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**APPLICATIONS OF GEOTHERMAL RESOURCES IN THE
EVAPORATION AND CRYSTALLIZATION INDUSTRY**

Final Report, September 1976–October 1977

By
S. C. May
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P. T. Doyle
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October 1977

Work Performed Under Contract No. EY-76-C-03-1328

**Bechtel Corporation
San Francisco, California**

**U. S. DEPARTMENT OF ENERGY
Geothermal Energy**

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**BECHTEL CORPORATION
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San Francisco, California**

OCTOBER 1977

**PREPARED FOR THE
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
DIVISION OF GEOTHERMAL ENERGY
UNDER CONTRACT No. EY-76-C-03-1328**

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ABSTRACT

The objective in this study was to determine the technical and economic feasibility of using low-temperature geothermal energy (hot brines) in place of steam from conventional sources in the evaporation and crystallization industry.

A survey of major industries was carried out in order to choose three industries that were significant users of energy, could utilize geothermal brine, and demonstrate the broad range of industrial evaporation and crystallization operations. The selected industries were the preserved fruit and vegetable, sugar and confectionary products, and chemical industries. From among each of the selected industries, an example case was chosen for technical and economic evaluation. This evaluation included use of the "feed-and-bleed" process for energy extraction from the low-temperature geothermal brine. This process was chosen as the best process to use because it provides one of the most efficient means of utilizing geothermal brine in evaporation/crystallization operations.

This study concludes that, under certain conditions, geothermal energy could be used economically in the evaporation and crystallization industry. The factors that would most affect cost include geothermal resource characteristics (well flow, temperature, and distance of transportation); the energy extraction process chosen (the feed-and-bleed process uses the least amount of brine); and the duration of the evaporation/crystallization process.

A program to aid in implementing the use of geothermal energy is included.

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Section 1

INTRODUCTION

Over the past several years, the United States has had to rely increasingly on imported crude oil to meet its energy needs. This trend will continue unless greater use is made of all available domestic energy resources. With this in mind, the Energy Research and Development Agency (ERDA), through its Division of Geothermal Energy, has established as one of its goals the development of the abundant U.S. geothermal resources. To provide early momentum to this effort, ERDA has initiated several research, development, and demonstration-type projects to stimulate rapid exploitation of "liquid-dominated hydrothermal" resources. This class of geothermal resource, in comparison with the various other types of geothermal resources, is considered most likely to make a significant contribution to the nation's energy supplies in the near future.

High-temperature (above 150°C) hydrothermal resources are likely to be used for electric power generation. However, the extent of such high-quality resources is expected to be limited. Therefore, emphasis has been placed on the development of the vast low-temperature hydrothermal resources, which are more suited for nonelectric uses.

As part of the overall effort, Bechtel Corporation, in October of 1976, was awarded a contract by ERDA to look into one phase of geothermal resource development. Bechtel was to investigate that phase of development classified by ERDA as "non-site specific, general industrial use of geothermal energy."

1.1 OBJECTIVE

Bechtel's objective in this study was to determine whether or not it is technically and economically feasible to use low-temperature geothermal energy (hot brines) in place of steam from conventional sources for industrial use. Industrial use was restricted to users of multiple-effect evaporation and crystallization, a key industrial operation which consumes significant amounts of low-level energy. The key aspect of the study was that a "multiflash feed-and-bleed" system, a Bechtel concept, would be incorporated with the evaporation and crystallization processes to make efficient use of the geothermal resource.

In order to achieve the study objective, users of multiple-effect evaporation and crystallization were identified. Only those located within the broad region of geothermal resources were considered. From these users, three "candidate" industries were chosen to be evaluated in detail. Flowsheets were developed and conceptual designs were prepared for example cases. From this, the feasibility of using low-temperature geothermal brines for multiple-effect evaporation and crystallization was determined.

1.2 BACKGROUND

Evaporation and crystallization operations consume large amounts of thermal energy. For example, the pulp and paper industry in the evaporation of black liquor, consumes roughly 2-1/2 percent of all the energy consumed in the United States.¹ Since this process requires large amounts of energy, a number of processes have been developed to minimize this consumption by increasing thermal efficiency. The most common technique is the multieffect vertical tube evaporator (VTE), in which the vapor boiled off in the first vessel (effect) of the train condenses in the second effect, giving up its latent heat to boil a further quantity of liquor. By a somewhat different mechanism,

multistage flash (MSF) plants likewise evaporate a number of pounds of water for each pound of steam entering the plant. The MSF design is used primarily for the desalination of seawater (over one-half billion gallons per day installed capacity at present), but it has been applied also to the concentration of spent pulping liquors, evaporating plants for aluminate liquors, and evaporation-crystallization of industrial salts.^{2,3,4}

In spite of these improvements, the consumption of heat is impressive. Table 1-1 lists the heat required to produce one pound of each of several commercial products. The Lawrence Livermore Laboratory reports that the total annual nonelectrical requirement of energy (industrial, commercial, residential) below 150°C in the United States exceeds 20 quads (20×10^{15} Btu).⁷ The use of geothermal heat to supply this requirement was explored in several papers published in the journal, Geothermal Energy, the more recent of which provides a breakdown of current applications.^{8,9} Numerous surveys have been presented on the availability and distribution of geothermal resources. A recent report states that the United States is estimated to have up to 8,000 quads of recoverable (without regard to cost) heat stored to a depth of 10 km; 4 percent of this, namely 330 quads, is available for non-electric uses.¹⁰ Thus, it appears that geothermal resources can potentially supply a significant portion of the U.S. nonelectric energy requirement.

Like any energy resource, there are costs involved with its use. There is a strong incentive to utilize geothermal resources efficiently so as to minimize these costs (wells, pipelines, etc.). Several of the evaporation-crystallization industries listed in Table 1-1 would require very large flows of geothermal brine if conventional evaporative processes were employed. Thus, use of a process such as Bechtel's feed and bleed concept, which can be more efficient than standard evaporative processes, may be necessary for the economical use of geothermal resources by these industries.

Table 1-1

STEAM REQUIREMENTS TO MANUFACTURE
SOME TYPICAL EVAPORATION-CRYSTALLIZATION INDUSTRY PRODUCTS

	Heat Required (Btu/lb)	Ref.
Basic Mg Carbonate	8,500	5
Refined Beet Sugar	6,000	5
Refined Cane Sugar	1,500	6
Sodium Chloride	1,000	6
Wood Pulp	4,000	5
Aluminum Sulfate	3,000	5
Ammonium Chloride	2,500	5
Boric Acid	2,000	5
Potassium Chloride	1,000	6
Ammonium Nitrate	1,500	5

Section 2

SUMMARY AND RECOMMENDATIONS

2.1 SUMMARY

The evaporation and crystallization industry is a large user of low-grade heat. This report discusses the technical considerations of applying geothermal brine at 300°F to the three selected industries — tomato paste processing (preserved fruits and vegetables); sugar beet refining (sugar and confectionary); and sodium chloride production (chemicals). These industries were selected based upon their potential use of geothermal brine, actual or possible location near geothermal resources, significant energy requirements for their evaporation/crystallization operation, and demonstration of the broad range of evaporation/crystallization conditions prevalent in the industry. The economics of using geothermal brine is presented for both the retro-fit of an existing plant and the construction of a new plant. These results are summarized in Table 2-1.

The processes for extracting heat energy from geothermal brine that were studied include simple flashed steam, a liquid-liquid heat exchange, and a feed-and-bleed process. Based on this study, it was determined that the feed-and-bleed process minimizes the brine flow requirements and scale formation problems from scale-forming brines.

Heat and material balances, equipment specification lists showing all the significant equipment additions or deletions, and a revised electrical energy requirement list are used as a basis for an economic analysis for each of the processes studied. The cost of geothermal

Table 2-1

SUMMARY OF THE ECONOMICS RESULTS FOR THE SELECTED INDUSTRIES

Industry	Tomato Paste	Beet Sugar	Sodium Chloride
Size (tons per day)	4,800	4,000	500
Typical Season (Days/year)	70	160	270
Retrofit Cost:			
Capital — MM\$	7.04	8.74	2.07
Energy — \$/MMBtu	3.88	3.21	1.64
New Plant Cost:			
* Capital — MM\$	2.15	3.24	1.02
Energy — \$/MMBtu	1.93	2.06	1.10

M = 1,000 MM = 1,000,000

*As compared to an oil or gas fired system

energy is expressed as dollars per million Btu in terms of the equivalent fossil requirement for the process, i.e., the annual cost for the geothermal energy divided by the annual fossil fuel requirement.

2.1.1 Tomato Paste

In order to apply geothermal energy to tomato paste processing, new plants should be located near geothermal resources or the manner in which tomatoes are processed should be modified. Either an existing plant or a new plant can be adapted to the use of geothermal brine, but approximately 7 percent of the required steam flow must still be generated by a fossil-fueled boiler as the boiler is used for an aseptic system for sterilization and vacuum production.

For existing plants major equipment changes are required and include the following:

- Addition of heat exchanger area
- Conversion of pump drives from steam turbine to electric motor drives
- Modification of hot breaks to use lower temperature steam
- Addition of a small packaged boiler
- Addition of 3,700 kW of electrical power

2.1.2 Beet Sugar

Beet sugar and cane sugar production requires large amounts of energy. For the typical 4,000 tons/day plant, a substantial amount of electricity is cogenerated by the steam from the boiler prior to supplying the evaporators. As a result, after conversion to geothermal energy, there is a substantial increase in the electrical power requirement.

The use of geothermal energy in sugar beet and cane sugar production requires major changes including the following items:

- Redistribution of the number of vessels in each effect
- Addition of a concentrator prior to the crystallizers
- Modification of the plant liquid and vapor piping
- Increase in cooling system capacity
- Addition of 8,100 kW of electrical power

In the Hawaiian Islands the cane sugar industry appears to offer the best potential for utilizing geothermal brine due to operation throughout a substantial period of the year and the recent discovery of geothermal resources.

2.1.3 Sodium Chloride

About 10 percent of sodium chloride (salt) is produced by multiple effect evaporation and crystallization. Salt crystallization is similar to many other inorganic salt production processes as, for example, caustic soda concentration in chlorine-caustic production. The capacity of the selected typical plant is 500 tons per day and it uses the vacuum pan processes. For a retrofit plant, the changes required are:

- Replacement of the heat exchanger tube materials
- Conversion of the turbine pump drives to electric motor drives
- Addition of 760 kW of electrical power

Nine different types of inorganic salt production facilities were located with respect to geothermal resources. As a result, twelve inorganic salt production facilities were found to be located near "probable geothermal resource" areas.

2.1.4 Other Areas of Application

Although three processes were studied in detail, geothermal brine can be utilized in many other areas of evaporation/crystallization. Among these applications are the pulp and paper industry, dairy industry, and waste concentration.

2.2 CONCLUSIONS

Some of the most significant factors affecting the cost of utilizing geothermal brine are shown parametrically in this report and include the following:

- Geothermal Resource. For the processes considered, characteristics of the resources such as well temperature and cost, distance to point of use, and flow will significantly affect the economics of the processes. For example, transportation of the brine

more than 25 miles is not economical and a drop in brine temperature from 300°F to 250°F doubles the cost of the brine system.

- Energy Extraction Process. The feed-and-bleed process significantly reduces the brine flow requirements. As an example, the sodium chloride plant requires twice the brine flow when using a simple flashed steam process.
- Evaporation/Crystallization Process. Geothermal brine is most cost-effective when it is used throughout most of the year. In addition, the best equivalent energy cost will be obtained in a plant with the least amount of cogeneration of electricity (or its equivalent), as in tomato paste and sodium chloride production.

With favorable conditions, the equivalent energy cost can be less than \$1/MMBtu. In all cases studied, there is a higher capital cost associated with a new plant using geothermal brine as compared to a plant using an oil- or gas-fired fossil fuel. This results from the increased costs of equipment primarily associated with the geothermal energy supply system which exceeds the cost credit for the equipment no longer required, e.g., steam generator, turbine, etc.

2.3 RECOMMENDATIONS

No industries in the United States are presently using geothermal energy for evaporation and crystallization, even though many industries that are identified in this study can economically do so.

The lack of resource definition, technical knowledge, and operating experience are current obstacles to the development of geothermal energy. To assist in overcoming these obstacles and implementing the use of geothermal energy in the evaporation and crystallization industry, the following program is recommended:

- Define geothermal resources more accurately
- Provide relevant information to the evaporation and crystallization industry
- Provide relevant information to producers of geothermal energy
- Initiate a research and development program for the feed-and-bleed process
- Initiate a demonstration program applicable to the evaporation and crystallization industry

To acquaint industry with the potential of geothermal energy, a demonstration program appears essential. The most promising process resulting from the contacts with industry and energy producers would be selected for additional study. This study would be site specific and would include:

- A site specific study to demonstrate the potential economic advantages of using geothermal brine
- Testing of a portable test unit on the brine at the site
- A plant design based upon the portable test unit experience
- Construction of a demonstration plant or retrofit of an existing plant

Section 3

GEOHERMAL RESOURCES

For many years, geothermal energy has been used to heat homes, generate electricity, and to provide heat for industry. However, only a fraction of the total estimated recoverable geothermal energy has been utilized for these purposes, so that only a minute portion of the world's energy requirement is supplied from geothermal resources. Now, with increasing demands on our dwindling fossil fuel supplies, more attention must be given to the full use of what could be a significant energy source.

3.1 RESOURCE DESCRIPTION

Geothermal resources are stored in localized reservoirs in the earth's crust, and are capable of providing energy in the form of heat. These resources exist in a number of forms, each with its own distinct characteristics. All derive energy from the earth's interior, but differ in the level and form of heat they supply. These resources are classified and discussed in the following subparagraphs (see Refs. 11, 12).

3.1.1 Hydrothermal Convective Systems

Hydrothermal convective systems consist of a volume of hot water contained in a permeable formation of aquifer situated over a hot rock heat source, and enclosed by an impermeable "cap." Heat is transferred mainly by the convective circulation of water (or steam) rather than by thermal conduction through rock. In the U.S., most of the

hydrothermal systems have been found in the western states. Hydrothermal convective resources are subdivided into two categories:

- Vapor-dominated Systems — These relatively rare resources produce saturated or superheated steam with little or no water at temperatures above 150°C. An example of this type of resource in the U.S. is the Geysers in California. There, Pacific Gas and Electric uses the geothermal steam to produce electricity
- Liquid-dominated Systems — By far the most common of the hydrothermal resources, these systems produce either a mixture of liquid and vapor, or a single hot water phase. Hot springs are frequently evidence of this resource. Those systems that produce fluids between 90°C and 150°C (300°F) are considered "low-temperature," while those that produce fluids above 150°C (300°F) are "high-temperature" systems

3.1.2 Geopressured Systems

Geopressured resources are present in the U.S. along the Gulf Coast of Texas, Louisiana, and Mississippi. Such systems consist of a deep (below 6000 ft) pressurized water reservoir within a sedimentary basin. Along with heat energy, this resource can provide mechanical energy, which can be recovered by using a hydraulic turbine-generator. In addition, significant quantities of methane (dissolved, under pressure, in the hot water) can also be recovered.

3.1.3 Hot Dry Rocks

This resource consists of "non-molten, but very hot rock structures with insufficient water to be considered a hydrothermal convection system. Temperature is usually less than 650°C.¹¹ By circulating an outside source of water through these rocks, energy can be recovered.

3.1.4 Normal or Near Normal Gradients

These systems are made up of "conduction-dominated areas provided by heat flows, radiogenic heat production, and thermal conductivity of rocks, exhibiting temperatures from 15°C to about 300°C within the first 10 km of the crust." ¹¹ Natural fluid supply to these resources is usually inadequate.

3.1.5 Magma

This resource consists of "molten rock at temperatures in excess of 650°C." ¹¹ Generally, no fluid supply is available.

3.1.6 Resource Exploitation

Presently, only the hydrothermal resources are being exploited. However, geopressed resources, using current technology and with some further development work, may soon be tapped.

"Vapor-dominated" and "high-temperature liquid-dominated" hydrothermal resources are used most efficiently in power generation systems. "Low-temperature liquid-dominated" resources, on the other hand, are best used for "nonelectric" heating purposes. For this study, only these low-temperature geothermal resources were considered for use in the process industries.

3.2 HISTORICAL BACKGROUND

Throughout history, man has used the hot water from various surface hot springs for simple heating applications. The first large scale commercial use of geothermal resources was for the generation of electricity at Larderello, Italy in 1904. Since then, generating plants using geothermal steam have been put into operation in a number of countries around the world, including the Geysers facility in the United States. ¹³ Along with the power production applications, many

"nonelectric" uses of geothermal energy have been found, including residential and commercial space heating; agricultural and industrial uses.

3.2.1 Residential and Commercial Space Heating

In the 1890's, one of the first home heating systems using hot (77°C) geothermal brine was constructed in Boise, Idaho. It is still in use today. Since the Boise system was built, numerous other geothermal district heating systems have been put into operation. Most notable is the Reykjavik, Iceland network, which was started in 1928, and now is used to heat the homes of 88,000 residents of the city.¹⁴ Other countries have taken advantage of local geothermal resources to provide residential and commercial space heating. Systems have been built, in addition to those in the United States and Iceland, in the USSR, New Zealand, Japan, Hungary, and France.¹⁵

3.2.2 Agricultural Use

Recently, more attention has been given to the use of geothermal heat in agriculture. There are a number of installations around the world that use hot geothermal brines to heat greenhouses, warm animal shelters, or maintain optimal environmental conditions for the year-round breeding of aquatic species. One of the largest operations is in the USSR, where 25 million square meters of greenhouse are heated by geothermal brine. Over one million tons/yr of tomatoes, cucumbers, and other vegetables are produced at this facility.¹⁵

3.2.3 Industrial Uses

The number of industries presently using geothermal energy is not great, although there are many potential applications. Two of the major industrial users of geothermal resources are the Tasman Pulp and Paper Mill in New Zealand, and the Kisilidjan H/F Diatomaceous Earth Plant in Iceland.

