wash Water Heating	247,654	-o-
Evaporators	114,594	-o-
Miscellaneous, L.P.	2,952	-o-
Black Liquod Heating	-o-	5,630
Digester	-o-	160,734
Dryer	-o-	333,016
Miscellaneous, H.P.	-o-	69,980
Totals	365,200	569,360

In addition to this process steam, 29,800 KW of electricity is needed for plant operation. The energy needs are met by generating steam at 450 psia, 700°F in a black liquor boiler, a bark boiler and a conventional fossil fuel fired boiler. Most of this steam is passed through a back pressure/extraction turbine to generate the required electricity before being utilized in the processes.

In examining the process heat usage it was found that water heating and heating of air for paper drying could be partly accomplished with geothermal hot water instead of steam. Also, some heat could be supplied at lower pressures. Thus, with these simple changes in process equipment, the adjusted heat requirements for geothermal use became: Hot water - 221,010 M Btu/hr; 25 psia steam - 484,375 #/hr; 75 psia steam - 76,090 #/hr; 135 psia steam-162,685 #/hr.

The geothermal energy system designed to supply this energy is shown in Figure 4. In this system, the bark boiler and fuel oil boiler used in the conventional system is eliminated and the heat previously supplied by these units is now furnished by a geothermal self-beneficiation system using 6,289,000 #/hr of geothermal fluid at 250°F. This saves 2,340,600 MM Btu/yr from bark and 3,422,300 MM Btu per year from fuel oil. However, now only 20,000 KW of electricity is generated. Thus, 9800 KW of electricity must be purchased, generated from additional geothermal fluid, or generated from steam produced by the wastes from the wood chemicals plant.

