INDUSTRIAL UTILIZATION OF GEOTHERMAL ENERGY

A Thesis
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by

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ABSTRACT

Certain industrial processes were studied in order to evaluate the potential for the application of geothermal energy to various Idaho industries. It was found that geothermal energy is most applicable to the food processing industry. Energy and economic studies indicate that while large portions of conventional fossil fuels used for heating and for industrial processing can be conserved by the application of geothermal energy, such application is not economically favorable for an individual industry at this time. However, the application of geothermal energy for multiple use systems such as industrial parks for space heating result in improved economics.
INTRODUCTION

In past years, little consideration had been given to the limitation of the world's energy supply. Conventional energy supplies were considered to be inexhaustable due to the tremendous quantities of this fossil fuel supply found beneath the earth's surface. However, as years passed, the consumption of this energy continued to increase and the realization dawned that this energy was not inexhaustable and was dwindling at an ever increasing rate. The energy crisis in 1974 brought this realization acutely into focus. As a result, there are now massive efforts throughout the United States and in other countries attempting to develop alternate sources. One potential energy source is geothermal energy.

Since Idaho possesses large quantities of geothermal energy, it was suggested that the possible development of this energy should be studied for applications within Idaho. This thesis is an assessment of the potential applications of geothermal energy to various industries in the state of Idaho.

The term "geothermal energy" broadly refers to the intrinsic heat in rocks and water beneath the earth's surface. The total volume of the earth is about 260 billion cubic miles and all but a thin crust at its outermost layer is very hot due to natural radiation and pressure. Geothermal heat takes many forms and may be classified by resource type as follows (2):

- Geothermal energy can be used for:
  - Heating
  - Power generation
  - Aquaculture
  - Industrial processes
  - Bathing
1. Vapor-dominated hydrothermal systems (dry steam)

2. Liquid-dominated hydrothermal systems
   a. High temperature systems (>150°C)
   b. Moderate-temperature systems (90-150°C)
   c. Low-temperature systems (<90°C)

3. Hot dry rock formations

4. "Near Normal" thermal gradient environments (20 to 40°C/km of depth)

5. Magma, generally found at great depths.

Quantitative data of the stored heat capacity are unavailable but visible signs such as lava flows, geysers and fumaroles indicate that the reservoirs of high temperature energy is immense. Except for solar energy, geothermal energy represents potentially one of the largest sources of energy available to man.

Until recently, geothermal energy was regarded merely as natural curiosity with little potential for use other than for health resorts and a few minor space heating applications. However, as the supply of conventional fossil fuels continued to diminish and the cost of these fuels continued to rise, the search began for new economic sources of non-polluting energy. Investigations of alternate energy source indicate that geothermal energy has the potential to supply a significant percentage of current fossil fuel demands. Some advantages of geothermal energy are:

1. Renewable.

2. Relatively non-polluting as compared to fossil fuel emissions and nuclear waste.
3. Consumes little precious material.
4. A constant source of energy (as opposed to solar energy).
5. Minimal land impact.

Estimates of the potential of geothermal energy vary widely depending upon the basic assumptions used by the investigators in making the estimates. It is projected that 700,000 Q*(4) of economically recoverable and usable "heat" lies in the earth's crust within the continental United States. This figure was obtained by assuming that usable geothermal energy (>21°C) could be mined over half of the land area of the U.S. between a one and two mile depth below ground. The above figure amounts to 10,000 times the current yearly demand in the United States. These estimates are not meant to imply that geothermal energy can supply 100 percent of the United States' energy demand but they do indicate that a tremendous reservoir of energy is available for use when the technology required to capture it becomes available.

Reistad(5) has produced a more conservative estimate of geothermal potential. The energy requirements of the United States were evaluated to determine where the substitution of geothermal energy could result in substantial savings compared with conventional energy sources. The evaluation was limited to those applications which could be supplied by a geothermal source with a maximum temperature of 250°C. Figure 1 shows the approximate temperatures required for various applications.