The New Zealand pulp and paper mill has been using up to 400,000 lb/hr of steam from a geothermal resource since 1960. The resource is in the form of steam, flashed from the geothermal brine at 175°C and 120 psi. The steam is used to generate clean, low-pressure process steam for the kraft pulping step and for pulp/paper drying. In addition, any surplus steam is used in turbine-generators to generate part of the plant's electricity. The exhaust from these turbines is fed to a black liquor evaporator.

The Iceland diatomaceous earth plant was started up in 1968, and uses up to 100,000 lb/hr of 185°C geothermal steam (flashed from the hot brine) to heat and dry a slurry of diatomaceous earth that has been pumped from the bottom of a nearby lake.

3.3 HYDROTHERMAL-CONVECTIVE RESOURCES

This section discusses the characteristics of the liquid-dominated, low-temperature hydrothermal resources considered for this study.

3.3.1 Estimated Recoverable Heat

Over the years, the U.S. Geological Survey of the Department of the Interior has made estimates of the extent of geothermal resources. Looking only at liquid-dominated, low-temperature (90° to 150°C) hydrothermal resources, without regard to recoverability, it has been estimated that the heat content of this resource is from 1400×10^{15} to 5500×10^{15} Btu's (240 to 940 billion barrels of oil equivalent). If only those resources that are assumed recoverable using present or near-term technology are taken into account, then the estimated extent of this 90° to 150°C resource would range from 80×10^{15} to 330×10^{15} Btu's (14 to 58 billion barrels of oil equivalent).^{11, 12}

3.3.2 Resource Locations

The U.S. Geological Survey has made a tabulation of hydrothermal resources.^{11, 16} As mentioned previously, in the U.S., most of these

have been discovered in the western United States. Figure 3-1 shows the locations of "known hydrothermal systems" (90°-150°C), while Figure 3-2a and 3-2b show the broad "probable geothermal areas" as classified by the USGS.

3.3.3 Brine Characteristics

The "working fluid" from a liquid-dominated hydrothermal resource is a brine made up of water, various dissolved solids, and dissolved gases. In the evaluation of any geothermal resource for industrial use, the composition of the brine is an important consideration because it determines what materials of construction are required to limit corrosion, whether or not scaling (salting out of dissolved solids as they reach saturation) will be a problem, what manner of spent brine disposal will be necessary, and what thermodynamic and heat transfer characteristics should be expected.

The composition of geothermal brines can vary greatly, depending on location (see Table 3-1). Total dissolved solids (TDS) can range from a low of less than 300 ppm to a high of over 300,000 ppm in some areas. However, these extremes are rare; more common are brines ranging in TDS from 4000 to 30,000 ppm.

Because brine composition is an important consideration, two "typical" brines, one of low salinity and one of medium salinity, were chosen for this study (Table 3-1) to show the effect of varying brine composition on the cost of geothermal heat (see Section 7). Table 3-1 shows the compositions of a wide range of brines from developed geothermal fields. Using these as a guide, the compositions of the two "typical" brines were selected.

3.4 RESOURCE DEVELOPMENT

Compared to most other energy resources, the development of geothermal resources has only just begun. The majority of the known geothermal

fields were found because of obvious surface manifestations. Relatively little exploration has as yet been done to locate and develop what, potentially, is a very large resource. Although a number of the more prominent geothermal resources have been, to some degree, exploited over the years, most of the known fields have not been used.

The lack of interest in geothermal energy has been due mainly to the abundance of inexpensive fossil fuel and, to a lesser extent, the rather unfavorable placement of the known geothermal sources (relative to existing industrial sites). Added to these is the traditional reluctance of major industry to utilize "untried" technology, the lack of an organized approach to resource development, and the legal problems of resource ownership and use. Also, there is uncertainty about the magnitude and longevity of the resources themselves. All of this has hindered the development and exploitation of geothermal resources.

With the increasing cost of fossil fuels, and a more active role by government, a greater incentive exists for the utilization of geothermal resources. As outlined in the Geothermal Energy Research, Development and Demonstration Program Definition Report, programs to aid in the development of geothermal resources have been established by the federal government.¹² Briefly, these programs are:

- Resource Exploration and Assessment — In order to reduce the risks involved with exploration and the estimation of resource characteristics, efforts in the areas of geosciences research, exploration technology development, resource assessment, and data collection will be funded by the Government
- Technology Development — In this area, programs will be funded that are intended to advance the "state-of-the-art" of geothermal well drilling, reservoir engineering, conversion equipment design, and geothermal pollution abatement technology. Where appropriate, commercial-scale demonstration plants will be considered to demonstrate the feasibility of using a given type of geothermal resource

- Institutional Development — In an attempt to develop geothermal resources rapidly for commercial exploitation, the Government has tried to provide incentives to industry. These include a leasing program to make federal lands available for geothermal development; the Geothermal Loan Guaranty Program which provides assistance to industry in the form of loan guarantees of up to 75 percent of a geothermal project cost to a maximum of \$25 million; and, finally, a research program to identify and develop policy alternatives to resolve the social, legal, economic, and environmental problems associated with geothermal resource development.

It is expected that, with these programs, many of the problems associated with the development of geothermal resources and their use by industry will be overcome. This will ensure that this large energy resource will be more fully utilized.

Table 3-1

TYPICAL BRINE COMPOSITIONS

	Sea-Water	Midland, Ca.	Holtville, Ca.	Wairakei, N.Z.	Reykjavik, Iceland	Raft River, Idaho	Boise, Idaho	Klamath Falls, Or.	Low Salinity Brine	Med. Salinity Brine
Dissolved Solids, ppm									Assumed ⁽¹⁾	
Na	10,360	53,800	11,000	1,320	60	400	90	200	1,500	8,560
Ca	400	28,800	1,370	20	4	60	2	20	25	2,820
Mg	1,270	10	20	nil	nil	1	nil	nil	1	5
Ba	nil	250	60	nil	nil	nil	nil	—	0.3	nil
Sr	10	440	230	nil	nil	3	nil	—	2.2	nil
K	380	16,500	1,430	230	3	30	2	5	85	140
Cl	19,000	155,000	18,000	8,730	30	700	10	50	1,970	18,000
SO ₄	2,700	nil	20	40	20	60	20	410	150	80
HCO ₃	140	nil	nil	20	nil	60	70	—	610	650
SiO ₂	7	400	100	640	160	100	160	180	150	400
Fe	nil	2,000	nil	nil	nil	nil	nil	3	1	90
Mn	nil	1,370	1	nil	nil	nil	nil	—	nil	2
Br	380	nil	40	nil	nil	2	nil	—	—	—
Other ⁽²⁾										
Total Dissolved Solids	34,900	258,800	32,400	11,000	280	1,400	370	870	4,495	30,792
Noncondensable Gases, ppm										
H ₂ S	nil	—	—	4	3	nil	nil	—	2	30
CO ₂	nil	500	—	90	90	16	nil	—	20	300
Other ⁽³⁾	—	—	—	3	6	100 ⁽⁴⁾	20 ⁽⁴⁾	—	—	—
T, °C	—	230	165-180	240	100	140	80	70	150	150
pH	8.0	6.1	7.6	8.6	9.3	7.5	9.0	8.1	6.2	6.7

Notes:

- (1) These brines have been selected as the typical low and medium salinity brines and will be used in this report for systems evaluation.
- (2) F, Li, NH₃, S
- (3) H₂, CH₄, N₂, Ar, O₂
- (4) Mainly N₂
- (5) References: 17, 18, 19, 20, 21

Figure 3-1. Known 90°-150°C Hydrothermal Systems

Figure 3-2a. Probable Geothermal Areas

Figure 3-2b. Probable Geothermal Areas

Section 4

MULTIPLE-EFFECT EVAPORATION/CRYSTALLIZATION AND THE CANDIDATE INDUSTRIES

There are many industries which, potentially, can use geothermal brines to provide low-temperature heat. This study, however, is restricted to those that use multiple-effect evaporation or crystallization in some phase of their operations. In this section, the multieffect process is discussed, those industries that employ it are identified, and the basis for candidate industry selection is discussed.

4.1 MULTIPLE-EFFECT PROCESS

Multieffect evaporation and crystallization operations are similar in principle. Both provide steam economy. In either operation, the amount of steam used is less than it would be if only a single "effect" (evaporator/crystallizer) were used. In the evaporation of aqueous fluids in a single effect, roughly one pound of steam is required to evaporate one pound of water whereas, in a three-effect system for example, only about 1/3 pound of steam is required to evaporate one pound of water. Or, for N effects, approximately N pounds of water will be evaporated for every pound of steam supplied.

A typical triple-effect evaporator system is shown in Figure 4-1. In this standard scheme, three vertical tube evaporator bodies are connected to form a three-effect system. The piping between the bodies is arranged so that the vapor from one evaporator serves as the heating medium for the next. A condenser and some device such as an ejector establishes a vacuum in the third effect, and withdraws noncondensibles from the system. Raw steam is fed to the tube bundle of the first effect. In this effect, the pressure in the vapor space is highest. Vapor from the boiling liquid in this first body passes overhead and is fed to the

tube bundle of the second effect. This operation is then repeated in the second effect where the vapor space pressure is less than that in the first effect. Finally, the vapors from the effect are withdrawn and condensed. The vapor space pressure is lowest in the last effect.

For optimum heat transfer, multieffect systems are fed in a number of ways, depending on the characteristics of the liquor feed and the product desired. In the example system, dilute liquor is fed in series, starting with the first effect and discharging, as a concentrated liquor, from the last effect. This is known as "forward feed." The sugar beet process discussed in Section 9 is a good example. For some applications, "backwards feed" is used. Here the dilute liquor is fed in series starting with the last effect. Other feed systems include "parallel feed" where the dilute liquor is split into parallel streams and fed to each effect (an example is salt crystallization discussed in Section 10), and "mixed feed" where, for example, the dilute liquor might be pumped from first to third to second effects (a tomato paste example is shown in Section 8).

Since, for this study, we were interested in the use of low-temperature geothermal brines (less than 300°F) to supply the steam for evaporation, only those multieffect evaporation/crystallization systems requiring low-pressure raw steam (below, say, 50 psig) were considered.

4.2 USERS OF MULTIEFFECT EVAPORATION/CRYSTALLIZATION

The "candidate industries" — those industries most likely to benefit from using geothermal steam in their evaporation/crystallization operations — were selected from various major industries which are large users of energy. Table 4-1 is a summary of the broadly classified major industries giving their energy consumption and indicating those that use multieffect evaporation/crystallization as well as those that are located in geothermal regions.^{22, 23, 24, 25}

The major industry summary shows that those multieffect evaporation/crystallization users located in the western U.S. (geothermal regions) are primarily confined to the food, paper, and chemicals industries. From among these broadly classified industries, a more detailed breakdown was made so that specific processes could be investigated. This comprehensive listing of western U.S. low-temperature multieffect evaporation/crystallization users is shown in Table 4-2. From this list, the candidate industries were chosen.

4.3 CANDIDATE INDUSTRY SELECTION

From the listing of users of multieffect evaporation/crystallization given in Table 4-2, three industries were selected as having the most potential for geothermal use. These "candidate" industries are:

- Preserved fruit and vegetables (SIC-203)
- Sugar and confectionary (SIC-206)
- Chemicals (SIC-28)

These industries were selected as the "candidate industries" based on the following criteria:

- It is a significant user of energy in general, and in particular for its evaporation/crystallization operations
- It uses steam at 300°F or less in its evaporators/crystallizers
- It is presently near or can be located near geothermal resources
- There is a significant incentive to change to geothermal use
- Their process is such that geothermal brine can easily be integrated into the system
- Taken together, the three selected candidates demonstrate the broad range of evaporation/crystallization conditions prevalent in industry

From within each candidate industry, an example process was chosen as a typical example of the evaporation/crystallization process as used within this industry group:

- Tomato paste production (preserved fruit and vegetables industry)
- Beet sugar production (sugar and confectionary industry)
- Sodium chloride production (chemicals industry)

In order to determine the cost of geothermal versus conventional (fossil fuel) energy for each process, a typical plant design for each of the example processes was developed. A summary of the major parameters describing these plants is given in Table 4-3, while the example processes are discussed in detail in Sections 8, 9, and 10.

Table 4-1

MAJOR INDUSTRY SUMMARY OF ENERGY USE

Industry	1967 Energy Consumption (10 ¹² Btu/yr)	Uses multi- stage evaporation or crystallization w/low level heat (<300°F)	Presently located in vicinity of geothermal sources
Food			
Meatpacking	84	No	—
Fluid milk	64	No	—
Dry milk	27	Yes	Yes
Canned fruit and vegetables	48	Yes	Yes
Frozen fruit and vegetables	27	Yes	Yes
Beet sugar	72	Yes	Yes
Cane sugar	32	Yes	Yes
Animal feeds	49	No	—
Bakery products	49	No	—
Paper			
Pulp and paper mills	2,156 ⁽¹⁾	Yes	Yes ⁽²⁾
Fiberbox	30	No	—
Building paper and board	40	No	—
Chemicals			
Alkalis and chlorine	268	Yes ⁽³⁾	Yes
Industrial gases	65	No	—
Organic cyclic intermediates	132	No	—
Industrial organic chemicals	858	Yes	—
Inorganic chemicals	536 ⁽⁴⁾	Yes	Yes ⁽⁵⁾
Plastic and resins	130	Yes	—
Synthetic rubber	61	Yes	—
Manmade fibers	152	Yes	—
Petroleum refining	2,300	No	—
Stone, Clay, and Glass			
Glass	239	No	—
Cement	463	No	—
Brick and clay	97	No	—
Ready-mix concrete	37	No	—
Lime	78	No	—

Table 4-1 (Cont'd)

Industry	1967 Energy Consumption (10 ¹² Btu/yr)	Uses multi- stage evaporation or crystallization w/low level heat (<300°F)	Presently located in vicinity of geothermal sources
Primary Metals			
Steel	3,007	No	—
Electrometallic products	76	No	—
Iron and steel castings	99	No	—
Copper rolling	32	No	—
Nonferrous wire	25	No	—
Iron and steel forgings	53	No	—
Aluminum	636	Yes ⁽⁶⁾	—

Notes:

1. 1971 data
2. Percent of energy consumption by area:
NE — 13 percent
NC — 14 percent
S — 57 percent
W — 16 percent
3. Caustic soda concentration in diaphragm cell electrolytic caustic-chlorine process.
4. Not including uranium enrichment plants
5. Evaporation of potassium brine by Trona process or crystallization of KCl by U.S. potash process (dry).
6. Alumina spent liquor concentration.

Table 4-2

MULTIEFFECT EVAPORATION/CRYSTALLIZATION INDUSTRIES

<u>Preserved Fruits and Vegetables</u>	<u>Chemical, SIC-28</u>
<u>SIC-203[†]</u>	Caustic soda (from diaphragm-cell chlorine-caustic production) Salt (from vacuum pan operations) Soda carbonate Sodium sulfate* Sodium phosphate* Alkali chlorides* Borax Ammonia sulfate Boric acid
Fruit juice concentrate	
Citrus	
Grape	
Apple	
Tomato Paste	
<u>Dairy Products, SIC-202</u>	
Dry milk products	
Skim milk	
Condensed milk	
Evaporated milk	
Dry whole milk	
<u>Sugar and Confectionary Products</u>	<u>General</u>
<u>SIC-206</u>	Waste concentration Cooling tower blowdown High BOD plant effluents Pharmaceutical wastes Yeast waste
Beet sugar	
Cane sugar	
<u>Pulp and Paper, SIC-261,262</u>	<u>Others</u>
Pulp mill products	Molasses
Integrated pulp/paper mill products	Corn syrup
	Glycerine
*From brine by evaporation	[†] SIC — Standard Industrial Classification Manual Definition

Table 4-3

EXAMPLE PLANT SUMMARY

Candidate Industry	Example Process	Plant Capacity Ton/Day Product	On Stream Days/Yr (Typical)	Multieffect Evaporator System	
				Number of Effects	Process
Preserved fruit and vegetables	Tomato paste production	4,800	70	3	Evaporation
Sugar and confectionary	Beet sugar production	4,000	160	4	Crystallization
Chemicals	Salt (sodium chloride) production	500	270	4	Crystallization

Figure 4-1. Triple-Effect Evaporator

Section 5

PROCESS COMPARISONS

5.1 GEOTHERMAL ENERGY EXTRACTION

To make use of low-temperature geothermal brines in the evaporation and crystallization industries, an efficient means must be found to extract the heat energy, thereby minimizing the brine flow. Three processes are shown in Figure 5-1 and compared below to show the relative advantages of each. These processes are:

- A single flashdown of geothermal brine to supply steam to the prime heater
- The transfer of heat from geothermal brine to the evaporating liquor via a liquid-liquid heat exchanger
- The feed-and-bleed process

5.1.1 Simple Flashing Steam

This process is characterized by its simplicity. First, geothermal brine enters a flash tank where the brine pressure is lowered in order to flash some of the brine into vapor. No modifications to the evaporator system are required if the brine temperature is higher than the required process temperature. The brine is flashed at a temperature of the first effect evaporator and then discharged. However, the simple flashed process requires the largest brine flow since only that portion of heat in the brine at the first stage temperature is extracted. For example, with a brine temperature of 300°F and a process steam temperature of 259°F, the sodium chloride crystallization process discussed in detail in Section 10 requires twice the brine flow when using a single-stage flash as compared to the feed-and-bleed process.

5.1.2 Liquid-Liquid Heat Exchange

An alternative to simple flashed steam is the use of a liquid-liquid heat exchanger to extract the heat from the brine, as shown in Figure 5-1. An intermediate heat exchanger extracts heat from the brine and transfers it to a secondary fluid. The secondary fluid can then be used to supply heat to the evaporation process in a manner similar to the simple flashed steam process. The primary advantage is that the geothermal brine is not depressurized and thus loses no noncondensable gases thus eliminating the possible environmental and heat transfer effects.

Disadvantages include the possibility of potential scale formations and corrosion caused by the brine on the heat exchange surface, the additional equipment for the large heat exchanger surface, and the lowered thermodynamic efficiency resulting from the terminal approach temperatures. The process can be modified to be similar to the feed-and-bleed process so that there is multistage energy extraction. This allows for increased efficiency with respect to brine utilization but other disadvantages still exist.

This process is most applicable when the likelihood of fouling is low and the cost of retrofitting a plant is high. For example, the retrofit cost might be high in the case of the flashed steam process where an excessive amount of hydrogen sulfide in the steam would attack the copper surfaces in the heat exchangers.