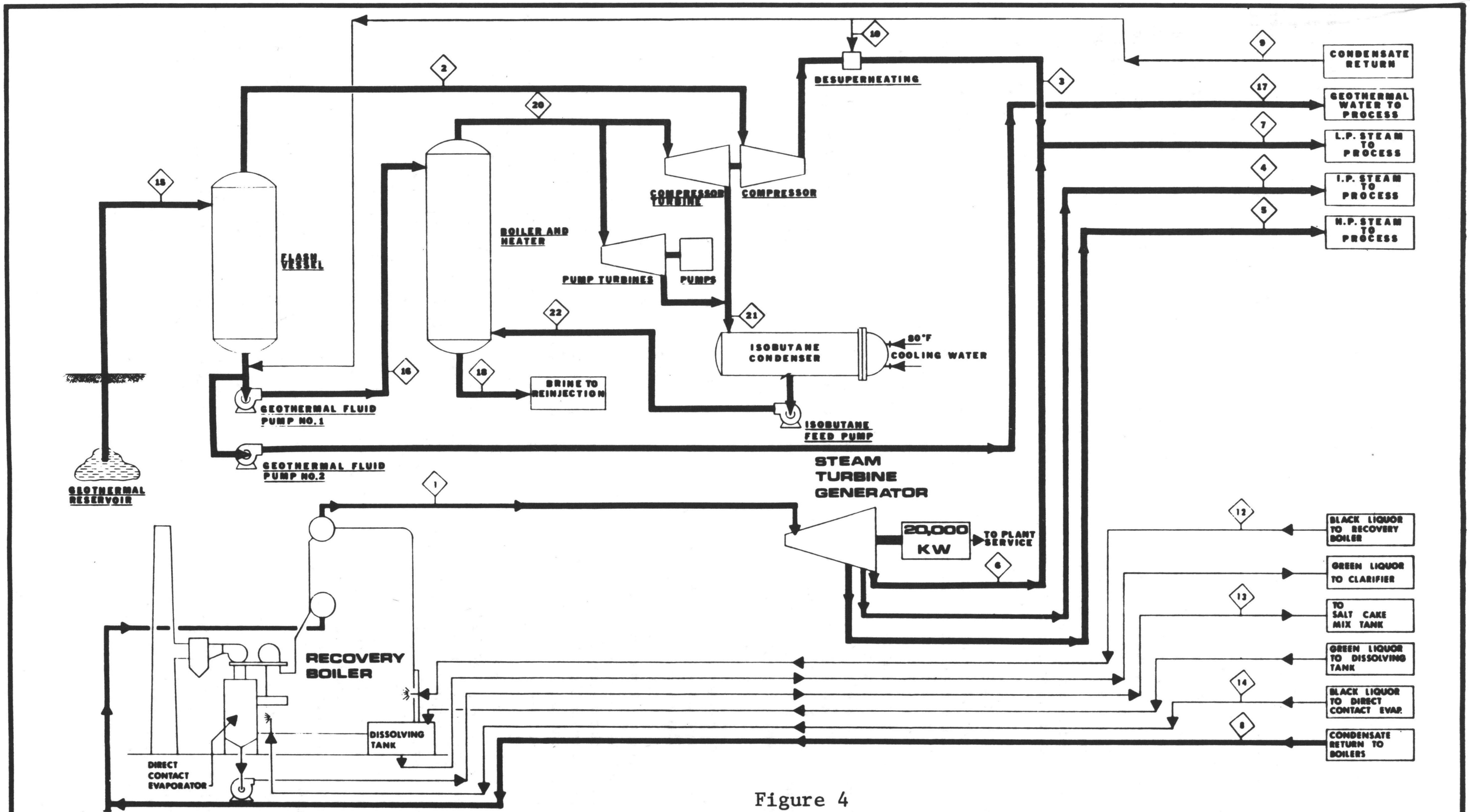


Figure 4

MATERIAL BALANCE — PROCESS STREAM NUMBERS

	H.P. STEAM FROM RECOVERY BOILER	GEOTHERM FLASHED STEAM	GEOTHERM COMPRESSED STEAM	I.P. STEAM TO PROCESS	H.P. STEAM TO PROCESS	L.P. STEAM FROM TURBINE GENERATOR	L.P. STEAM TO PROCESS	CONDENSATE RETURN TO BOILER	CONDENSATE RETURN TO GEOTH. ENERGY	CONDENSATE TO DESUPER-HEAT		BLACK LIQUOR TO RECOVERY BOILER	LIQUOR TO SALT CAKE MIX TANK	BLACK LIQ. TO DIRECT CONTACT EVAP.	GEOTHERM BRINE TO FLASH VESSEL	BRINE TO BOILER AND HEATER	GEOTHERM WATER TO PROCESS	BRINE TO REINJECTION		ISOBUTANE TO TURBINES	ISOBUTANE TO CONDENSER	ISOBUTANE TO HEATER
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
FLOW (#/HR)	464,450	249,130	258,700	76,090	162,685	225,675	488,375	469,462	258,700	9,570		246,792	244,170	293,000	6,289,000	3,456,000	2,833,000	3,456,000		1,405,400	1,405,400	1,405,400
TEMPERATURE (°F.)	700	212	245	388	480	245	245	318	240	240		220	185	134	250	213	213	146.3		160.0	124.5	105
PRESSURE (PSIA)	680	14.7	25	75	135	25	25	—	50	50		—	—	—	—	165	50	159.8		159.8	84.5	165
ENTHALPY (BTU/#)	1349.9	1150.5	1163.5	1225.7	1260.7	1163.5	1163.5	287.9	208.5	208.5		—	—	—	218.6	177.4	177.4	112.0		151.8	149.5	1.9

PLANT SIZE: 1000 TONS/DAY

DSS ENGINEERS, Inc.

GEOTHERMAL ENERGY SYSTEM
PULP & PAPER MANUFACTURE

080-5008

Wood Chemicals Plant

The cornerstone of the wood chemicals plant is the dilute acid hydrolysis process for separation of the lignin from the other constituents of wood. This process has been commercially employed, but on a limited basis. Following hydrolysis, a two stage flash process extracts the methanol and furfural leaving wood sugars for processing. The other processes are employed in the fermentation and chemical industries but usually with some different equipment and arrangement than employed for the present concept. For this reason, it was necessary to develop detailed process flow diagrams for each process (where possible) and size all equipment needed in order to estimate total capital costs. Total costs of producing the products using geothermal energy could then be estimated and the economics of integrating the wood chemicals plant with a pulp and paper mill analyzed.

Basic design information for the main processes presented in the final report was taken from the pilot plant data reported on the pilot plant operation by the Forest Products Laboratory,[8] the development work carried out by TVA[9] and preliminary designs presented by Katzen and Associates.[10] Complete process flow diagrams for the processes along with sizes of all equipment needed are given in the final report. Most of the equipment required is standard chemical/ process plant equipment and has been designed in accordance with good chemical engineering practice.