* Q = 10^{15} Btu
Table 1. Required temperatures (approximate) of geothermal fluids for various applications. Ref. (6)

<table>
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<th>Temperature (°C)</th>
<th>Referred Application</th>
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<td>20</td>
<td>Fish matching and farming</td>
</tr>
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<td>30-40</td>
<td>Swimming pools, pond irrigation, fermentations, soil warming</td>
</tr>
<tr>
<td>50</td>
<td>Alumina via Boyer's process</td>
</tr>
<tr>
<td>60-70</td>
<td>Space heating</td>
</tr>
<tr>
<td>80</td>
<td>Greenhouses by combined space and heated heating</td>
</tr>
<tr>
<td>90</td>
<td>Drying organic materials, seaweed, grass, vegetables, etc.</td>
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<tr>
<td>100-110</td>
<td>Fresh water by distillation</td>
</tr>
<tr>
<td>120</td>
<td>Food canning</td>
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<tr>
<td>130</td>
<td>Extraction of salts by evaporation and crystallization</td>
</tr>
<tr>
<td>140-150</td>
<td>Alumina via Boyer's process</td>
</tr>
<tr>
<td>150</td>
<td>Dry fish</td>
</tr>
<tr>
<td>160</td>
<td>Drying miscellaneous organic materials</td>
</tr>
<tr>
<td>170-190</td>
<td>Deicing, digester digestion in sugar refining, digestion in paper pulp, wax harvesting, etc.</td>
</tr>
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Note: The table lists temperatures ranging from 20°C to 190°C. The applications include various processes such as fish matching, soil warming, alumina production, space heating, water distillation, food canning, and sugar refining, among others. The temperatures are approximate and refer to specific applications as indicated.
In Reistad's study no attempt was made to match geothermal application to known geothermally active areas. The study concluded that greater than 40 percent of the U.S. energy requirements could be supplied by geothermal resources at temperatures less than 94°C if resources were available at each application site. Approximately half of the 40 percent savings is from space heating in industrial residential and commercial locations which can utilize geothermal energy at less than 100°C. Other savings are from water heating, air conditioning and certain industrial processes. Reistad's work indicates that there exists a real potential for geothermal energy application.

Development and Utilization of Geothermal Energy

Man's use of geothermal energy is at least as old as recorded history. Roman documents record the application of geothermal energy for space heating from Lardarello fields in Italy(7). The Icelanders, Japanese and Turks also used geothermal energy for space heating through the ages.

Major applications of geothermal energy in modern times did not begin in earnest until 1928 when the first boreholes for hot water were drilled in the vicinity of Reykjavik, Iceland yielding 0.5 ft³/sec of hot (87°C) water(8). A 20-mile long pipeline was constructed to feed a pilot district comprised of 70 houses, two swimming pools and a school house. The success of this venture led to more extensive drilling for hot water at the Reykir thermal springs area approximately 11
miles from Reykjavik. As years passed, more wells were drilled so that currently 99 percent of the population of Reykjavik uses geothermal energy for space heating. From the time that the Reykir fields were first developed, approximately 11.0 billion cubic feet of water have been withdrawn without any drop in temperature or production rate.

**Electrical Production from Geothermal Energy**

Experimental production of electricity from geothermal energy began in the Lardarello fields in 1904(9). By 1931, sufficient quantities of electricity were being generated to begin selling electricity to the Italian Railway System. After being destroyed in World War II, the generating facilities were rebuilt and expanded. The Lardarello fields currently generate enough electricity to supply a city of 600,000 at U.S. consumption rates. Commercial generation of electricity from geothermal energy in the United States began in 1960 at the Geysers (California). By 1973 the U.S. was the world's largest producer of electricity from geothermal steam(10). Currently 1000 MW of electricity are generated from geothermal steam worldwide, half of which is produced at the Geysers.

Although world-wide production of electricity from geothermal sources continues to increase yearly, it is doubtful that the overall contribution of this production will be significant in the near future. Assuming that production in the world continues to increase at the present rate, 3000 MW will be produced by 1980(11). This projected production still
would constitute less than one percent of the current energy demands.