5.1.3 The Feed-and-Bleed Process

This process extracts the most energy from the brine. In flash tank No. 1, shown in Figure 5-1, the geothermal brine produces steam at the highest temperature required by the evaporator and delivers it to the shell side of effect No. 1. From this point on, the evaporator functions in the conventional manner, sending vapor generated in each

effect to heat the following effect. The feed-and-bleed process consists of a series of flash tanks, one for each effect. The vapor generated from the geothermal brine in each flash tank then supplements the heat delivered to the associated effect from the preceding effect. In this manner, the heat content of the incoming geothermal brine is most effectively employed in the evaporator.

A further advantage in the use of flashed steam is that the heat transfer coefficient from condensing vapor is superior to that attainable in liquid-liquid heat transfer. Scale-forming brines that would foul heat exchangers have minimal effect in this process. The brine itself never contacts the heat exchange surfaces. Should any scale deposit in the flash vessels, it will do little harm; and if the deposit becomes thick enough to interfere with fluid flow, it can be removed readily from the large, smooth surfaces.

The utilization of the energy of the geothermal brine can be increased even further by a simple extension of this concept. Merely adding one or more flash tanks for the geothermal brine, over and above the flash tanks required for the evaporator-crystallizer, will provide additional quantities of steam at lower temperatures. The low-temperature streams can be used for space heating and for process heat in the plant.

5.2 PROCESS COMPARISON

A comparison of the three processes described in this section is shown in Table 5-1. These processes were selected as the most economical methods of using geothermal energy. Shown in Figure 5-2 is a comparison of the brine requirements for the feed-and-bleed and a simple flashed steam process. This is a simplified case with an assumption of constant areas, heat transfer coefficients, total evaporation, steam inlet temperature, and condensing temperature. Less brine flow is required for the feed-and-bleed process. This can be as little as

half of that required for the simple flashed steam process. The exact value is largely determined by the difference between the steam temperature and the brine temperature. The smaller this difference, the greater the advantage of the feed-and-bleed process.

In all of the cases studied, the cost of obtaining and transporting the geothermal brine represented the largest cost, even when using the feed-and-bleed process. The feed-and-bleed process was selected because it requires the minimum brine flow.

Table 5-1

PROCESS COMPARISON
APPLICATION OF GEOTHERMAL ENERGY TO NON-ELECTRIC USES

Engineering Factor	Feed and Bleed	Simple Flashed Steam	Liquid-Liquid Heat Transfer
Extraction of usable energy	Greatest	Least	Medium
Required flow of geothermal brine	Small	Large	Medium
Additional heat exchanger equipment required	Small	None	Large
Additional benefits	Pure water as by-product	Pure water by-product, but in smaller quantities	No loss of non-condensable gases
Process limitations	—	—	Scale formation; corrosion by brine
Retrofitting requirements for an existing evaporator-crystallizer	Medium	Small	Large

Figure 5-1. Energy Conversion Process Comparison

Figure 5-2. Evaporation Brine Flow Comparison of Feed-and-Bleed Process to Simple Flash Steam

Section 6

PROCESS DESIGN

Described below are the bases for the process modifications and additions required by each example process for geothermal use (new and retrofit cases).

6.1 HEAT AND MATERIALS BALANCES

Flow diagrams and heat and materials balances were developed for the selected evaporation and crystallization processes. The information included:

- Equipment configuration
- Process flows, temperatures, and pressures
- Product stream physical properties
- Heat transfer coefficients
- Equipment types and sizes

The flow diagrams were based upon information showing processes typical of those used in the particular industry. The values for heat transfer coefficients and maximum operating limitations used were based upon information from users wherever possible.

It is recognized that the process design of evaporation operations is a combination of extensive experience in addition to a thorough understanding of engineering principles. Examination of all design criteria of the selected processes is beyond the scope of this study. However, each process design was reviewed with equipment designers or users to

confirm that each process was of a practical and workable design. It is hoped that with a more detailed study, process designs will result that will even more efficiently use geothermal brine. If this can be done, further reductions in the cost of utilizing geothermal brine (from that shown in this study) may be expected.

The heat and materials balances for the feed-and-bleed process are more complicated than in a normal multiple-effect evaporator. As a result, a series of computer programs was developed to aid in calculating these balances. An example of one of these programs is shown in Appendix A.

6.2 GEOTHERMAL BRINE SYSTEM

6.2.1 Description

The geothermal brine supply and reinjection system is shown in Figure 6-1. Production wells supply the hot brine via the production pipeline to the process plant to provide process heat and steam. ReInjection wells are required for return of the spent brine, through the reinjection pipeline, to the geothermal source to minimize land surface subsidence (see Section 13.2.3).

The major costs of a new or retrofit plant are in the geothermal brine system, the design of which is largely defined by several geothermal resource characteristics including:

- Brine temperature
- Well depth
- Well flow
- Distance of resource to the process plant

For thermodynamic calculations, the specific heat is assumed to be 0.95 Btu/lb-°F for both of the selected "typical" brines.

6.2.2 Design Assumptions

The geothermal brine system design is based on the following assumptions.

Wells. Production wells with 8-inch casings are assumed to be 1,000 feet deep and capable of delivering the selected "typical" brines at 250 gpm and 300°F (base case) (see Figure 6-2). Each well has a stainless steel downhole pump which delivers the brine to the surface in single-phase flow. It is assumed that 700 feet of head are required. The brine from individual wells is collected in a header and flows to one of two 100-percent capacity filters. Underground pipe carries the brine to the plant. For each of the plants considered, all production wells are assumed to be slant-drilled from one two-acre production well stand.

Reinjection wells with 8-inch casings are assumed to be 1,000 feet deep and capable of accepting the spent brine from the process plant at 500 gpm. Two 50-percent capacity stainless steel reinjection pumps, adjacent to the reinjection wells, provide the assumed 300 psig pressure for reinjection. Reinjection wells are also slant-drilled from one two-acre reinjection well island, and located approximately 1,000 feet from the production well island. Twenty-percent spare production and reinjection wells are provided. Electric power for the production well and reinjection pumps is assumed to be available from a local utility's 13.8 kV power line located one mile from the field pumps.

For the base case, the wells are located one mile from the process plant. The effects of well temperature and distance to the plant are shown parametrically in Section 12.

Brine Piping. Hot brine from the production well system flows to the plant in underground, fiberglass-insulated, carbon steel pipe. Expansion pits are provided for pipe expansion. At the plant, the brine is flashed in single- or multi-flash vessels to provide process steam and heat. The condensed brine steam and the unflashed brine are combined and pumped to the reinjection well island with two 50-percent capacity stainless steel brine transfer pumps located at the plant. The brine reinjection line is also underground; however, it is uninsulated, concrete lined and coated, carbon steel pipe.

6.3 MULTISTAGE FLASH VESSELS

In the multistage flash vessel process, steam is flashed from the brine in a series of steps to provide steam to the individual effects. The design of this vessel is common to that used in the seawater desalting industry. An example of the flash vessel is shown in Figure 6-3. Brine from the supply lines flows to the first of four units of the multistage flash section. Each vessel consists of three or four chambers or "stages," as required. In Figure 6-3, an elevation view of one of the vessels, brine enters the vessel at the left, flashing into the first stage. The steam that is flashed off rises through the mist eliminator to remove suspended solids and vapor. This steam then delivers heat to the appropriate effect in the process plant. The returned condensate and remaining brine are discharged through the flash device into the second stage, where the flashing process is repeated at a slightly lower pressure. The brine finally leaves the unit via the discharge pipe (at the right end of the figure) and enters transfer pumps prior to reinjection.

The condensing temperature of the supplied steam is determined by the boiling point rise of the brine and the approach to equilibrium of the flashing brine. The boiling point elevation is a function of total dissolved solids in the brine. Typically, this is 1°F or less for the

selected brines. Nonequilibrium may be minimized by stage geometry and proper design of the interstage flashing device. This was assumed to be zero for these designs.

There are two constraints on vessel dimensions — sufficient height; and vapor release area. Sufficient height must be provided above the flashing brine to permit disengagement of a large fraction of the liquid droplets from the ascending vapor stream. The diameter and length of the vessel must be adequate to provide the required mist eliminator area. Too small an area will result in an excessive vapor velocity through the mist eliminator. A high vapor velocity will strip the coalesced liquid from the mesh and reentrain it in the vapor. In addition, a high vapor velocity will increase the pressure drop through the mist eliminator.

With these limitations in mind, the two flash stages were sized on the basis of operating experience with seawater desalination plants. As the operating conditions used in this flash vessel are outside the range of values normally used in existing designs, a research program conducted under anticipated operating conditions may permit a reduction in size and cost of the flash vessels.

6.4 PLANT EQUIPMENT

For a plant retrofit, plant modifications include, as a minimum, a geothermal flash vessel and additions to piping. For some plants, barometric condensers, cooling towers, small package boilers, electrical equipment, and bulk materials are also required. For a new plant construction, the steam generator, steam turbine pump drives, or steam turbine/generator normally associated with a plant using natural gas or fuel oil for the process heat source will not be required.

6.5 MATERIAL SELECTION

Among the various factors that affect corrosion are: pH, dissolved oxygen, hydrogen sulfide, and chloride ions. The interaction of several types of corrosive action is considered in this section.

Operating experience and published data are used to recommend certain materials for various types of service. Specific material recommendations are contained in other sections of this report, where the individual items of equipment are described in detail.

For the purpose of this study, it was assumed that all hydrogen sulfide and carbon dioxide were removed in the first-stage flash and subsequently vented to the atmosphere, and that the oxygen level in the brine remained very low, and no ammonia was present. As a result, the following general material selections were specified.

6.5.1 Flash Vessel

A carbon steel shell is provided with a quarter-inch corrosive allowance. The first-stage mist eliminator is Incoloy 825 and in the subsequent effects, Monel. The product trays are Monel.

6.5.2 Heat Exchangers

For the first-stage tubes of the salt plant, Incoloy 855 is used in place of the copper materials. The stainless steel tube materials in the tomato paste and sugar plant are satisfactory. The tube sheets are expected to be of sufficient thickness so that no replacement is required.

It must be emphasized that corrosion is a very complex phenomenon, not readily amenable to extrapolation. Consequently, the final material specification must be based on a series of carefully designed corrosion tests using the particular fluid at a specific site.

Figure 6-1. Flow Diagram R-1, Geothermal Brine Supply and ReInjection

ISSUED FOR FINAL REPORT	DATE	BY	DATE	BY	DATE	BY	DATE	BY	DATE
BECHTEL SAN FRANCISCO									
ERDA NON-ELECTRIC USES OF GEOTHERMAL BRINE									
FLOW DIAGRAM GEOTHERMAL BRINE SUPPLY AND REINJECTION SYSTEM									
	11940	R-1	0

Figure 6-2. Geothermal Well Flow Characteristics

Figure 6-3. Multistage Flash Vessel

Section 7

ECONOMIC ANALYSIS

To establish the potential economic advantage of using geothermal brine in the evaporation/crystallization industry, an economic analysis was made. The three processes chosen as examples of the candidate industries (see Section 4.3) were analyzed. Capital and operating costs were estimated for two cases for each process:

- Existing plant retrofitted for geothermal use
- New plant designed for geothermal use

From these figures, an annual geothermal energy cost for each process was calculated and compared to the annual energy cost for a conventional plant using fossil fuel. The bases for the conceptual estimates and for the annual geothermal energy costs are summarized below. Details are given in Appendix B.

7.1 BASIS FOR THE CONCEPTUAL COST ESTIMATE

7.1.1 Capital Costs

Capital costs include all construction and owner's costs necessary to retrofit an existing plant for geothermal use, or to construct that portion of a new plant required for geothermal energy use. Following is a summary of, and basis for, these costs:

- Field Construction Costs
 - Plant equipment (from vendor's estimates and Bechtel data)

- Material such as piping, concrete, wire, etc.
(quantities estimated from past experience, costs from historical data)
 - Well system costs (\$56,000 per well, from ERDA guidelines)
 - Subcontracts (from Bechtel experience)
 - Construction labor (from recent productivity rates, using an average wage rate of \$17/hr)
 - Indirect field costs (65 percent of direct labor costs from Bechtel experience)
- Engineering Services (15 percent of total field costs from historical data)
 - Allowance for uncertainty (20 percent of total field costs and engineering and home office cost, from Bechtel experience)

In addition to the above construction costs, it is necessary to include an estimate of owner's costs. Owner's costs are charges for:

- Owner's engineering, financing, and other costs
- Process royalties and licenses
- Site investigation and land acquisition
- Environmental impact investigations and reports
- Allowance for funds during construction (AFDC)
- Initial training of plant operators
- Plant startup

The owner's costs were taken as percentages, based on historical data, of the capital costs for plant equipment, geothermal wells, and brine

pipeline, including:

- Process plant equipment and materials (12 percent of construction costs)
- Production and reinjection wells (15 percent of well construction costs)
- Production and reinjection brine pipelines (12 percent of pipeline construction costs)

7.1.2 Annual Capital Costs

To arrive at an annual geothermal energy cost, the total capital cost must be determined in terms of an annual capital cost. This is done by applying a fixed charge rate which is the equivalent levelized rate of annual variable charges. The components which make up the final charge are rate of return, depreciation, insurance, property or ad valorem tax, and administrative and general expenses. The rate of return is equal to the weighted composite sum of the investment on borrowed money, dividends on preferred stock, and equity return to the common stockholder.²⁹ For this study, an 18 percent fixed charge rate is used for the process industries.

7.1.3 Operating and Maintenance Costs

In addition to capital costs, annual operating and maintenance costs are required to arrive at the cost of geothermal energy for new and retrofit plants. Operating and maintenance costs are for materials, supplies, and labor needed for the geothermal portion of the plant. These annual charges are taken over the operating period assumed for each example process. The bases for the operating and maintenance costs are summarized as follows:

- Plant Equipment and Materials. (Operational and maintenance costs conservatively assumed to be the same as for the conventional plant fossil fuel energy equipment)

- Production and Reinjection Wells (Annual operational and maintenance costs estimated to be 6 percent of the total capital cost of the production and reinjection wells - from Bechtel data)
- Production and Reinjection Pipelines (Annual operational and maintenance costs estimated to be 2 percent of the total capital cost of these pipelines - from Bechtel data)
- Electric Power. Power used for additional equipment required by a geothermal plant such as well pumps and process pumps that, in a conventional plant, would be driven by steam (electric power rate of 25 mills per kWh was assumed)

7.2 COST OF GEOTHERMAL ENERGY

The geothermal energy cost is a function of the total capital costs, together with the operating and maintenance costs associated with geothermal energy production. The geothermal energy costs are expressed in equivalent dollars per million Btu (Equiv-\$/MMBtu) of the current fossil fuel energy requirement.

Geothermal energy costs are expressed on an equivalent fossil fuel energy basis because the amount of geothermal energy required by a given process is not necessarily the same as the fossil fuel energy that would be required in a conventional process. This is due to the differences between the geothermal and conventional processes. For example, there are no boiler losses in the geothermal process; steam drives in conventional processes are replaced by electric drives; the evaporator system incorporates the feed-and-bleed concept in the geothermal plants, while in a conventional system, it does not. These and other process differences make it necessary to arrive at an equivalent-\$/MMBtu by dividing the annual geothermal energy cost by the current annual fossil fuel energy requirement.

The resulting geothermal energy costs can now be directly compared with published fossil fuel energy costs to determine the economics of geothermal energy. The prices of currently used fuels in 1976 were:

	<u>November 1976 price: \$/MMBtu²⁸</u>	
	<u>No. 6 Fuel Oil</u>	<u>Natural Gas</u>
Mountain Region	2.09	1.18
Pacific Region	2.34	1.78

Fuel oil prices have been dropping slightly while natural gas prices have been on a steady rise throughout 1976. These pricing changes in 1976 and the unavailability of natural gas have precipitated the switch of industrial users to fuel oil.

It should be noted that even though natural gas may cost as little as 1.18 \$/MMBtu, it is not always available at this price. Many of the industries contacted expressed concern over current or planned curtailment of their natural gas supply and their need to switch to alternative sources of energy.

Section 8

PRESERVED FRUIT AND VEGETABLE INDUSTRY

Tomato-pulp concentration, a process used to make tomato paste, was chosen as the example case for this industry which includes vegetable and fruit juice concentration as well. The background of the tomato paste industry, the process requirements for both a retrofit and new plant, the economics of the processes, and the requirements to implement the use of geothermal energy in this industry are discussed in this section.

8.1 TOMATO PASTE INDUSTRY BACKGROUND

Over 90 percent of the tomatoes produced in the western United States are grown and processed in California. About 5 billion pounds of tomatoes per year are used for paste production in the U.S. The bulk of this is processed in the Sacramento and San Joaquin Valleys of California. For the evaporation step alone, 1.89×10^{12} Btu/year (400,000 bbl oil/year equivalent) of energy are required to produce the tomato paste.^{24,30} Natural gas and/or oil are used almost exclusively to produce the low-pressure steam required for paste production. A listing of the companies that produce tomato paste in the western U.S. is given in Table 8-1. The locations of tomato paste plants (along with fruit juice concentration facilities) with respect to "probable geothermal areas"¹⁶ are shown in Figure 8-1.³¹

8.2 DESCRIPTION OF CONVENTIONAL PLANT PROCESS

In discussing tomato paste processing, a good example is Tri/Valley Growers' 200 ton/hr facility at Volta, California.³³ Operations there are typical of those used in the industry. Tomatoes are processed at

the Volta facility during the typical 70 day/year harvest season using the following sequence of operations (see Figure 8-2):

- Washing of tomatoes to remove dirt, etc.
- Chopping to reduce size
- "Hot breaking" or cooking for a brief time at 210°F to deactivate enzymes and separate the skins
- Scalping, pulping, and finishing to remove skins, seeds, etc.
- Interim storage to provide operating flexibility
- Multiple effect evaporation to concentrate from 5 to 30 wt percent solids
- Heating to 210°F by direct steam injection to sterilize the product
- Cooling to 80°F in vacuum coolers before filling 55-gallon drums with the tomato paste product

These operations are completed using the major pieces of equipment discussed in the following subparagraphs.