The plant requires 220,100 lbs/hr steam at 45 psia, 112,200 pounds per hour at 100 psia and 77,000 pounds per hour at 250 psia. The electricity required is 6650 KW. A system similar to that for the pulp and paper mill was designed to supply this required energy. Sludge from the first stage flash drum of the seperation process is burned in a recovery boiler to produce 308,000 pounds per hour steam at 450 psig, 700°F. An extraction and condensing turbine is used to generate all the electricity for the plant plus the 9800 KW required by the pulp and paper mill. Extraction steam is 77,000 pounds at 250 psia and 112,200 pounds per hour at 100 psia. The balance is condensed at 1.3 psia in order to produce a total electrical generation of 16,450 KW. Thus, for the basic wood chemicals plant (without acetic acid production), 220,100 pounds per hour of steam at 45 psia is needed from geothermal fluid. This would be supplied by a self-beneficiation system in accordance with the design described previously.

COSTS AND ECONOMICS

General Procedure

For the economic analysis we selected the general location of Southern Oregon for the Forest Products Complex. Specifically, we examined the cases of Lakeview and Hot Lake as affecting the geothermal energy supply costs and profits. Otherwise, we assumed a typical average condition existing for construction and operation.

Since the pulp and paper plant is a standard bleached Kraft process plant it is not considered necessary to estimate the total capital and operating costs but only to determine the costs applicable to changes needed to utilize geothermal energy. This included changes in process equipment as well as the energy supply systems.

This was not possible for the wood chemicals plant since there is no present commercial plant incorporating the processes and combination conceived for the Forest Products Complex. Therefore, it was necessary to estimate base equipment costs and/or obtain quotations and factors were then applied to these for construction costs to arrive at the total capital costs. Thus, the profitability of this type of plant as well as the geothermal energy system for it were determined.

In all cases, capital and operating costs are based on mid-1977 costs. This was determined by escalating costs from prior year costs in accordance with engineering equipment and construction cost indexes.

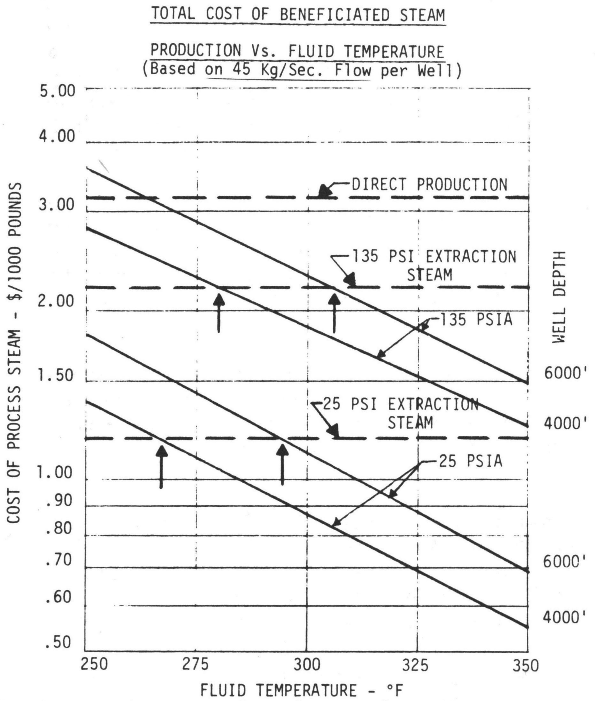
The costs of geothermal wells were based on a flow rate of 45 kg/sec/well and 6000'depth. Cost data for wells as presented by Milora and Tester was used. Reinjection wells equal to the number of supply wells was assumed. With appropriate factors applied for surface piping and indirect costs, the total well cost used is 3 times the cost of drilling and casing the production wells required.