There are several inherent problems in producing electricity from geothermal energy. One major problem is locating geothermal sources with the necessary heat content to produce electricity. Generating electricity from geothermal water at 150°C or less is generally not economical due to the low efficiencies (less than 7 percent) and large specific low rates required\(^{(12)}\). However, it is likely that the competitive economics of electrical generation using lower temperature geothermal sources will improve as the technology in the field advances and conventional energy costs continue to rise.

Another problem associated with using geothermal energy is that geothermal water tends to contain a higher mineral content than ground water. The salt content in California's Imperial Valley generally runs from 3,000 to 20,000 mg per liter\(^{(13)}\). This high mineral content produces scaling problems in equipment and inhibits production capabilities. Calcium carbonate deposits also cause scaling problems in wet steam utilization. As the hot water moves up the well bore, flashing occurs which releases carbon dioxide and causes calcium carbonate to deposit a scale in the well and in the surface equipment. Heavy scaling resulted in the closure of eight production wells in Kizildere, Turkey\(^{(14)}\). Flashing could be prevented by pumping the hot water up under pressure. However, this would require deep well pumps operating at depths of 400 meters which are capable of pumping tremendous quantities of hot water. Such pumps are not currently available.
The development of hot dry rock systems holds the possibility of expanded electricity production from a geothermal source. The basic approach is to drill into the hot rock, produce a fissure in the rock, and pump water in the fissure to capture the heat. The hot water is then pumped to the surface and used for the production of electricity. The development of this geothermal source is in its preliminary stages with completion many years away.

Non-electric Utilization of Geothermal Energy

The production of a significant amount of electricity from geothermal energy is years in the future. In comparison, the utilization of geothermal energy for non-electrical demands holds great possibilities in the more near future. The advantages of non-electric utilization of geothermal energy are as follows:\(^{(15)}\):

1. Approximately one-third of the U.S fossil fuel consumption is used for residential purposes, the majority of which could potentially be supplied from low-temperature geothermal sources.

2. Low-temperature sources are more numerous and generally less polluting than the high-temperature sources, which are required for electrical production.

3. The efficiency of non-electric utilization is greater than for electrical production.

4. Technology is sufficiently advanced to allow immediate development where the resource exists.

Space heating accounts for 18 percent of the United States' yearly energy consumption\(^{(16)}\). Because known geothermal sites do not correspond to large population centers, this energy
cannot presently be used to supply the bulk of space heating demands. However, as exploration techniques improve and new geothermal sites are discovered, an increase in the application of geothermal energy to space heating can be expected. A project is presently underway to investigate the possibility of geothermal space heating for Portland, Oregon. Significant application already exists in Klamath Falls, Oregon and Boise, Idaho. Space heating is particularly suited to geothermal energy application because of its relatively low temperature requirements which is a characteristic of the bulk of the geothermal water available for use.

Residential and commercial air conditioning amount to 2.5 percent of the United States' yearly energy consumption in 1968 and is responsible for peak power load use during the summer months\(^\text{(17)}\). Lithium bromide absorption refrigeration units are already available which operate at heating temperatures of 95°C to 120°C and could utilize geothermal water at temperatures from 110°C to 135°C. Other non-electric geothermal uses include water irrigation, greenhouse and animal space heating, and agricultural and process heat applications. Table 1 is a list of current non-electric uses of geothermal energy.

The above information indicates that applications for geothermal energy are real and promising. Currently, the utilization of geothermal energy in industries is non-existent. However, the level of energy required by typical industrial processes as found in Idaho are compatible with the use of geothermal energy. Therefore, in order to accurately assess the
TABLE 1

Current Non-Electric Uses of Geothermal Energy(18)

1. Balneology (health resorts & spas)

2. Agricultural
   a. Hot water irrigation
      1) Crop spraying
      2) Soil warming
   b. Greenhouses & hothouses
      1) Vegetables - cucumbers, tomatoes, mushrooms
      2) Fruits - melons, papayas, bananas, grapes
      3) Flowers - cut flowers, orchids
      4) Garden & house plants - rubber trees, ornamental plants
      5) Tree Seedlings
   c. Animal raising
      1) Egg hatching
      2) Poultry - chickens, turkeys
      3) Swine (houses, soil, feed)
      4) Dairy farms (soil, feed)
      5) Slaughterhouse operations (including tallow production)