8.2.1 Boilers

Process steam for Tri/Valley's Volta plant is supplied by two 125,000 lb/hr boilers. Each boiler is rated at 150 psia pressure and can produce steam at 365°F. The boilers were originally designed to use natural gas as fuel, but have recently been modified to use oil as well. At operating conditions, the boilers consume an estimated 1800 gal/hr of No. 6 fuel oil (at 80 percent efficiency). Boiler steam is used:

- In the hot break unit (48 percent)
- In the multieffect evaporator system, after exhausting from the evaporator-circulation pumps (45 percent)
- In the injection heater/flash cooler system, drum fillers, and for miscellaneous plant uses (7 percent)

8.2.2 Hot Break Units

The hot-break system consists of 10 stainless steel rectangular tanks connected in parallel. There is a rotary coil heat exchanger in each vessel to which 365°F boiler steam is fed. As the steam condenses in the stainless steel coils, the tomato pulp is heated to deactivate the enzymes and loosen the skins. The rotating coils serve to enhance heat transfer by agitating the pulp.

8.2.3 Evaporator System

The multiple-effect evaporator system consists of three 60 ton/hr parallel trains. Each train is made up of three 2050-square-foot Rossi-Catelli forced-circulation evaporators to give a three-effect system. As designed, tomato pulp at 5 wt percent solids is fed to the first effect at about 200°F. Here, the pulp is concentrated to 7 wt percent solids at approximately 210°F. The product is then discharged to the third effect where its concentration is increased to 13 wt percent before being pumped to the second-effect body. Product tomato pulp is discharged from the second effect at 30 wt percent and 160°F for final sterilization and drum filling. The tomato pulp is routed from first to third to second effect to counter problems of high viscosity and low heat transfer coefficients at increasing paste solids concentrations. Ideally, a 25°F steam-to-product temperature differential is maintained in the first effect, while the pulp temperature is limited to a maximum of 210°F to prevent "burning" of the pulp. Condensate from the first and second effects is collected, flashed (to provide additional heat to respective downstream effect), and returned to the boilers. The evaporator system is constructed almost entirely of 316 stainless steel, as is most of the other process equipment in the plant.

8.2.4 Aseptic System (Injection Heaters/Flash Cooler)

After being concentrated to 30 wt percent solids in the evaporators, the 160°F tomato paste is pumped to three stainless steel 400-gallon

tanks where, by direct boiler steam injection, the paste is quickly heated to 210°F. This ensures sterile conditions. From these tanks, the hot product is pumped to three stainless steel vacuum-flash coolers arranged in parallel. In each cooler, product is evaporative-cooled to approximately 80°F. Direct boiler steam is used in an ejector system to produce the vacuum, while a barometric condenser downstream condenses the steam.

8.2.5 Drum Filler

After the tomato paste product is cooled, it is pumped to six drum filler units. Here, 55-gallon drums are automatically filled with product and sealed. Each drum filler consists of feed conveyor, lift table, steam chamber, cap remover, and sterilizing system. Boiler steam is used to maintain sterile conditions during filling.

8.3 DESCRIPTION OF GEOTHERMAL RETROFIT PLANT PROCESS

Figure 8-3 shows the process flow diagram (heat and material balance) for the retrofitted geothermal plant. The two primary uses for geothermal energy are for the hot-break units and the evaporators. A multiple-flash energy extraction process can be used on both systems with proper modifications. The primary design criterion is to use the maximum amount of geothermal brine with minimum effects on the process. Geothermal steam cannot be used in the aseptic system due to potential contamination problems from dissolved gases.

Geothermal brine enters at 300°F and is flashed down to 160°F; 1.805×10^6 lb/hr of brine is required. Two flash vessels, T-1 and T-2, are used to supply the heat to the hot breaks and evaporators. Fossil fuel-generated steam is still required for the injection heaters, flash cooler, and drum sterilization system. Additional heat exchanger area is required to utilize the geothermal brine efficiently. Area is added to both the hot breaks and the evaporators. Since the maximum

allowable tomato paste temperature is 210°F, this limits the maximum steam supply temperature. Adding area to the third-effect exchanger accommodates the additional heat requirements in this effect. With the design shown, the last effect temperature (125°F) is higher than in the existing process (120°F), which minimizes the equipment design modifications due to vapor disengagement and cooling system requirements.

Since it is not feasible to use geothermal steam for the aseptic system, a small auxiliary boiler must be supplied. The geothermal steam cannot be used due to its insufficient pressure level and the potential detrimental effects to the tomato paste quality resulting from direct contact of noncondensable gases (such as hydrogen sulfide) with the product. For a new plant this auxiliary boiler steam requirement could be cut approximately another 50 percent by use of a pressure aseptic system. This reduces the steam requirement, but the system has a higher capital cost.

8.3.1 Plant Equipment Modifications

Tables 8-2 and 8-3 show the revised tomato paste process equipment listing. The major equipment changes to the facility are:

- Addition of heat exchanger area to third-effect evaporator
- Conversion of pump drives from steam turbine to electric motor
- Modification of hot break units including addition of heat exchange surface
- Addition of a small package boiler

Some of the more significant changes are detailed in the following subparagraphs.

8.3.2 Hot Breaks

Substantial design changes are required for the hot breaks in order to minimize the brine flow. The existing units are designed to use high-temperature steam to minimize the heating time. For the unit to use lower temperature brine most effectively, a countercurrent design based upon multi-flash of the brine is required. The lowest temperature flash steam is used at the inlet to the unit where the coldest temperature tomato enters. This will require a substantial change in the exchanger area in addition to modifications to the design to allow for the countercurrent flow.

Stainless steel will be used for the exchanger surface materials. Since this is a substantial design change, it will require developmental testing.

8.3.3. Evaporators

From the heat and mass balance, additional area is required in the third-effect heat exchanger due to the increased heat load. This is provided by replacing the exchanger with one of sufficient size (3600 square feet) in each train. Stainless steel, the standard material for these exchanger surfaces, is required.

8.3.4 Pump Drives

The steam turbine drives are replaced by electric motor drives. In addition, the pump drives on the second effect are increased in size due to the additional pumping requirements in this stage.

8.3.5 Steam Generator

Due to the nature of food processing, some steam is required to maintain aseptic conditions. In addition, the cost to retrofit a plant can be minimized by using the existing final heaters, flash coolers, and drum fillers which depend upon high pressure steam for operation. Since this

steam flow represents only about 7 percent of the total steam generated, a small packaged boiler has been provided to fill these steam requirements.

8.3.6 Energy Requirements

For the retrofit and new plant, energy in the form of electricity and oil will be required. This energy is mainly required for the following:

- Brine supply system
- Tomato paste recirculation pumps
- Small packaged boiler

A total of 3,700 kW is required and a summary of electrical usage is shown in Table 8-4. In addition, fuel-oil usage of 140 gallons per hour is required.

8.4 DESCRIPTION OF GEOTHERMAL NEW PLANT PROCESS

For the new plant design, a credit can be obtained for the equipment no longer required. The major equipment deletions are two 125,000 lb/hr boilers and nine turbines for pump drives. As a result, there are no plant modification costs.

The process flow diagram for the retrofit case as shown in Figure 8-3 would apply. Additional savings in energy costs could be obtained by using a pressure aseptic system which reduces the fuel requirement to half of its previous value if the additional fuel savings are required. Electrical energy requirements would be the same as for the retrofit plant.

8.5 PLANT ECONOMICS

A summary of major cost items for the new and retrofit plants is shown in Tables 8-5 through 8-7. Table 8-8 shows a cost summary in terms of an equivalent energy cost (see Section 6.) of the major cost components. It is seen that more than 60 percent of the cost for a retrofit plant is associated with the geothermal brine system, and only about 20 percent with the plant equipment.

From the cost of geothermal energy, shown in Table 8-7, it is seen that, under suitable conditions, it can be advantageous to use geothermal energy. Retrofitting an existing plant is not cost effective under the conditions shown. However, the cost is quite favorable under current fuel prices for a new plant that uses oil as a fuel source on a plant operation schedule of 70 days/year. This period of operation is one of the most significant factors affecting the equivalent energy cost. This period is determined by the harvest season and the fact that tomatoes can only be transported for a few hours before spoilage begins. Since the use of geothermal energy is so capital intensive, any means to utilize the brine system more thoroughly throughout the year will yield an apparent decrease in the equivalent cost.

A combined facility which uses the geothermal wells for other operations when the tomato process is not in operation, or which extends the operation, will yield a significant saving in apparent energy cost. Thus, even retrofitting an existing plant can be economically favorable if the period of operation is extended.

8.6 IMPLEMENTATION

Two possible approaches exist for implementing the use of geothermal energy in the tomato paste industry: locate new plants near geothermal resources or change the way tomatoes are processed so that the processing plants can be located near the resource with initial processing done at the harvest location.

New tomato paste facilities are being built since the demand for tomato paste products is increasing at about 8 percent per year.

Considerations for the location of future facilities are as follows:

- Located in California. Over 90 percent of the tomatoes in the western states are grown and processed in California.
- Inexpensive land. Tomato waste products and wastewater would be used to upgrade the soil around the plant for future agricultural use.
- Short transportation distance. A total of 75 percent of the tomatoes used in the facility should come from no further away than 150 miles. This would hold down transportation costs and reduce spoilage in transit.
- Readily available utilities. Some 400 to 800 gallons of water per ton of tomatoes is required. Some of this could be obtained from water produced in using the geothermal brine. Additional water could be obtained by desalting the geothermal brine.
- Readily available part and full-time labor.

California, with its extensive geothermal resources, is an excellent area for this development. Unfortunately, most of the present processing is done in the San Joaquin and Sacramento Valleys. Therefore, only a few existing plants are located within a feasible brine transportation distance (see Figure 8-1a). Before a new plant is constructed, the area should be explored for geothermal resources and the plant should be located as close as possible to any geothermal resources that are discovered, as well as to the tomato fields themselves.

There are also new procedures being developed for tomato processing. Among these is the process of "field cutting." In this procedure, the tomatoes are picked and sliced in the field. The resulting slurry is then transported over longer distances to the paste plant. The disadvantage is that the enzymes in the tomatoes, which at temperatures

between 100 and 140°F are active and eventually destroy the pectin in the fruit, either have to be killed by heating ("hot breaking") before transporting, or be deactivated by shipping in refrigerated trucks. If "field cutting" is adopted, paste plants can be located further from the tomato fields and nearer the geothermal resource.

Prior to implementation of the use of the feed-and-bleed process in the preserved food and vegetable industry, it is necessary that a pilot plant program be conducted to determine the effects resulting from geothermal steam. There are stringent sanitary and quality requirements in the final product. Potentially, the product could be affected by contact from the geothermal steam. This could best be evaluated in pilot plant tests.

Table 8-1

WESTERN U.S. TOMATO PASTE PRODUCERS ³¹

Firm	Factory Location
California Cannery & Growers	Gilroy, California San Jose, California Stockton, California Sunnyvale, California Thornton, California
Contadina Foods	San Jose, California Woodland, California Riverbank, California Hollister, California Hanford, California
Del Monte Corporation	Modesto, California Stockton, California
Gangi Brothers Packing Company	Santa Clara, California
Heinz U.S.A.	Tracy, California
Hickmott Foods Inc.	Antioch, California
Hunt-Wesson Foods, Inc.	Davis, California Oakdale, California Hayward, California
Joan of Arc Company	Turlock, California
Kern Foods, Inc.	City of Industry, California
Libby, McNeill & Libby	Sacramento, California
NCC Food Corporation	San Jose, California Hollister, California
Pacific Coast Producers	Lodi, California Oroville, California
Ragu Foods, Inc.	Merced, California
Sacramento Foods Division	Sacramento, California
Stanislaus Foods Products Company	Modesto, California
Sun Garden Packing Company	San Jose, California
Tille Lewis Foods, Inc.	Stockton, California ⁽²⁾ Modesto, California Antioch, California
Tri/Valley Growers	Modesto, California ⁽²⁾ Stockton, California Los Banos, California
Valley Tomato Products, Inc.	Stockton, California

Table 8-2

**TOMATO PASTE PLANT RETROFIT
MECHANICAL EQUIPMENT LIST**

Equipment	Description	
Flash Tanks	Quantity Type Size Design Pressure Design Temperature Material Remarks	Two Horizontal 5 ft. dia 20 ft. length 67 psia 300°F Carbon steel Include three flash stages, product trays, and mist eliminator.
Supply Wells	Quantity Depth	Seventeen 1000 feet
Reinjection Well	Quantity Depth Miscellaneous	Nine 1000 feet Surge tank 75,000 gallons steel
Supply Pump	Quantity Capacity Type Efficiency Driver	Seventeen 250 gpm at 750 feet Deep submersible 80% Induction motor, 60 HP
Transfer Pump	Quantity Capacity Type Efficiency Driver	Two 1800 gpm at 45 feet Centrifugal 80% Induction motor, 30 HP
Reinjection Pumps	Quantity Capacity Type Efficiency Driver Material	Two 1800 gpm at 740 ft head Centrifugal 80% Induction motor, 450 HP Cast iron case, SS impeller
Recirculation Pump Electric Motor Conversions	Quantity Type Size	Nine Induction motor weatherproof Type II (6) 250 HP (3) 400 HP
Third Effect Heat Exchanger	Quantity Size Material	Three 3600 square feet of area SS tubes
Hot Breaks Exchanger Surface	Quantity Size Material	Ten 1800 square feet SS
Packaged Boiler	Quantity Size	One 150 pounds at 15,000 lb per hour

Table 8-3

TOMATO PASTE PLANT RETROFIT
MAJOR PIPING LIST

<u>Description</u>	<u>Diameter (in.)</u>	<u>Schedule</u>	<u>Length (ft.)</u>	<u>Material</u>
<u>Brine System Piping</u>				
Brine Inlet	16	40	5280	CS
Brine Reinjection	16	40	5280	CS
<u>Steam Lines</u>				
Effect 1 and 3 and Hot Breaks	20	40	400	CS
Effect 2	12	40	200	CS

CS — Carbon Steel

Table 8-4

TOMATO PASTE PLANT
ADDITIONAL ELECTRICAL REQUIREMENTS

	<u>Item</u>	<u>Hp</u>
1	Brine Supply Pump	1080
2	Brine Reinjection Pump	900
3	Recirculation Pump	2900
4	Vacuum Pump	10
5	Miscellaneous	<u>50</u>
	Total	4940

(kW = 3700)

Table 8-5

**TOMATO PASTE PLANT
CONCEPTUAL ESTIMATE DETAIL
PLANT RETROFIT**

	Installed Cost \$1000	
Plant Equipment and Materials		1320
Pumps and Drives	131	
Condensers	-	
Heat Exchangers	636	
Tanks and Vessels	28	
Cooling Towers	-	
Steam Generator	114	
Electrical	206	
Concrete	8	
Piping	197	
Wellfield Equipment and Materials		3160
Production Wells and Brine Header	1294	
Production Well Pumps	340	
Production Brine Piping (1 Mile)	307	
Reinjection Wells and Brine Header	716	
Reinjection Pumps	155	
Reinjection Brine Piping (1 Mile)	114	
Electrical	222	
Concrete	12	
Total Field Cost		4480
Engineering and Home Office		670
Contingency		1030
Construction Cost		6180
Owner's Cost		860
TOTAL RETROFIT CAPITAL COST Second Quarter, 1977		7040

Table 8-6

**TOMATO PASTE PLANT
CONCEPTUAL ESTIMATE DETAIL
NEW PLANT**

	Installed Cost \$1000
Plant Equipment and Materials (from Table 8-5)	1320
Wellfield Equipment and Materials (from Table 8-5)	3160
Credit for Fossil Fuel Plant Equipment Not Required for New Construction Steam Generator Steam Turbine Pump Drives Steam Turbine-Generator	(1760)
Credit for Fossil Fuel Plant Bulk Materials Not Required for New Construction 0.8 x Installed Cost of Fossil Fuel Plant Equipment	(1410)
Total Field Cost	1310
Engineering and Home Office	200
Contingency	300
Construction Cost	1810
Owner's Cost	340
NEW CONSTRUCTION CAPITAL COST* Second Quarter, 1977	2150

* As compared to an oil or gas fired plant.

Table 8-7

**TOMATO PASTE PLANT
COST OF GEOTHERMAL ENERGY**

	Plant Retrofit	New Plant
Total Construction Capital Cost(x\$1000)	7040	2150*
Annual Capital Cost at 18% Fixed Charge Rate(x\$1000)	1270	390
Annual Operating and Maintenance Cost (Includes Electric Energy)(x\$1000)	<u>480</u>	<u>480</u>
Annual Geothermal Energy Cost(x\$1000)	1750	870
Days of Continuous Plant Operation	70	70
Fossil Fuel Energy Requirements (1,000 MMBtu/Season)	450	450
Cost of Geothermal Energy (EQUIV-\$/MMBtu) (Directly Comparable to Current Fossil Fuel Energy Costs)	3.88	1.93

* As compared to an oil or gas fired plant

Table 8-8
ENERGY COST SUMMARY

Cost Item	\$/MMBtu	
	Plant Retrofit	New Plant
Geothermal Wells	2.30	2.30
Pipeline	0.32	0.32
Plant Equipment	0.81	0.81
Electrical Power	0.35	0.35
Fossil Fuel	0.10	0.10
Equipment Credit	—	(1.95)
Cost of Geothermal Energy (Equivalent \$/MMBtu)	3.88	1.93

Figure 8-1a. Location of Western Tomato Pulp and Fruit Juice Concentration Facilities

Figure 8-1b. Location of Western Tomato Pulp and Fruit Juice Concentration Facilities

Figure 8-2. Process Flow Diagram T-1, Tomato Paste Plant

Figure 8-3. Process Flow Diagram T-2, Tomato Paste Plant Utilizing Geothermal Brine

Section 9

SUGAR AND CONFECTIONARY PRODUCTS INDUSTRY

The production of beet sugar is the example case chosen for this industry which includes both beet and cane-sugar solution concentration, a process that requires the use of multieffect evaporation.