Geothermal Energy Supply Systems Cost

Capital and unit operating costs were estimated for geothermal self-beneficiation steam production facilities with a capacity of 250,000 #/hr. This was done for pressures of 25,45,75 and 135 psia, different fluid temperatures and different well depths. Capital costs range from $9,432 per 1000 lbs/hr to $47,183 per 1000 lbs per hour. The total unit costs to produce steam via these systems vary from $.70 per pound of 25 psia process steam from 350 F fluid with 2000 foot wells to $3.65 for 135 psia steam from 250 F fluid with 6000 foot wells. Total unit production costs vs. fluid temperatures for 4000' and 6000' wells are plotted in Figure 5.

Also shown on this graph is the cost of steam produced from fossil fuel costing $2.50 per MM Btu. This is $3.20 per 1000 pounds for steam produced directly and then at reduced costs for steam extracted from a high pressure turbine. The break even points between costs of extraction steam and geothermal steam are 290°F and 310°F for 25 psia and 135 psia steam from 6000' wells.

FIGURE 5



The investment cost for the geothermal energy supply systems for a pulp and paper mill were estimated at $29,240,000 with 120°C fluid, $18,370,000 with 160°C fluid and $13,784,000 with 180°C fluid. Unit production costs using 5% annual depreciation would be $0.886, $0.556 and $0.417 per MM Btu with these respective fluid temperatures. These costs are low because about half the heat is extracted directly from the geothermal fluid without the need for producing steam.

For the wood chemicals plant the investment cost for the energy supply system is $14,846,000 and $11,601,000 with 160°C and 180°C fluid, respectively. The unit costs are $1.02 and $0.80 per 1000 pounds of 45 psia steam. These costs are based on 5% annual depreciation and no interest.

Pulp and Paper Mill

Capital and operating costs for the pulp and paper mill were not estimated but the changes needed in the process equipment and the standard energy system were estimated. The total reduction in invested capital due to these items would be $11,157,000. The total reduction in annual costs due to this plus revenue from bark and fuel oil savings is estimated at $10,488,000. This amount was considered to be revenue to the geothermal supply system in calculating the ROI for that system.

Wood Chemicals

The total investment for the grass roots wood chemicals plant is estimated to be $91,290,000. For this same plant built as part of the pulp and paper mill, the investment costs would be reduced to $80,757,000.

The annual costs would be $35,525,000 and $34,325,000 for the grass roots and integrated plants respectively. This is based on waste wood at $28.90/ODT, geothermal steam at $2.65/1000 pounds and credit for electricity produced at $.04/Kw-hr.

Profitability

The return on investment (ROI) criteria was used to measure the relative profitability of each venture. This was done as return on total investment required and return or 50% of the total investment with 50% financed at 8% interest. No discounted cash flow analysis was made.

For the pulp and paper mill, the annual savings of $10,488,000 was considered revenue to the geothermal energy system. The profits and corresponding ROIs (before taxes) are as follows:

PULP AND PAPER GEOTHERMAL ENERGY SYSTEM

FLUID TEMP.	INVESTMENT $ 1000s	PROFIT $1000s	ROI(%) OVERALL	ROI(%) 50% EQUITY
250°F	27,240	7,137	24.4	40.8
320°F	18,370	8,387	45.7	83.4
356°F	13,784	8,911	64.6	121.2

For the wood chemicals plant, it was arbitrarily decided to make the charges for the geothermal energy such that the ROI for the geothermal energy system would be 19% overall and 30% with 50% equity and 50% debt at 8% interest. This was for a system using 320°F fluid and amounts to charges/revenues of $4,600,000 per year. With higher fluid temperatures, the ROI will increase. The profits and ROIs are as follows:

WOOD CHEMICALS GEOTHERMAL ENERGY SYSTEM

FLUID TEMP.	INVESTMENT $ 1000s	PROFIT $1000s	ROI(%) OVERALL	ROI(%) 50% EQUITY
320°F	14,826	2,826	19,0	30.0
356°F	11,601	3,212	27.7	57.4

A combined energy system for both plants would yield 29.3% and 50.6% ROIs from 320°F fluid and 42% and 70% from 356°F fluid. This is without considering possible savings in investment costs due to the single larger system.

Assuming all the output from the wood chemicals plant is sold, the total annual sales would be $58,937,000 based on prices as of September 1977. Deducting 15% for transportation, sales and administration costs leaves $50,197,000 as operating revenue. The annual profit before taxes for an integrated plant would be $15,872,000 for an ROI of 19.7% (total investment) and 31.4% on 50% equity capital, 50% debt at 8% interest.

FINDINGS AND CONCLUSIONS

1. The three industrial complexes that have the highest potential for near term implementation are Forest Products, Caustic/Chlorine products and Corn Products.

2. Energy supply systems should incorporate beneficiation of flashed steam for process use. Mechanical compression via "self-beneficiation" using isobutane turbines appears very promising.

3. Non-Condensable gas that may be in some geothermal fluids can most effectively be handled if a steam generator using total fluid flow through the tubes is employed. This will produce "clean steam" for beneficiation and process use.

4. A wood chemicals plant can be designed based on the dilute acid hydrolysis process to produce ethanol, methanol, furfural, yeast and lignin. The hydrogenation of this lignin to phenol and benzene appears feasible but information is lacking to prepare a definitive design.

5. The cost of producing beneficiated steam from geothermal fluid down to 250°F should be less than steam produced at the same pressures directly from fossil fuel. This is at average expected conditions. However, compared to steam that is produced from fossil fuel at higher pressures and partially expanded through a turbine prior to process use the minimum geothermal fluid temperature would have to be 265 - 350°F or the other conditions for the geothermal fluid supply would have to be more favorable than those assumed.

6. The heat that can be supplied from geothermal fluid for a 1000 ton per day pulp and paper mill is about 479.7 MM Btu/hr or $3.8x10^{12}$ Btu/year. About half of this is low level heat derived directly from the geothermal fluid.

7. The geothermal heat that can be supplied to a wood chemicals plant processing 2000 ODT/day of wood is 220.1 MM Btu/hr or $1.74x10^{12}$ Btu/year. This would be supplied at 45 psia.

8. A geothermal system to supply heat to a pulp and paper mill would be highly profitable even using geothermal fluid as low as 250°F.

9. The wood chemicals plant would yield reasonable ROIs when integrated with a pulp and paper mill and operating with 320°F or higher geothermal fluid. The ROI's are marginal for a grass roots facility.

REFERENCES

1. Lindal, B. "Industrial and Other Applications of Geothermal Energy", in Geothermal Energy; Review of Research and Development (United Nations Education, Scientific, and Cultural Office), Paris, 1973. LC No.72-971, 38, pp. 135-148.

2. Hornburg, C.D. and Morin, O.J., DSS Engineers Inc. "Geothermal Resource Utilization, Paper and Cane Sugar Industries", for Lawrence Livermore Laboratory, Contract No. W-7405-Eng-40, March 1975.

3. Howard, J.H., Editor, "Present Status and Future Prospects for Non-Electrical Uses of Geothermal Resources", Lawrence Livermore Laboratory for ERDA. Contract W-7405-Eng-48, October 1975.

4. Reisted, G.M., "Analysis of Potential Non-Electrical Applications of Geothermal Energy and Their Place in the national Economy", Lawrence Livermore Laboratory for the ERDA, Contract W-7405-Eng-48, February 1975.

5. Kunze, J.F. & Richardson, A. S. "National Definition Study for Non-Electrical Utilization of Geothermal Energy", INEL Report ANCR-1214, June 1975 for the ERDA.

6. Suratt, W.B. and Hart, G.K. "Study and Testing of Direct Contact Heat Exchangers for Geothermal Brines", June 1975-July 1976. DSS Engineers, Inc. for ERDA under Contract No. E-(40-1)-4893.

7. Suratt, W.B. and Lee, Chang-Ou, "Testing and Development of Direct Contact Heat Exchangers for Geothermal Brines", July 1976-September 1977. DSS Engineers, Inc. for ERDA under Contract No. E-(40-1)-4893.

8. Harris, E.E. and Beglinger, E., "Madison Wood Sugar Processes", Industrial and Engineering Chemistry, Vol.38, No. 9 (1946) pp 890-894.

9. Gilbert, N., et.al. "Hydrolysis of Wood Using Dilute Sulfuric Acid", Industrial and Engineering Chemistry, Vol.44, No.7 (1952) pp 1712-1720.

10. "Chemicals from Wood Wastes", Raphael Katzen Associates, AN441 for USDA, Forest Service. December 1975.

11. Milora, S.L. and Tester, J.W. Geothermal Energy as a Source of Power, MIT Press, Cambridge, Mass. 1976.