9.1 BEET SUGAR INDUSTRY BACKGROUND

The beet sugar industry converts approximately 26 million tons per year (1972) of raw sugar beets into various sugar products. Roughly 70 percent of these beets are processed in 36 beet sugar factories located in the western United States.³² In 1971, the industry consumed a total of 83.3×10^{12} Btu, of which about 12.5×10^{12} Btu (15 percent) were used for multieffect evaporator operations.^{24,30} Thus, in the western United States, about 8.75×10^{12} Btu (1,800,000 bbl oil/yr equivalent) are used for evaporation. A list of the companies that produce beet sugar in the western United States is given in Table 9.1. The location of beet sugar plants with respect to "probable geothermal areas" are shown in Figure 9-1.

9.2 DESCRIPTION OF CONVENTIONAL PLANT PROCESS

Sugar beet refining is a relatively complex process involving nearly every chemical engineering unit operation. The flow diagram for a conventional beet sugar facility is shown in Figure 9-2. This "typical" plant has the capacity to convert 4000 tons/day of raw sugar beets (8-16 wt % sugar) to pure refined sugar during a harvest season ranging upwards from 120 to about 300 days/year. The typical operating period is assumed to be 160 days/year. The factory is a "straight (non-Steffen) house;" it does not recover sugar from the molasses by-product.

9.2.1 Boilers

Sugar beet refining requires large amounts of steam — about 15,000 lb of steam per ton of beets. Two 600-lb boilers are used for the example plant. At operating conditions (152,540 lb/hr steam at 750°F), the boilers consume an estimated 1450 gal/hour of No. 6 fuel oil at 80 percent boiler efficiency. Before being used for process heating, virtually all of the boiler steam is used to drive a number of turbines. The turbines are used to drive generators, which supply the factory's electric power requirement, and to power various large pumps and compressors. Most of the exhaust steam from these turbine drivers is used in the first effect of the plant's multiple-effect evaporator system, while the remainder is used directly for process heating, for example, in some of the evaporator feed preheaters.

9.2.2 Evaporator System

The multiple-effect evaporator operation of the selected example is typical of many beet sugar factories. Sugar solution is concentrated from 15 wt % to 60 wt % sugar in the four-effect system. A total of seven long-tube vertical evaporator bodies are used — two in the first effect, three in the second, and one each in the last two effects. One of the second-effect evaporators is a "swing body" — it can be used in the first-effect system as well. Steam is supplied in parallel to the bodies in the first and second effects, while the sugar solution is fed in series through all seven bodies, from first to last effect (forward feed). Each evaporator has a heat transfer surface area of about 8000 sq ft, using 1½-inch diameter by 24-foot stainless steel tubes. Some of the steam generated in each effect is withdrawn between effects, for process heating, as listed in Table 9-2. Condensate from the first effect is cycled back as boiler feedwater. In addition, the condensate from each effect is flashed to provide additional heat to the following effect. Evaporator piping is arranged so that any individual body can be taken out of service and bypassed for cleaning.

9.2.3 Process Units

The steam withdrawn from the multieffect evaporator system is used throughout the plant in various process units. These uses are summarized in Table 9-2, shown in Figure 9-2, and discussed below:

- Thin Juice Heaters. The dilute sugar-solution evaporator-system feed is preheated in these shell and tube heat exchanger units.
- White, Intermediate, and Raw Vacuum Pans. In a sugar factory, vacuum pans are batch evaporator/crystallizers which are used to further concentrate the thick sugar solution discharged from the multi-effect evaporator system.
- Diffuser. A diffuser in a beet sugar factory is a large vessel in which the sugar content of the beets is extracted by contact with a hot water stream.
- Standard Liquor, and Thick Juice Heaters. The thick juice discharged from the multi-effect evaporator system is, before being fed to the vacuum pans, preheated in these shell and tube exchanger units.
- Second Carbonation Heaters. Steam is used in the second carbonation heaters to heat the dilute sugar solution prior to the second carbonation purification step.
- Raw Juice Heaters. Raw juice (dilute sugar solution) from the diffuser is heated in the shell and tube raw juice heaters before being fed to the first carbonation purification unit.
- Melters. In order to increase the purity of the evaporator thick juice, higher purity crystallized sugar solution from the intermediate and raw vacuum pans is dissolved in steam heated melter vessels and added to the incoming thick juice stream.

9.2.4 Dryers

The main plant requirement for fuel, other than for steam generation, is for beet pulp drying. This pulp, left after sugar is extracted from

the beets, is used as animal feed. Fossil fuel dryers are used to reduce the moisture content from about 80 percent to under 10 percent by weight. Approximately 30 to 50 percent of the fuel requirement in a typical beet sugar factory is for pulp drying.

9.3 DESCRIPTION OF GEOTHERMAL RETROFIT PLANT PROCESS

Figure 9-3 is a heat and material balance for the retrofit geothermal plant. The criteria used to establish this balance are:

- Utilize as much geothermal steam as possible
- Utilize existing effects, but arrange as necessary to accommodate using geothermal brine
- Minimize effect of auxiliary heat exchange equipment

If modifications to the auxiliary heat exchangers are required, they can become a major cost item in retrofitting a plant. For this case, the drawoff conditions were selected so that no changes were required in the extensive auxiliary heat exchanger system; this resulted in less overall heating in the thin juice heaters. This also lessened the steam drawoff requirements.

The brine flow requirements were calculated at 3,150,000 lb/hr for a 300°F brine case with a flashdown to 218°F. A single flash vessel with four stages of flashdown was required.

9.3.1 Plant Equipment

Shown in Tables 9-3 and 9-4 are revised equipment and piping lists for the retrofit geothermal case. The major changes are:

- Redistribution of the number of evaporator bodies in each effect
- Addition of a concentrator prior to the vacuum pans

- Modifications of steam and liquid piping
- Increased capacity of the cooling system

Some of the more significant changes are detailed below.

Evaporators. The area distribution within the four effects has been changed so that only one body is in the first, second, and third effects, and three in the fourth effect. Since stainless steel tubes were used in the heat exchangers, there was no necessity for retubing. In other sugar beet plants, this might not be the case, as materials such as copper, mild steel, and bronze are used. These may not be compatible in the geothermal environment. This would substantially affect the capital cost associated with these plants, but not materially affect the equivalent energy cost. Mist eliminators were added to the last-effect evaporators to allow for the increased evaporation rate.

Concentrator. Because processing of the sugar solution must be accomplished in a short period of time, a concentrator must be added, owing to the lower available steam temperature for this process. Additional area must be added to the white pan or a concentrator can be added that is designed for this duty. For the retrofit case, the addition of the concentrator is the best solution.

Cutters. The "cutters" are used to slice the beets. Direct injected live steam is used for cleaning the cutters. Because compressed air can be used for this purpose, it will be used for the retrofit plant.

Cooling System. Due to the increased evaporation in the fourth effect, the cooling system must be substantially enlarged. This includes addition of a barometric condenser, cooling tower, and cooling water recirculation system.

9.3.2 Steam Drive Conversion

Large steam turbine drives for the carbon dioxide compressor and recirculation water pump must be converted to electric motor drives. The steam ejectors used for vacuum production must be changed to electrically driven vacuum pumps.

9.3.3 Energy Requirement

For a plant operating without steam generation, electricity will be required. The main uses for electricity are to replace the in-house generator requirements, and for the brine supply and reinjection system. These electrical requirements are summarized in Table 9-5.

9.4 NEW PLANT

For a new plant designed to accommodate geothermal brine, a credit can be obtained for major equipment deleted within the plant. The major items are shown in Table 9-6.

9.5 PLANT ECONOMICS

The results of the economic analysis are summarized in the following tables and figures:

- Table 9-7 - Conceptual Estimate Detail,
Plant Retrofit
- Table 9-8 - Conceptual Estimate Detail,
New Plant
- Table 9-9 - Cost of Geothermal Energy
- Table 9-10 - Energy Cost Summary
- Figure 12-1b - Cost Versus Period of Operation
- Figure 12-2b - Cost Versus Brine Transportation
Distance

For the typical plant selected, the equivalent energy cost is \$3.18/MMBtu for a plant retrofit and \$2.07/MMBtu for a new plant.

A sugar plant represents a thermodynamically efficient process as it is designed for cogeneration of power and heat. As a result, the increased electrical power represents a larger fraction of the revised energy cost (Table 9-10). Of this cost for a plant retrofit, 60 percent can be attributed to the geothermal wells, 30 percent to the increased electrical power, and 10 percent to the cost of retrofitting the plant. For a new plant, about 45 percent of the cost is attributed to the increased electrical power and the remainder to the net increase in capital cost due to addition of the geothermal wells.

9.6 IMPLEMENTATION

At the present time, the domestic beet and cane sugar industries are in difficult economic straits due to depressed raw sugar prices. No new beet sugar plants have been built by the largest producers in more than 10 years and no new plants are expected to be built in the near future. In addition, serious inroads are being made into the market by high fructose corn syrup.

Since the possibility for new plants is very limited, the best probability for implementating the use of geothermal energy in this industry is through retrofit of existing plants. Figure 9-1 lists the beet sugar factories in the western United States. Some 15 factories are within 25 miles of probable resource areas. In addition to these, there are 16 cane sugar factories in the Hawaiian Islands. Five of these are located on the Island of Hawaii where a producing geothermal well was recently completed.

Beet sugar factories have the advantage of being able to extend the period of operation. Sugar beets are not as susceptible to spoilage

as some fruits and vegetables so that they may be shipped by rail over considerable distances. This can be used for increased operating economy (see Section 12.1.2) by extending the period of operation of selected plants. This increased operating time can lower the equivalent energy cost to as low as \$1.50/MMBtu.

The cane sugar factories present an excellent opportunity for plant retrofits. The plants typically operate nine or ten months a year which is of significant economic advantage. Fuel for the boilers is supplemented by bagasse which is used to generate steam for power production in addition to supplying steam for the evaporators. Were geothermal energy to be used for the evaporators, additional excess electrical power would be available for sale or use elsewhere in the facility to provide additional income. It is recommended that further definition of the geothermal resource in Hawaii be undertaken, with the objective of utilizing the brine in cane sugar factories.

A site specific study has been awarded by ERDA for applying geothermal energy to sugar beet processing. This study is being conducted by TRW under Contract No. EY76-C-03-1317. It considers the use of geothermal energy for pulp drying as well as for the evaporation and crystallization process.

Table 9-1

WESTERN U.S. BEET SUGAR PRODUCERS

Firm	Factory Location
Amalgamated Sugar Company 2	Lewiston, Utah Paul, Idaho Twin Falls, Idaho Nampa, Idaho Nyssa, Oregon
American Crystal Sugar Company	Clarksburg, California Rocky Ford, Colorado
Great Western Sugar Company	Loveland, Colorado Greeley, Colorado Eaton, Colorado Sterling, Colorado Fort Morgan, Colorado Billings, Montana Lovell, Wyoming Ovid, Colorado
Holly Sugar Corporation	Hamilton City, California Santa Ana, California Worland, Wyoming Tracy, California Sidney, Montana Torrington, Wyoming Hardin, Montana Brawley, California
Spreckels Sugar Company, Division Amstar Corporation	Spreckels, California Manteca, California Woodland, California Mendota, California Chandler, Arizona
Utah-Idaho Sugar Company	Garland, Utah Idaho Falls, Idaho West Jordan, Utah Toppenish, Washington Moses Lake, Washington
Union Sugar Division, Consolidated Foods Corporation	Betteravia, California

Table 9-2

PROCESS HEAT FROM EVAPORATOR SYSTEM

Steam Generated From	Pressure psia	Process Equipment Steam To Be Used In
First Effect	42.9	Thin Juice Heaters White Pan
Second Effect	28.8	Thin Juice Heaters Diffuser Standard Liquor Heater Thick Juice Heater 2nd Carb. Heaters Melters White Pan Intermediate Pan Misc. Process Uses
Third Effect	16.7	Diffuser Raw Juice Heaters 2nd Carb. Heaters Raw Pan
Fourth Effect	8.8	Raw Juice Heaters

Table 9-3

**BEET SUGAR PLANT
MECHANICAL EQUIPMENT LIST**

Equipment	Description	
Flash Tank	Quantity Type Size Design Pressure Design Temperature Material Remarks	One Horizontal 5 ft dia. x 28 ft. length 67 psia 300°F Carbon steel Includes four flash stages, product trays, and mist eliminator
Supply Wells	Quantity Depth	Twenty Six 1000 feet
Reinjection Well	Quantity Depth Miscellaneous	Thirteen 1000 feet Surge Tank 125,000 gallons concrete
Supply Pump	Quantity Capacity Type Efficiency Driver	Twenty six 250 gpm at 800 feet Deep submersible 80% Induction motor, 70 Hp
Transfer Pump	Quantity Capacity Type Efficiency Driver	Two 3150 gpm at 55 feet Centrifugal 80% Induction motor 60 Hp
Evaporators	Quantity Miscellaneous	Four effects Conversion to single vessel in first three effects and three vessels in fourth effect. Addition of mist eliminator
Reinjection Pumps	Quantity Capacity Type Efficiency Driver Material	Two 3150 gpm at 740 ft. head Centrifugal 80% Induction motor, 800 Hp Cast iron case, SS impeller
Concentrator	Quantity Capacity Miscellaneous	One 98,000 lb/hr SS tubes
Electric Motor Conversions		500 Hp carbon dioxide compressor, 200 Hp circulating water
Condenser Direct Contact	Quantity Type Material Steam Flow Cooling Water Flow	One Multiple jet direct contact Fabricated steel 1.26 x 10 ⁵ lb/hr 7500 gpm
Condenser Vacuum Pump (and motor)	Quantity Type Capacity Driver	One Rotary liquid seal 220 scfm, 9 psia Induction motor, 20 Hp
Cooling Tower	Quantity Type Flow Rate Fan Drivers Fan RPM Remarks	One Mechanical draft 8000 gpm Induction motors, 200 bhp 1700 Approach is 10°F
Circulating Water Pump	Quantity Type Capacity Efficiency Driver Material	Two Centrifugal 4000 gpm at 40 feet 80% Induction motor, 60 Hp Cast iron

Table 9-4

BEET SUGAR MAJOR PIPING LIST

<u>Description</u>	<u>Diameter (in.)</u>	<u>Schedule or Thickness (in.)</u>	<u>Length (ft.)</u>	<u>Material</u>
<u>Brine System Piping</u>				
Brine Inlet	20	40	5280	CS
Brine Reinjection	20	40	5280	CS
<u>Steam System Piping</u>				
Effect 3	16	40	110	CS
Effect 2	18	40	130	CS
Effect 1 and 4	20	40	130	CS
Condenser	36	20	60	CS
<u>Liquid Systems</u>				
Evaporators	4	40	100	CS
	8	40	150	CS
Cooling Water	24	40	200	CS

CS - carbon steel

Table 9-5

**BEET SUGAR PLANT,
ADDITIONAL ELECTRICAL REQUIREMENTS**

	Item	Hp
1	Brine Supply Pump	1760
2	Brine Reinjection Pump	1580
3	Steam Driven Pumps	700
4	Replacement for Generator	6380
5	Cooling System	310
6	Vacuum Pump	20
7	Miscellaneous	120
	Total	10,870

(kW = 8100)

Table 9-6

MECHANICAL EQUIPMENT LIST — NEW BEET SUGAR PLANT

Deletions		
1. Boiler System	Quantity Capacity Fuel Miscellaneous	One 600 pounds at 160,000 pounds per hour Oil or natural gas Feedwater system pumps and fans
2. Electrical Generator and Turbine	Quantity Capacity	One 5000 kVA 600 psig inlet steam 45 psig discharge

Table 9-7

SUGAR BEET FACTORY
CONCEPTUAL ESTIMATE DETAIL
PLANT RETROFIT

	Installed Cost \$1000	
Plant Equipment and Materials		855
Pumps and Drives	59	
Condensers	20	
Heat Exchangers	-	
Tanks and Vessels	98	
Cooling Towers	125	
Steam Generator	-	
Electrical	158	
Concrete	6	
Piping	389	
Wellfield Equipment and Materials		4685
Production Wells and Brine Header	2000	
Production Well Pumps	519	
Production Brine Piping (1 Mile)	370	
Reinjection Wells and Brine Header	1087	
Reinjection Pumps	309	
Reinjection Brine Piping (1 Mile)	139	
Electrical	243	
Concrete	18	
Total Field Cost		5540
Engineering and Home Office		830
Contingency		1275
Construction Cost		7645
Owner's Cost		1095
TOTAL RETROFIT CAPITAL COST Second Quarter, 1977		8740

Table 9-8

SUGAR BEET FACTORY
CONCEPTUAL ESTIMATE DETAIL
NEW PLANT

	Installed Cost \$1000
Plant Equipment and Materials (from Table 9-7)	855
Wellfield Equipment and Materials (from Table 9-7)	4685
Credit for Fossil Fuel Plant Equipment Not Required for New Construction Steam Generator Steam Turbine Pump Drives Steam Turbine-Generator	(2020)
Credit for Fossil Fuel Plant Bulk Materials Not Required for New Construction 0.8 x Installed Cost of Fossil Fuel Plant Equipment	(1540)
Total Field Cost	1980
Engineering and Home Office	300
Contingency	455
Construction Cost	2735
Owner's Cost	505
NEW CONSTRUCTION CAPITAL COST [*] Second Quarter, 1977	3240

* As compared to oil or gas fired plant

Table 9-9

SUGAR BEET FACTORY — COST OF GEOTHERMAL ENERGY

	Plant Retrofit	New Plant
Total Construction Capital Cost (x\$1000)	8740	3240*
Annual Charge Cost at 18% Fixed Charge Rate (x\$1000)	1570	580
Annual Operating and Maintenance Cost (Includes Electric Energy) (x\$1000)	1190	1190
Annual Geothermal Energy Cost (x\$1000)	2760	1770
Days of Continuous Plant Operation	160	160
Fossil Fuel Energy Requirements (1000 MMBtu/season)	860	860
Cost of New Construction Geothermal Energy (Equiv-\$/MMBtu) (Directly Comparable to Current Fossil Fuel Energy Costs)	3.21	2.06

*As compared to an oil or gas fired plant

Table 9-10

BEET SUGAR ENERGY COST SUMMARY

	\$/MMBtu	
	Plant Retrofit	New Plant
Geothermal Wells	1.86	1.86
Pipeline	.19	0.19
Plant Equipment	0.24	0.24
Electrical Power	0.92	0.92
Equipment Credit	—	(1.15)
Cost of Geothermal Energy (Equivalent \$/MMBtu)	3.21	2.06

Figure 9-1a. Location of Western Beet Sugar Factories

© BEET SUGAR

Figure 9-1b. Location of Western Beet Sugar Factories

Figure 9-2. Process Flow Diagram S-1, Beet-Sugar Factory

Figure 9-3. Process Flow Diagram S-2, Beet-Sugar Factory Utilizing Geothermal Brine

Section 10

CHEMICAL INDUSTRY

For this study, salt (sodium chloride) production by evaporation is used as the example case from the chemical industry. Multieffect evaporation/crystallization is also used in this industry for inorganic salts production and caustic soda concentration in chlorine-caustic production.

10.1 SALT INDUSTRY BACKGROUND

The salt industry produces over 45 million tons per year (1972) of sodium chloride, most of which is used by the chemical industry itself (see Table 10-1). About 4.5 million tons/year (10 percent) of the salt is produced using multieffect evaporation/crystallization — the remainder being produced by various other processes.^{24, 25, 34} "Evaporated" salt is produced in 29 plants located in eleven states. Two of these plants are in the western United States.³⁴ The locations of salt plants (along with caustic and inorganic salts plants) with respect to "probable geothermal areas" are shown in Figure 10-1.

10.2 DESCRIPTION OF CONVENTIONAL PLANT PROCESS

A vacuum pan salt facility having a capacity of 500 tons/day of salt product is used as the example plant for the discussion of the salt process. The flow diagram of this "typical" evaporated salt facility is shown in Figure 10-2. This typical plant operates approximately 270 days/year.

The production of food-grade salt by multieffect evaporation begins by pumping a saturated brine, obtained from an impure salt source, to an

aerator to remove most of any hydrogen sulfide that may be present. Addition of small amounts of chlorine completes the H_2S removal by oxidation. The brine is then pumped to settling tanks where it is treated with caustic soda and soda ash to precipitate calcium, magnesium, and ferric ions. The clear overflow from the settling tanks is pumped to the multiple effect evaporators where the salt is crystallized out of the saturated solution. The resulting slurry is washed to remove calcium sulfate fines by hydraulic classification, and then filtered — the mother liquor filtrate being returned to the evaporators. Moist salt crystals from the filters are dried to a moisture content of 0.5 wt % or less in a fossil-fueled rotary drum dryer, and then screened to yield the various product salt grades.

10.2.1 Boilers

Plant steam is generated in two fossil-fueled 150 pound boilers. At operating conditions (43,500 lb/hr, steam at $360^{\circ}F$), the boilers consume an estimated 360 gal/hr of No. 6 fuel oil at 80 percent boiler efficiency. Most of the steam is used, first, to drive the evaporator-circulation turbine-pumps, and then as exhaust at 35 psia to the first-effect evaporator. In the production of salt, about one pound of steam is required per pound of product.

10.2.2 Evaporator System

In the example plant, a four-body, quadruple-effect evaporator/crystallizer system is used. Each long-tube forced-circulation evaporator is equipped with an external copper-nickel tube bundle having a heat-transfer surface area of 5500 sq ft. Brine, saturated with salt at about 25 wt %, is fed in parallel to each effect. As water is evaporated in each unit, salt crystals are formed, and discharged in an elutriating leg as a 25 wt % solids solution of salt crystals and saturated brine.

10.2.3 Dryer

The salt dryer consumes roughly 5 percent of the facility's fossil fuel requirement, which is currently natural gas. No consideration is given in this study to converting this process to the use of geothermal brine, although this possibility exists.

10.3 DESCRIPTION OF GEOTHERMAL RETROFIT PLANT PROCESS

Figure 10-3 shows the process flow diagram for the retrofitted salt plant. This plant represents a straightforward application of geothermal energy, as steam is used only in the evaporator system; whereas in the tomato paste and sugar beet cases, boiler steam is required for other uses besides evaporation.

The principal objective is the maximum use of geothermal energy. Geothermal brine enters at 300°F and is flashed down in three stages to 148°F. A total of 478,000 lb/hr are required. When the areas are re-distributed so that there are three effects of crystallization in four vessels, brine flow is at a reasonable minimum.

10.3.1 Plant Equipment Modifications

Tables 10-2 and 10-3 show the revised sodium chloride process equipment and major piping lists. The major equipment changes are:

- Replacement of the tube material
- Conversion of the pump drives to electric motor drives
- Modification of the system to a three-effect evaporator

The significant items are described below.

Evaporators. Some of the copper nickel heat exchanger tube material will have to be replaced owing to corrosion from hydrogen sulfide.

The tube material in the first effect was changed to Incoloy 825 material; no change was made in the other effects as it was assumed that most of the noncondensable gases are released in the first flash.

Pump Drives. The steam turbine drives must be replaced by electric motors.

10.3.2 Energy Requirements

For both the retrofit and new plant, additional electrical energy is required. For both of these cases, the usage totals 760 kW and is summarized in Table 10-4. The replaced recirculation drives require the most energy followed by the brine supply and reinjection pumps.

10.3.3 Brine Supply

For a 300°F supply temperature, four supply wells and two reinjection wells are required if the feed-and-bleed process is used. There is a substantial increase in brine flow requirements with decreasing brine temperature. For example, at 260°F, the brine flow increases by 40 percent over the 300°F brine case (see Section 12.1.3 for details).

10.4 DESCRIPTION OF GEOTHERMAL NEW PLANT PROCESS

For a new plant, the process flow diagram for the retrofit case as shown in Figure 10-3 is applicable. The electrical requirements are the same as for the plant retrofit.

For a new plant designed to accommodate geothermal brine, a credit can be obtained for the following major equipment:

- Packaged steam generator and support equipment, 45,000 lb/hr at 150 psi
- Four steam turbines

10.5 PLANT ECONOMICS

Geothermal energy can be economical in a plant where the sodium chloride crystallization process is used. Among the factors affecting the economic feasibility, long-term yearly operation is the most important along with the relatively low conversion cost. The results of the economic analysis are summarized in the following tables and figures:

- Table 10-5 Sodium Chloride Conceptual Estimate
Detail, Plant Retrofit
- Table 10-6 Sodium Chloride Conceptual Estimate
Detail, New Plant
- Table 10-7 Sodium Chloride Cost of Geothermal Energy
- Table 10-8 Sodium Chloride Energy Cost Summary
- Table 12-1 Sodium Chloride Conceptual Cost Estimate
Single Flash and Feed-and-Bleed Process
- Figure 12-1c Sodium Chloride Cost vs Period of Operation
- Figure 12-2c Sodium Chloride Cost vs Brine Transportation
Distance

For the typical plant selected, the equivalent energy cost is 1.64/MMBtu for a plant retrofit and \$1.09/MMBtu for a new plant. Over 60 percent of the cost is attributed to the geothermal wells and the cost of brine transportation, 21 percent to the additional electrical power, and 16 percent to the cost of retrofitting the plant.

10.6 IMPLEMENTATION

The sodium chloride crystallization process is typical of many inorganic salt production processes. Figure 10-1 shows the location of some of the major inorganic chemicals production facilities. Twelve existing plants are identified within an economically feasible distance of potential geothermal resources (see Section 12-2). If these plants can be retrofitted, there will be a significant savings in energy usage.

Table 10-1

USES OF SALT IN THE U.S.²⁵

Area of Use	Percent
Chlor-Alkali Industry	45
Soda Ash Production	13
Food Processing	6
Other Chemical Production	4
Animal Feed Dealers and Mixers	4
Other Industry	1
Miscellaneous	27

Table 10-2

SODIUM CHLORIDE PLANT RETROFIT, MECHANICAL EQUIPMENT LIST

Equipment	Description	
Flash Tank	Quantity Type Size Design Pressure Design Temperature Material Remarks	One Horizontal 4 ft dia. x 15 ft length 67 psia 300°F Carbon steel Includes three flash stages, product trays, and mist eliminator
Supply Wells	Quantity Depth	Four 1000 feet
Reinjection Well	Quantity Depth Miscellaneous	Two 1000 feet Surge Tank 20,000 gallons steel
Supply Pump	Quantity Capacity Type Efficiency Driver	Four 250 gpm at 850 feet Deep Submersible 80 Induction motor, 70 Hp
Transfer Pump	Quantity Capacity Type Efficiency Driver	Two 500 gpm at 90 feet Centrifugal 80 Induction motor, 15 Hp
Evaporator	Quantity Miscellaneous	4 Effect. Change tube material in first effect to Incoloy 825. Conversion to three effects with four vessels
Reinjection Pumps	Quantity Capacity Type Efficiency Driver Material	Two 500 gpm at 740 ft. head Centrifugal 80% Induction motor, 125 Hp Cast iron case, SS impeller
Electric Motor Conversions	Quantity Type Miscellaneous	Four Electric motor Total horsepower is 300
Condenser Direct Contact	Quantity Type Material Steam Flow Cooling Water Flow	One Multiple Jet direct contact Fabricated Steel 30,000 lb/hr 2000 gpm
Condenser Vacuum Pump (and motor)	Quantity Type Capacity Driver	One Rotary liquid seal 40 scfm Induction motor, 10 Hp
Cooling Tower	Quantity Type Flow Rate Fan Drivers Fan RPM	One Mechanical draft 2000 gpm Induction motors, 20 bhp 1700
Circulating Water Pump	Quantity Type Capacity Efficiency Driver Material	One Centrifugal 2000 gpm @ 40 feet 80% Induction motor, 30 Hp Cast Iron

Table 10-3

SODIUM CHLORIDE PLANT RETROFIT, MAJOR PIPING LIST

<u>Description</u>	<u>Diameter (in.)</u>	<u>Schedule or Thickness (in.)</u>	<u>Length (ft.)</u>	<u>Material</u>
<u>Brine System Piping</u>				
Brine Inlet	28	40	5280	CS
Brine Reinjection	28	40	5280	CS
Evaporators	14	40	50	CS
	16	40	50	CS
	20	40	20	CS
Condenser	30	20	40	CS
<u>Liquid Systems</u>				
Cooling Water	10	40	200	CS

CS - Carbon Steel

Table 10-4

SODIUM CHLORIDE PLANT
ADDITIONAL ELECTRICAL REQUIREMENTS

	Item	Hp
1	Brine Supply Pump	270
2	Brine Reinjection Pump	250
3	Recirculation Pump	300
4	Cooling System	70
5	Vacuum Pump	10
6	Miscellaneous	40
		<hr/> 940

(kW = 760)

Table 10-5

SODIUM CHLORIDE
CONCEPTUAL ESTIMATE DETAIL
RETROFIT PLANT

	Sodium Chloride Multi-Flash Installed Cost, \$1000	
Plant Equipment and Materials		345
Pumps and Drives	51	
Condensers	9	
Heat Exchangers	83	
Tanks and Vessels	10	
Cooling Towers	35	
Steam Generator	-	
Electrical	50	
Concrete	6	
Piping	101	
Wellfield Equipment and Materials		975
Production Wells and Brine Header	314	
Production Well Pumps	80	
Production Brine Piping (1 Mile)	148	
Reinjection Wells and Brine Header	207	
Reinjection Pumps	54	
Reinjection Brine Piping (1 Mile)	60	
Electrical	100	
Concrete	12	
Total Field Cost		1320
Engineering and Home Office		200
Contingency		300
Construction Cost		1820
Owner's Cost		250
TOTAL RETROFIT CAPITAL COST Second Quarter, 1977		2070

Table 10-6

SODIUM CHLORIDE PLANT
CONCEPTUAL ESTIMATE DETAIL
NEW PLANT

	Installed Cost \$1000
Plant Equipment and Materials (from Table 1-2)	345
Wellfield Equipment and Materials (from Table 1-2)	975
Credit for Fossil Fuel Plant Equipment Not Required for New Construction Steam Generator Steam Turbine Pump Drives	(380)
Credit for Fossil Fuel Plant Bulk Materials Not Required for New Construction 0.8 x Installed Cost of Fossil Fuel Plant Equipment	(300)
Total Field Cost	640
Engineering and Home Office	95
Contingency	145
Construction Cost	880
Owner's Cost	140
NEW CONSTRUCTION CAPITAL COST* Second Quarter, 1977	1020

* As compared to an oil or gas fired plant.

Table 10-7

SODIUM CHLORIDE PLANT
COST OF GEOTHERMAL ENERGY

	Retrofit	New Plant
Total Construction Capital Cost (x\$1000)	2070	1020 [*]
Annual Capital Cost at 18% Fixed Charge Rate(x\$1000)	370	180
Annual Operating and Maintenance Cost (Includes Electric Energy)(x\$1000)	<u>200</u>	<u>200</u>
Annual Geothermal Energy Cost(x\$1000)	570	380
Days of Continuous Plant Operation	270	270
Fossil Fuel Energy Requirement (1000 MMBtu/Season)	350	350
Cost of New Construction Geothermal Energy (Equiv-\$/MMBtu) (Directly Comparable to Current Fossil Fuel Energy Costs)	1.64	1.10

* As compared to an oil or gas fired plant

Table 10-8

SODIUM CHLORIDE ENERGY COST SUMMARY

Cost Item	\$/MMBtu	
	Plant Retrofit	New Plant
Geothermal Wells	0.82	0.82
Pipeline	0.20	0.20
Plant Equipment	0.27	0.27
Electrical Power	0.35	0.35
Equipment Credit	<u>—</u>	<u>(.54)</u>
Cost of Geothermal Energy (Equivalent \$/MMBtu)	1.64	1.10

Figure 10-1a. Location of Western Inorganic Salts Facilities

Figure 10-1b. Location of Western Inorganic Salts Facilities

Figure 10-2. Process Flow Diagram N-1, Sodium Chloride Plant

**Figure 10-3. Process Flow Diagram N-2,
Sodium Chloride Plant
Utilizing Geothermal Brine**

Section 11

OTHER AREAS OF APPLICATION

This section discusses other industries — pulp and paper, dairy, and waste concentration — that are potential users of geothermal energy.

11.1 PULP AND PAPER INDUSTRY

The segment of the pulp and paper industry (SIC Industry Groups 261, 262) which includes pulp-mill, as well as combined pulp-paper mill operations, is a potential candidate for geothermal brine use. This industry uses multieffect evaporation with up to seven effects to concentrate black liquor from kraft pulping operations.

The pulp and paper industry is a major energy consumer. In 1971, about 1700×10^{12} Btu's were consumed in pulp and integrated pulp/paper mills (over 35 percent of this energy is produced internally from waste products). Roughly 15 percent of the total energy is consumed by mills in the western United States. Since black liquor multieffect evaporator operations use about 15 percent of the energy required in an integrated pulp/paper mill, nearly 36×10^{12} Btu's (7,500,000 bbl oil/yr) are consumed by multieffect evaporation of black liquor in western mills.^{23,24} A number of these mills are located near "probable geothermal areas" (see Figure 11-1).

Both pulp and pulp/paper mills are highly integrated facilities. Heat from the combustion of black liquor and bark is used to generate steam at 450 to 600 psi. This steam, after passing through a turbine to produce electrical power, is exhausted at two pressures and used in a number of process heating operations. The low pressure portion (40 to 50 psia) of the exhaust steam is used in the black liquor

evaporators. Unlike beet sugar production, where the required process heating steam is drawn off between evaporator units, or tomato pulp concentration, where all process steam is used at low pressure, pulp/paper mills would require, in a geothermal plan, a combination of high-pressure turbine-exhaust steam and low-pressure geothermal steam.

The feasibility of using geothermal heat in the pulp and paper industry has been discussed by others. A March 1975 study, "Geothermal Resource Utilization, Paper and Cane Sugar Industries," looks at the use of geopressure resources by the paper industry.³⁵ An integrated pulp/paper mill in New Zealand has been using geothermal steam for some of its operations, including a black liquor pre-evaporator, since 1960.¹⁴

11.2 DAIRY INDUSTRY

The dairy industry (SIC Industry Group 202) uses multieffect evaporation to produce skim milk, condensed milk, evaporated milk, whey, and dry milk. In 1971, 22.5×10^{12} Btu's (4,600,000 bbl oil/yr equiv.) were consumed by this segment of the dairy industry.²⁴ Of this, 10×10^{12} Btu's were used in multieffect evaporator operations.³⁰ Approximately 13 percent of these milk products are produced in the West where roughly 1.3×10^{12} Btu's (266,000 bbl oil/yr equiv.) are used for evaporation. A number of these plants are located near "probable geothermal areas." (See Figure 11-2).

From two to four effect evaporator systems are typically used by the dairy industry. These systems are similar in operating conditions to those used in the preserved fruit and vegetable industry (Section 8).

11.3 WASTE CONCENTRATION

Although it cannot be classified as an SIC industry, waste concentration using multieffect evaporators for recovery, reuse, or disposal of waste materials is a potential candidate for energy from geothermal brine.

Some examples are:

- Recovery of ferrous sulfate from pickling liquors
- Recovery of alumina from spent liquor for reuse
- Concentration of salts in cooling-tower blowdown for disposal

The operating conditions of these evaporation processes are similar to those used in the chemical industry (Section 10).

Because of increasing economic incentives, and more stringent pollution standards, a greater number of facilities will be concentrating their waste products. In many cases, multieffect evaporation will be used.

Figure 11-1a. Location of Western Pulp and Paper Mills

Figure 11-1b. Location of Western Pulp and Paper Mills

Figure 11-2a. Location of Western Dry Milk Plants

Figure 11-2b. Location of Western Dry Milk Plants

Section 12

ECONOMIC FACTORS

This section sets forth the significant economic factors that influence the cost of utilizing geothermal brine and the cost saving that can result over fossil-fueled operation. Since this study is not site specific, values for the most significant factors which affect economics have been selected in order to complete the economic analysis. For a site specific study, these factors can significantly affect the final result. In this section, some of these factors are analyzed.

12.1 FACTORS AFFECTING ECONOMICS

12.1.1 Period of Operation

The process becomes more capital-intensive after conversion to geothermal energy. The capital portion of the cost of geothermal energy is therefore inversely proportional to the number of days the geothermal energy source is being utilized in the process plant. This is shown in the following figures for each of the selected processes:

- Figure 12-1a Tomato Paste
- Figure 12-1b Sugar Beet
- Figure 12-1c Sodium Chloride

From these figures, it can be seen that, if the process plant uses the geothermal source continuously over the calendar year, the cost of geothermal energy for new construction can be less than \$1.00 per MMBtu. This is a significant saving in energy costs over fossil fuel, which ranges from \$1.18 to \$2.39 per MMBtu. Therefore, the industrial plant

owner contemplating a retrofit or new geothermal process plant should make maximum use of the geothermal source throughout the year, possibly by using the plant for multiple products or in conjunction with some other process such as power generation.

12.1.2 Brine Transportation Distance

The cost of geothermal energy has been based upon an assumption of a one-mile distance from wellfield to plant. However, while the costs of plant and wells are unaffected by distance, the costs of brine transportation significantly affect the cost at much beyond this distance as demonstrated by the following figures:

- Figure 12-2a Tomato Paste
- Figure 12-2b Sugar Beet
- Figure 12-2c Sodium Chloride

Even with a long period of operation, as geothermal brine lines approach 25 miles in length, geothermal energy costs exceed fossil-fuel energy costs.

An additional factor in long transportation distances is the brine temperature loss due to heat transfer to the surroundings. With distances of 25 miles and no pipe insulation, these losses are substantial. However, with insulation, these losses can be held to less than 10°F .⁴⁰

12.1.3 Brine Temperature

The effects of various brine temperatures on brine flow for the tomato paste plant discussed in Section 8 are shown in Figure 12-3. The tomato paste plant was selected as a typical example. For the brine requirements with a 300°F supply temperature, seventeen supply wells and nine reinjection wells are required when using the feed-and-bleed process. However, at lower brine temperatures there is a substantial

increase in brine flow requirements. For a 250°F brine, the brine supply system nearly doubles in size, making geothermal brine an expensive source of energy based upon fuel prices and the present shorter period of operation. Also, additional equipment changes may be required due to the decreased density of the steam.

12.1.4 Energy Extraction Method

Compared to the feed-and-bleed process, a simple flash may require twice the brine flow rate, hence a larger brine supply system. The actual difference is determined by the brine and process temperature. With a temperature greater than 300°F, this difference diminishes. The sodium chloride plant was selected as a typical evaporation/crystallization example to compare the cost of the energy extraction method (see Table 12-1).

Table 12-1 is a capital cost comparison for these two processes. It is seen that, even though there is minimal equipment cost to retrofit the plant using a simple flash, it is the increased size of the brine supply system that substantially increases the cost. This results in an equivalent energy cost of \$2.48/MMBtu for the single-flash process vs \$1.64/MMBtu for the feed-and-bleed process (see Table 12-2).

12.1.5 Plant Capital Cost

Table 12-3 is a comparison of the capital cost requirements to both retrofit and construct a new plant using geothermal energy. For new plant construction, the steam generator, steam turbine pump drives, or steam turbine/generator normally associated with a plant using natural gas or fuel oil for the process heat source will not be required. A capital cost credit, equal to the capital cost of the plant equipment and bulk materials which are not required, is available to offset the cost of the plant and wellfield and brine piping. This is discussed further under Cost of Geothermal Energy, Section 7.2.

However, even with this credit, the capital cost of a new plant is more than the equivalent oil- or gas-fired plant primarily because of the cost for the brine supply system. A plant retrofit is even more expensive than a new plant because of the cost of the additional equipment and because no credit is allowed for the unused steam generator, turbines, etc.

12.1.6 Conclusions

This study has shown that geothermal energy is an economically viable alternative to fossil fuel energy for the evaporation and crystallization industry under the following conditions:

- When the characteristics of the geothermal resource (the depth, flow rate, and temperature) are similar to the study parameters
- When the process plant is reasonably close to the geothermal wells
- If the process plant can make use of the geothermal source throughout a substantial portion of the year

It should be emphasized that this study is generic (non-site specific) and thus the economics are only estimates for the costs of utilizing geothermal energy in these selected industries. A site specific study of a particular process plant is required in order to specify the various economic factors so that the "true cost" of utilizing this energy can be obtained.

12.2 FUEL SAVINGS

By using the energy of low-temperature geothermal brines to generate steam for use in the evaporation and crystallization industry, fossil fuels now used for this purpose can be saved.

The use of low-temperature geothermal resources by those industries that employ multieffect evaporation/crystallization in their operations could result in a savings of 9.6 million bbl/yr of fuel oil (or the equivalent in other fossil fuels). Table 12-4 gives a detailed breakdown, by industry, of potential geothermal energy use.

The quantity of "fuel saved" (in effect, "replaced" by geothermal energy), was arrived at by analyzing multieffect evaporation/crystallization users within, or no more than 25 miles from, a "probable geothermal resource area" (see Figure 3-2). The 25-mile limit was chosen because it becomes increasingly difficult to justify the economics of geothermal use at distances much greater than this. From the analysis of users near geothermal areas, an estimate was made of the amount of energy that potentially could be replaced by using low-temperature geothermal brines (this ranged from 1000 to 6000 Btu/lb of product, depending on the industry).

A more conservative fuel saving of 1.6 million bbl/yr of fuel oil was estimated, taking into account only those multieffect evaporation/crystallization users within the "probable geothermal resource areas." Although these potential fuel savings are not great compared to the total amount of crude oil that is consumed daily in the United States, it must be recognized that only those major users of multieffect evaporation/crystallization located in or near "probable geothermal resource areas" were considered, for this study, in the estimate of fossil fuel savings. No attempt was made to project what could be substantial future energy savings if industrial geothermal energy use is shown to be economically and technically feasible, thereby providing an incentive to locate new plants or relocate existing plants near geothermal resources. In addition, because it is beyond the scope of this study, no estimate was made of potential low-temperature geothermal resource use by all those industries that do not use multieffect evaporators or crystallizers. As shown by others, this use of geothermal energy could also result in considerable fuel savings.^{14,15}

Table 12-1

SODIUM CHLORIDE
CONCEPTUAL ESTIMATE
SIMPLE FLASH AND FEED-AND-BLEED PROCESS

	Sodium Chloride Feed-and-Bleed Installed Cost, \$1000	Sodium Chloride Simple Flash
Plant Equipment and Materials	345	24
Pumps and Drives	51	-
Condensers	9	-
Heat Exchangers	83	-
Tanks and Vessels	10	4
Cooling Towers	35	-
Steam Generator	-	-
Electrical	50	6
Concrete	6	-
Piping	101	14
Wellfield Equipment and Materials	975	1916
Production Wells and Brine Header	314	688
Production Well Pumps	80	180
Production Brine Piping (1 Mile)	148	227
Reinjection Wells and Brine Header	207	405
Reinjection Pumps	54	101
Reinjection Brine Piping (1 Mile)	60	153
Electrical	100	150
Concrete	12	12
Total Field Cost	1320	1940
Engineering and Home Office	200	290
Contingency	300	450
Construction Cost	1820	2680
Owner's Cost	250	380
TOTAL RETROFIT CAPITAL COST Second Quarter, 1977	2070	3060

Table 12-2

**SODIUM CHLORIDE PLANT PROCESS COMPARISON
COST OF GEOTHERMAL ENERGY**

	Plant Retrofit	
	Feed-and-Bleed	Simple Flash
Total Construction Capital Cost (x \$1,000)	2,070	3,060
Annual Capital Cost at 18% Fixed Charge Rate (x \$1,000)	370	550
Annual Operating and Maintenance Cost (Includes Electric Energy) (x \$1,000)	<u>200</u>	<u>320</u>
Annual Geothermal Energy Cost (x \$1,000)	570	870
Days of Continuous Plant Operation	270	270
Fossil Fuel Energy Requirement (1,000 MMBtu/Season)	350	350
Cost of New Construction Geothermal Energy (Equiv-\$/MMBtu) (Directly Comparable to Current Fossil Fuel Energy Costs)	1.64	2.48

Table 12-3

CONCEPTUAL ESTIMATE CAPITAL COST COMPARISON

	Total Capital Cost, \$1,000	
Plant ⁽¹⁾	Retrofit	New ⁽²⁾ Construction
Tomato Paste Evaporation, Multistage Flash	7,040	2,150
Sugar Beet Crystallization, Multistage Flash	8,740	3,240
Sodium Chloride Crystallization, Multistage Flash	2,070	1,020

Notes: (1) Assumes process plant is one mile from geothermal energy source.

(2) As compared to an oil or gas fired plant.

Table 12-4

ESTIMATED FOSSIL FUEL SAVINGS

	Industry			Totals
	Food ⁽¹⁾	Paper ⁽²⁾	Chemical ⁽³⁾	
U.S. Totals				
Plants	480	220	100	
Energy Use, 10^{12} Btu/yr	142	1595	270	
Zone I ⁽⁴⁾				
Plants	8	1	0	
Potential Fuel Savings, 10^{12} Btu/yr	8.7	0.6	—	9.3
Zone II ⁽⁵⁾				
Plants	44	9	12	
Potential Fuel Savings, 10^{12} Btu/yr	17.8	13.5	15.0	46.3
Zone I + II Fuel Savings, 10^6 bbl oil/yr ⁽⁶⁾	4.6	2.4	2.6	9.6

Notes:

- (1) Includes beet sugar, tomato paste, frozen juice, and dry milk segments
- (2) Includes pulp mill and integrated pulp paper mill segments
- (3) Includes caustic (from diaphragm cells), salt (vacuum pan NaCl), other inorganic salts (by evaporation): soda ash, salt cake, sodium phosphates, calcium chloride, potassium chloride, borax; sodium chloride
- (4) Within "probable geothermal resource areas"
- (5) Within 25 miles of "probable geothermal resource areas," but outside Zone I
- (6) 5.8×10^6 Btu/bbl fuel oil
- (7) Energy figures are, for the most part, based on 1972 data
- (8) References: 23, 24, 30, 32, 33, 34, 36, 37

(A) TOMATO PASTE PLANT-MULTIFLASH
(ONE MILE FROM GEOTHERMAL WELLS)

(B) SUGAR BEET PLANT-MULTIFLASH
(ONE MILE FROM GEOTHERMAL WELLS)

(C) SODIUM CHLORIDE PLANT - MULTIFLASH
(ONE MILE FROM GEOTHERMAL WELLS)

Figure 12-1. Cost as a Function of Use

(A) TOMATO PASTE PLANT—MULTIFLASH
(70 OPERATING DAYS PER YEAR)

(B) SUGAR BEET PLANT—MULTIFLASH
(100 OPERATING DAYS PER YEAR)

(C) SODIUM CHLORIDE PLANT—MULTIFLASH
(270 OPERATING DAYS PER YEAR)

Figure 12-2. Cost as a Function
of Distance

Figure 12-3. Tomato Paste Plant, Brine Flow vs Brine Temperature

Section 13

ENVIRONMENTAL IMPACT

Most industrial operations will, of course, have some impact on the environment. This would be true even if these industries were to use geothermally derived steam. However, it appears that the environmental impact of a geothermal plant may not be as objectionable as that of a similar fossil-fueled facility. The probable effect on the environment by these geothermal facilities is discussed in this section.

13.1 CONSTRUCTION

Except for well drilling and pipeline installation, the effect on the environment during construction of a plant designed for geothermal brine use will be similar to that produced by the construction of a conventional plant.

The major long-term impact due to the construction of a new, or the retrofit of an existing, plant for geothermal use will be the loss of the few acres of land taken up by the wells and pipeline.

13.2 OPERATION

During the operation of a geothermal facility, there will be, potentially, some disruption to the environment. These effects are discussed below and compared with those environmental effects produced by similar fossil-fueled plants.

13.2.1 Induced Seismicity

In areas where earthquakes are prevalent, there is a potential for inducing seismic activity within the geothermal reservoir by reinjection

of fluid. This is based on the concept that increases in fluid pore pressure within a rock formation may trigger the release of built-up seismic energy. This behavior has been observed in connection with oil field and deep disposal activities in Colorado.

It will be necessary, in earthquake regions, to establish the level of seismic activity before construction, and to continuously monitor seismic conditions once operations begin.

13.2.2 Gaseous Emissions

For this study, the "worst case brine" is assumed to contain 300 ppm carbon dioxide and 30 ppm hydrogen sulfide. These noncondensable vapors, evolved as the hot geothermal brine is flashed, must eventually be vented from, for example, evaporator bodies. Release of carbon dioxide to the atmosphere is relatively harmless; however, hydrogen sulfide is "dangerous" to man in concentrations above 400 ppm, and is perceptible at levels above 0.1 ppm. ³⁸

For the "worst case" brine, somewhat less than 30 lb of H_2S will be discharged for every million pounds of brine required (about 0.1 lb sulfur/MMBtu). It is probable that, at this rate, local H_2S emission regulations will be satisfied (in California, the H_2S limit is 0.6 ppm max, at ground level, over 3 minutes). However, if H_2S control is required, a number of H_2S removal processes exist:

- Absorption Systems. There are several variations of this process, but, basically, H_2S is scrubbed out of the vent gases with an absorbent, and then, after oxidation, is recovered as elemental sulfur
- Iron Catalyst Systems. These processes use a scrubbing solution of a metal catalyst, such as ferric sulfate, and water to oxidize H_2S in the vent gases to elemental sulfur. The resulting sulfur-metal sludge is a waste stream, and must be disposed of

- Incineration. A third process oxidizes H_2S to sulfur dioxide by incineration, and then removes the SO_2 , if necessary, by alkali scrubbing. The resulting alkali- SO_2 sludge is dewatered and disposed of

Compared to the approximate 0.1 lb sulfur discharged per MMBtu's used (brine heat in - brine heat out) for a geothermal facility using the "worst case" brine, a conventional plant, depending on the fuel used, will discharge the following quantities of sulfur dioxide (as sulfur):

Natural Gas	Zero lb S/MMBtu
Fuel Oil (1% S)	0.6 lb S/MMBtu
Coal (1% S, 9,500 Btu/lb H.V.)	1.2 lb S/MMBtu
Coal (2% S, 11,500 Btu/lb H.V.)	2.1 lb S/MMBtu

Thus, a geothermal plant using a "worst case" brine would, like those conventional facilities using more valuable fuel oil, require only minimal, or no gas cleaning equipment. However, coal-fired facilities would most likely require sulfur removal equipment to maintain environmental standards.

13.2.3 Liquid and Solid Emissions

For this study, it has been assumed that the geothermal brine, after usable heat is extracted from it, will be reinjected into the ground, along with its dissolved solids. If discharged to the surface, these dissolved chlorides of sodium, calcium, and potassium could prove toxic to plant and animal life. Also, with surface discharge of fluids, the possibility of contamination of groundwater supplies is great. Reinjected geothermal fluid is expected to enter deep, saline aquifers that are not connected to potable groundwater supplies. However, during operation, underground potable water sources should be monitored in the

unlikely event that they should become contaminated by the brine. In addition to conserving the resource, reinjection of the brine ensures that the disruption to the environment will be minimal.

A conventional fossil-fueled facility will discharge small quantities of liquid wastes (mainly boiler blowdown) resulting from steam generation. These are normally discharged to surface waters after being treated, if necessary, to remove toxic chemicals.

Solids emissions will vary, depending on the fuel used. Coal, of course, will produce the greatest quantity of particulate matter. Presently, very few Western industries use coal in their boilers, but, with decreasing supplies of natural gas and oil, and new federal restrictions on the burning of these fuels to generate steam, there will certainly be many conversions to coal use. Dust removal equipment, often complex and costly, will be needed to limit these particulate emissions and minimize the environmental impact.

13.2.4 Land Surface Subsidence

Production of oil, gas, water, or geothermal fluid without subsequent reinjection may cause differential subsidence of the ground surface as mass and pressure are reduced in the reservoir. This is especially severe in areas of unconsolidated sediments. Subsidence to a maximum of 20 feet has been associated with production of oil, gas, and water from wells in various countries. Subsidence has also been reported at the geothermal field of Wairakei, New Zealand; it reached a maximum of 1.3 feet per year within an area of about one-quarter of a square mile in 1967. The total area affected by 20 years of production is about 25 square miles with an average subsidence of about one foot across that area. Maximum documented subsidence is 3.8 feet, but a maximum of up to 10 feet of subsidence is suspected. In each of these cases, there has been a continual, massive withdrawal of fluid

from the underground reservoir without replacement. It has been estimated that 0.1 foot of subsidence occurs for each uncompensated withdrawal of 10^{10} to 10^{11} pounds of water in the poorly consolidated reservoir of Wairakei.

With reinjection of fluids, the possibility of significant land surface subsidence may be small. However, well locations should be surveyed and their level lines established so that, once operations begin, periodic resurveys will determine if any subsidence has occurred.

Section 14

IMPLEMENTATION PROGRAM

This report has shown that, in many cases, geothermal energy can be used by the evaporation and crystallization industry. Given the proper conditions, it can be an economical substitute for fossil-fuel energy.

Identified in Section 12 are as many as 65 existing plants which could potentially use geothermal brine in their processes. Impediments to development by these facilities include the economic and technical uncertainty of utilizing geothermal brine in these processes, and the lack of resource definition. To facilitate the use of geothermal energy in the evaporation and crystallization industry, the following implementation program is recommended:

- Define geothermal resources more accurately
- Provide relevant information to the evaporation and crystallization industry
- Provide relevant information to producers of geothermal energy
- Conduct research and development program for the feed-and-bleed process
- Conduct demonstration program in the evaporation and crystallization industry

14.1 DEFINE GEOTHERMAL RESOURCES

The economics of the process will be strongly influenced by the geothermal resource. The economics, as related to the resource, will be primarily determined by:

- Cost of the well
- Potential well flow
- Temperature of the fluid
- Distance to point of use

Mainly because of pipeline cost, low-temperature geothermal brine can be transported over only a relatively short distance. Therefore, all of these factors must be defined prior to a complete economic analysis for a specific user. This is being accomplished through both government and private funding, and should be continued.

14.2 INFORMATION TRANSFER TO THE EVAPORATION AND CRYSTALLIZATION INDUSTRY

Although some users of the evaporation and crystallization process were contacted during this study and acquainted with the potential of using geothermal brine in their process, many more can be contacted. These contacts would have two goals:

- Acquaintance with the possibility of retrofitting existing plants
- Consideration of using geothermal energy for new plants

This could be accomplished by an extension of the survey in this report to the other industries using evaporation and crystallization (Table 4-2), followed by discussions with suitable groups within those industries on the economic potential of geothermal brine. This would be an extension

of the work of Lawrence Berkeley Labs but would have the advantage of presenting the economic potentials of geothermal energy to specific processes.³⁹

14.3 INFORMATION TRANSFER TO PRODUCERS OF GEOTHERMAL ENERGY

Many of the producers of geothermal energy think only in terms of electrical power production. Presentation of the findings of this report would acquaint these producers of energy with the advantage of the nonelectric uses of energy. This would allow these producers to consider alternate uses of geothermal energy such as the construction of combined facilities in order to utilize the resource more fully. An example of a combined facility would be a power plant from which the low-temperature brine could be put to further use in an evaporation process.

14.4 RESEARCH AND DEVELOPMENT PROGRAM

The goal of a research and development program would be to define more accurately the design factors required for a demonstration plant. Many of these factors are site specific in that they are determined by the actual geothermal brine. Some of the research and development goals are:

- Definition of brine characteristics
 - Salinity
 - Scale characteristics
 - Noncondensable gases
 - Reinjection ability
- Material selection
- Multistage flash characteristics
- Environmental problems

A portable test unit would provide the best means to meet these goals. Shown in Figure 14-1 is a flow diagram for a portable test loop. It is composed of two test loops. Loop No. 1 is based upon the multistage flash feed-and-bleed principle and allows for determining the effects of the geothermal brine on both the flash tanks (PC-1 to -3) and the steam side of the process heat exchangers (PE-1 to -3). Test Loop No. 2 is a simplified version of a feed-and-bleed process utilizing a liquid-liquid heat exchanger, and would be used in those cases where, for example, because of process constraints, steam directly flashed from the brine could not be used.

A test program would potentially start at the ERDA test facility at East Mesa followed by transportation of the unit to a site selected from contacts with industry and energy producers (Sections 14.2 and 14.3).

14.5 DEMONSTRATION PROGRAM

To acquaint industry with use of geothermal energy, a demonstration program appears essential. The demonstration program is important as there are many uncertainties in the use of geothermal energy at this time. The most promising process resulting from the contacts with industry and energy producers would be selected for additional study. This study would be site-specific and would include:

- A site-specific study to demonstrate the potential economic advantages of using geothermal brine
- Testing of the portable test unit on the actual brine at the site
- Plant design using the portable test unit experience
- Construction of a demonstration plant or retrofit of an existing plant

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Figure 14-1. Flow Diagram, Portable Test Loop

Appendix A

COMPUTER PROGRAM

A computer program was developed to calculate heat and material balances for multiple effect evaporator systems. The program will ultimately handle both forward and reverse feed arrangements with conventional steam supply or geothermal feed-and-bleed heat supply. The program is operational for conventional and geothermal steam supplies using a forward-feed arrangement.

A.1. CALCULATIONS

The capabilities of the program are summarized below for the forward feed arrangement:

- Input Data
 - Feed flow rate and temperature
 - Product flow rate and temperature
 - Number of effects
 - Value of UA for each evaporator, where U is the heat transfer coefficient and A is the heat transfer area
 - Steam supply temperature for a conventional plant design or the brine supply temperature for a geothermal plant design (this serves as a starting point for the calculation and is subsequently adjusted by the computer)
 - Options allow the program to calculate the amount of vapor to withdraw from the various effects for preheating the feed prior to the first effect

• Output Data

- For conventional plant designs, the required steam temperature and flow rate; for feed-and-bleed plant designs, the brine flow rate and interstage temperatures
- The temperatures of the steam and vapor for each effect
- The flows of steam and vapor and the amount of flash for each effect
- Optional output. This gives the amount of vapor from each effect for preheating the feed

The basic forward feed arrangement for the computer model is shown as a three-effect system in Figure A-1. The model for any intermediate effect in an N-effect system is shown in Figure A-2. The program operates in a conversational mode in which adjustments are made by the operator until convergence is obtained for a given problem. A general logic diagram of the calculation procedure is shown in Figure A-3.

A.2. SYSTEM OPTIMIZATION

Several designs, using various evaporator surface areas and arrangements, may be compared on the basis of equipment and operating costs by using the program to calculate energy requirements for each design. These costs may be plotted versus evaporator area, and the most economical selection of a plant design can be determined by examination of these costs.

Retrofitting an existing plant with geothermal steam is a matter of evaluating the system performance with existing equipment. This will enable the designer to determine the economic advantages of using geothermal steam versus a conventional energy source.

A.3. DISCUSSION OF OPERATION OF THE PROGRAM

The version presented here is operated in a conversational mode because of the sensitivity of convergence criteria to adjusted values within the iterative process. The automatic convergence is effective only in certain ranges of plant types and configurations inasmuch as excessive flexibility would require a very complex computer program.

LEGEND:

AS - AUXILIARY PLANT STEAM FROM VAPOR DRAWOFF, NOT USED WITH GEOTHERMAL DESIGN	FC - FLASHED CONDENSATE
B - BRINE	FT - FLASH TANK
BF - BRINE FLASH	P - PRODUCT
C - CONDENSATE	PH - PREHEATER
E - EVAPORATOR	PS - STEAM TO PREHEATER
F - FEED	S - STEAM
	V - VAPOR

Figure A-1. Forward Feed Model

LEGEND:

- TG(I) — BRINE TEMPERATURE INTO FLASH CHAMBER
- TG(I+1) — BRINE TEMPERATURE OUT OF FLASH CHAMBER
- TS(I) — SATURATION TEMPERATURE OF STEAM
- TFV(I) — VAPOR TEMPERATURE FROM EVAPORATOR
- BPEV(I) — BOILING POINT ELEVATION OF VAPOR
- BPEG(I) — BOILING POINT ELEVATION OF FLASHED BRINE
- MS(I) — STEAM FLOW TO EVAPORATOR
- MFV(I) — VAPOR FLOW FROM EVAPORATOR
- MFL(I) — LIQUID FEED FLOW TO EVAPORATOR
- MFL — TOTAL FEED FLOW TO SYSTEM
- MFVD(I) — VAPOR DRAWOFF FOR AUXILIARY USE
- MFVL(I) — VAPOR DRAWOFF FOR FEED HEATING
- UA(I) — HEAT TRANSFER COEFFICIENT TIMES SURFACE AREA FOR EVAPORATOR
- TFL(I) — TEMPERATURE OF FEED FROM THE PREHEATER CAUSED BY STEAM DRAWOFF FROM EVAPORATOR

NOTE: SUBSCRIPTS I, I+1, AND I-1 REFER TO THE EFFECT NUMBER

Figure A-2. Model for the Ith Effect

Figure A-3. Flow Diagram for Forward Feed System

Appendix B

ECONOMIC ANALYSIS

In this appendix, details are given on the bases for the conceptual estimate and the annual geothermal costs as summarized in Section 7.

B.1 BASIS FOR THE CONCEPTUAL COST ESTIMATE

B.1.1 General

The estimates are based on the conceptual design and engineering information prepared for the study in the form of engineering sketches, outline specifications, and equipment lists. Estimating methods consistent with the conceptual nature of the design information were employed and rely on informal vendor contact as well as extrapolation from Bechtel historical information. Because it is beyond the scope of this study, costs for any special construction, such as widening and strengthening of existing roads or additional structures for equipment and materials required for a plant retrofit have not been estimated.

The estimate is at second quarter, 1977, price and wage levels. No allowance has been made for future escalation.

B.1.2 Capital Costs

The capital cost estimate is composed of field costs, engineering services, allowance for uncertainty, and owner's costs. Field costs include the direct cost of permanent plant equipment and the indirect cost of temporary construction materials, supervision, etc. that are to be distributed across the entire facility. The estimate anticipates an engineer-constructor direct-hire operation employing field construction labor forces.

B.1.2.1 Field Construction Costs. The direct field construction costs of permanent plant equipment, materials, subcontracts, and construction labor have been included in the estimate on the basis of the following discussion.

Equipment. Budgetary suppliers' estimates based on conceptual designs and specifications were obtained verbally for the major equipment items. These include:

- Tomato paste plant
 - Hot break heat exchanger
 - Third-effect heat exchanger
- Sugar beet plant
 - Steam turbine/generator
- All plants
 - Steam generators
 - Switchgear and transformers

Other equipment was estimated using Bechtel data derived from recent purchase orders and vendor contacts.

For the retrofit cases, the cost of removing the existing equipment from a plant during retrofit is assumed to be equal to its salvage value. For new plants, a capital cost credit, equal to the capital cost of the conventional plant equipment (including bulk materials) which is not required for the geothermal case, is available to offset the cost of the plant and wellfield and brine piping.

Material. Quantity evaluations were made from the drawings for the identifiable materials of concrete, piping, wire and cable, etc., and these quantities were priced using current unit prices from Bechtel sources. Other materials that would be delineated on the final engineering

drawings have been evaluated by experience as a percentage of the installed cost of the identified materials. Following are examples of material costs used:

- Cable, 600 V, power \$0.75 per linear foot
- 10-inch spools, Sch 40 \$45 per linear foot
(including fittings)
- Brine production line, \$16 per linear foot
16-inch Sch 30
- Brine reinjection line, \$12 per linear foot
16-inch carbon steel
concrete-lined and
coated (C205 Spec)

Well System Costs. These costs include:

- Production wells and brine header
- Production well pumps
- Reinjection wells and brine header
- Reinjection pumps
- Associated electrical systems

Using the well design basis (Section 6.2) and the ERDA Guideline entitled "Rules of Thumb for Direct Geothermal Applications" (Figure B-1), a cost of \$56,000 for each production or reinjection well was reached. This cost includes a \$6,000 allowance for wellhead valves and instrumentation. As a comparison, Table B-1 shows well design data and costs developed in recent studies by Bechtel²⁶ and TRW.²⁷ In addition, the following assumptions were used to estimate well system costs:

- Production and reinjection wells have a service life of 20 years
- All production or all reinjection wells are slant-drilled from one two-acre production or reinjection well island

- Electric power for the production and reinjection pumps is available one mile from the field pumps
- Production brine temperature and pressure do not decline over the operating life of the plant

Subcontracts. Subcontracts for equipment and materials commonly installed by subcontractors, including cooling towers and pipe insulation, were estimated in accordance with Bechtel experience from current sources.

Construction Labor. The direct construction labor costs for the installation of the plant equipment and material were estimated using recent productivity experience and a wage rate based on labor contracts and fringe benefits for the western United States. This wage rate, \$17.00 per hour, is based on a craft mix appropriate to the type of construction together with a 5-percent allowance for casual overtime and 1 percent for craft-furnished supervision.

For field piping, installation labor is based on pipe length. Installation labor for pipe runs up to one mile is based on Bechtel standards for off-plot piping. The unit labor rate, in manhours/linear ft, decreases linearly with distance up to a pipe length of 25 miles. For pipe runs greater than 25 miles, the unit labor rate remains constant and is based on Bechtel standards for long pipe-runs. An example of the pipe-run cost for a 16-inch pipe for the brine production and reinjection lines is:

1 mile pipe	100 \$/linear foot
25 mile pipe	68 \$/linear foot

This price is for installation and covers material, labor, and insulation.

Indirect Field Costs. The indirect field costs are for those items of construction cost that cannot be ascribed to direct portions of the facility and thus are accounted separately. They are estimated by modifying the experience on fossil-fired electric power, refinery, and chemical plants, resulting in an assessment of 65 percent of direct labor costs, which has been distributed over the installation of direct equipment and materials as a function of the installation costs.

The items covered by indirect field costs are as follows:

- **Temporary Construction Facilities.** Temporary buildings, working areas, roads, parking areas, utility system, and general purpose scaffolding
- **Miscellaneous Construction Services.** General job cleanup, maintenance of construction equipment and tools, material handling, and surveying
- **Construction Equipment and Supplies.** Construction equipment, small tools, consumable supplies, and purchased utilities
- **Field Office.** Field labor of craft supervision, engineering, procurement, scheduling, personnel administration, warehousing, first aid, and the costs of operating the field office
- **Preliminary Checkout and Acceptance Testing.** Testing of materials and equipment to ensure that components and systems are operable
- **Project Insurance.** Public liability, property damage, and builder's risk insurances
- **Taxes and Permits.** State and local taxes and permits

B.1.2.2 Engineering Services. The engineering services include engineering costs, other home office costs, and fee. Engineering includes preliminary engineering, optimization studies, specifications, detail engineering, vendor drawing review, site investigation, and support to vendors. Other home office costs include procurement,

estimating and scheduling services, quality assurance, acceptance testing, and constructing and project management. Fee is included as a function of the total project cost.

The sum of these three categories falls into historically consistent percentages in the range of 10 to 20 percent depending on the complexity of the project. For this study, a figure of 15 percent of field construction costs is used for both the retrofit and new construction cases. In practice, retrofitting is likely to require more extensive engineering than new design, but the small differences have not been taken into account.

B.1.2.3 Allowance for Uncertainty. Included in the estimate is an allowance for uncertainty in quantity, pricing, or productivity within the conceptual design and that which is under the control of the constructor and within the scope of the project. Implicitly, the allowance will be expended during the design and construction of the project. It cannot be considered as a source of funds for overruns or additions to the project scope. Based on Bechtel guidelines for studies of this complexity and scope, an allowance for uncertainty of 20 percent of the field and engineering and home office costs has been used.

B.1.2.4 Owner's Costs. The owner's costs are considered percentages of the capital costs for plant equipment, geothermal wells, and brine pipeline. The following items are included in the owner's cost:

- Client engineering, financing, and other client costs
- Process royalties and licenses
- Site investigation and land acquisition
- Allowance for funds during construction (AFDC)
- Initial training of plant operators
- Plant startup

Process Plant Equipment and Materials. Owner's costs are estimated at 12 percent of retrofit construction costs or new geothermal energy system construction costs for each process plant. The allowance for funds during construction, AFDC (interest during construction and lender's fees), is included in the 12 percent owner's cost. AFDC is estimated at 5 percent of the construction costs.

Production and Reinjection Wells. Owner's costs are estimated at 15 percent of well construction costs for each process plant. The higher percentage for owner's cost (15 percent vs 12 percent) is due to geothermal exploration costs, obtaining drilling rights, and preparing the necessary environmental documents for government agencies. AFDC, which is included in the 15 percent, is estimated to be 5 percent of the well construction costs.

Production and Reinjection Brine Pipelines. Similarly, owner's costs are estimated at 12 percent of the pipeline construction costs. The costs include obtaining the necessary land rights-of-way for the pipelines and the necessary client costs in preparing documents to satisfy government environmental agencies. AFDC is estimated to be 5 percent of the pipeline construction costs.

B.1.3 Annual Capital Costs

The total capital cost is converted to an annual basis by applying a fixed charge rate. The fixed charge rate is an equivalent levelized rate of annual variable charges. The components which make up the final charge are rate of return, depreciation, insurance, property or ad valorem tax, and administrative and general expenses. The rate of return is equal to the weighted composite sum of the investment on borrowed money, dividends on preferred stock, and equity return to the common stockholder.²⁹ For this study, an 18-percent fixed charge rate is used for the process industries.

B.1.4 Operating and Maintenance Costs

The materials, supplies, and labor for plant operation and maintenance are estimated to reflect second-quarter 1977 price and wage levels. They are included in the estimate on the basis of the following discussion.

B.1.4.1 Plant Equipment and Materials. The operating and maintenance costs for the geothermal energy equipment are assumed to be the same as for the fossil fuel energy equipment. This is a conservative assumption, due to the larger capital investment associated with the fossil fuel steam boiler and the turbine pump drives compared to the capital cost of the geothermal multistage flash vessels and electric pump drives. Therefore, no additional operating and maintenance costs are required for the retrofit or new construction plant equipment.

B.1.4.2 Production and Reinjection Wells. The operating and maintenance costs for the wells and surface equipment include:

- Manual and salaried labor supporting well production and the associated labor overhead expenses
- Operating chemicals and materials
- Periodic downhole surveys, acidizations, and reworkings when necessary for production and reinjection wells
- Maintenance of well field surface facilities

The annual costs are estimated to be 6 percent of the total capital cost of the production and reinjection wells.

B.1.4.3 Electric Power. The electric power requirements for the process plants are the largest single operating and maintenance expense. Electric power is required by plant process and transfer pump drives, downhole geothermal well pumps, and brine reinjection well pumps. This electric power consumption is in addition to the process plant's existing

electrical requirement. The current pumps powered by steam turbine drives are left in place, but the drives are changed to electric motors. This pump drive change, along with the addition of the electrically-driven geothermal well pumps are the major contributors to the increased electric power requirement. Electric power for industrial applications is assumed to be purchased from the utility at 25 mills per kWh.

B.1.4.4 Production and Reinjection Pipelines. The operating and maintenance costs for the production and reinjection pipelines include:

- Maintenance of pipeline rights-of-way
- Maintenance of thermal expansion loops in the pipelines
- Personnel to regulate the pipeline flow rates during process plant operation

The annual costs are estimated to be 2 percent of the total capital cost of the production and reinjection pipelines.

B.2 COST OF GEOTHERMAL ENERGY

The geothermal energy cost is a function of the total capital costs, together with the operating and maintenance costs associated with geothermal energy production. The geothermal energy costs are expressed in equivalent dollars per million Btu (Equiv-\$/MMBtu) of the current fossil fuel energy requirement. These costs are calculated by dividing the annual geothermal energy costs for each example plant by the amount of fossil fuel energy required by the respective conventional plant over its yearly operating period.

Table B-1
COMPARISON OF PRODUCTION WELL DESIGNS

Well Location	Present Study Western U.S.	Bechtel ²⁶ Heber, Calif.	TRW ²⁷ E. Mesa, Calif.
Depth, ft	1,000	6,000	6,500
Temp, °F	300	360	350
Casing Dia., In.	8	10 3/4	9 5/8
Flow, GPM	250	1,800	1,000
Cost, \$	56,000	540,000	400,000
Unit Costs			
\$/GPM	225	300	400
\$/MM Btu*	3,550	3,330	4,680

*Assumes 160°F reinjection temperature

Figure B-1. Well Cost vs. Depth

Appendix C

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