3. Aquaculture
   a. Fish culture
      1) Catfish
      2) Alligators
      3) Eels
      4) Carp
      5) Seed fish
      6) Stock fish drying

4. Climate Control
   a. Heating
      1) District space heating (central control)
      2) Space heating (single unit)
      3) Hot water service
         (all of above for homes, schools, hotels, hospitals, factories, clinics, farm buildings, etc.)
      4) Year-round working of mines
   b. Cooling
      1) Air-conditioning (homes, hotels, factories, etc.)
   c. Refrigeration
TABLE 1 - Continued

5. Manufacturing Processes

1) Dry ice
2) Synthetic rubber
3) Ammonia
4) Protein manufacture
5) Vitamin manufacture
6) Dry curing of tea
7) Miscellaneous cryogenic processes
8) Desalination of sea water
9) Metallurgical processes (such as one flotation)
10) Seaweed drying
11) Rice parboiling
12) Wool washing & drying
13) Trace element recovery
14) Plastic explosives
15) Brewing & distillation
16) Diatomite manufacturing
17) Paper pulp manufacturing
18) Wood preparation & drying
19) Newsprint manufacturing
20) Kraft paper manufacturing
21) Timber drying & seasoning
22) Seed drying
23) Viscose rayon manufacturing
24) Peat drying
25) Sugar processing (beet & cane)
26) Ethyl alcohol from various feed stocks
27) Fermentation processes
28) Alumina via Bayer's process
29) Food processing & canning (fruit, juice, veg., etc.)
30) Milk pasteurization
31) Garbage cooking for animal feed
32) Lithium by ion exchange
33) Heavy water by $\text{H}_2\text{S}$ process
34) Sodium chloride (both table salt & coarse salt)
35) Calcium chloride
36) Borax
37) Iodine
38) Boric acid
39) Bromine
40) Hydrogen sulfide
41) Sulfur
42) Magnesium
demand for geothermal energy in Idaho, this thesis will determine the energy required by various Idaho industries and will assess the potential for geothermal energy in fulfilling that energy demand.

Geothermal Resources and Technology

Before possible industrial applications for geothermal energy are considered, it is essential to understand the various characteristics of the resource. Geothermal resource classifications are characterized in the following paragraphs:

1. Vapor-dominated systems: These are systems which contain primarily single-phase thermodynamically saturated or superheated steam.

2. Liquid-dominated: These are systems which consist of naturally occurring single-phase liquid water or naturally occurring two-phase mixture of liquid water and steam.

3. Hot dry rock: Hot dry rock geological formations contain abnormally high heat content but do not contain sufficient water or sufficient rock permeability to allow the removal of the hot water.

4. Magma: This system is comprised of molten rock at approximately 500 to 1500°C. Except for a few exceptions, magma is found at great depths (18 miles or more) below the earth's surface.

Since this study is limited to non-electric utilization of geothermal energy and since no vapor-dominated systems have been found in Idaho, only the liquid-dominated sources will be considered. Even though vapor-dominated systems are not considered in this study, the impact of geothermal steam is considered since steam can be obtained by flashing geothermal water.
The technology necessary to utilize geothermal resources is still in the developing stages. Reviews of current technology can be found in ERDA publication 1213(20) and in the Jet Propulsion Laboratory status report, Geothermal Program Definition Project(21).

Using exploration techniques and previously known geothermal sources, the United States recently classified certain land as Known Geothermal Resource Areas (KGRA). The term "Known Geothermal Resource Area" appearing in the Geothermal Steam Act of 1970 was used to designate areas in which "the geology, nearby discoveries, competitive interest or other indicia" would seem to warrant the expenditure of funds for geothermal exploration(22). Idaho has two KGRAs: the Yellowstone KGRA with a total of 14,114 acres and the Frazier (Raft River) KGRA with a total of 7,680 acres(23). The Geothermal Steam Act of 1970 also designates certain areas to be "areas valuable prospectively" (AVP). Approximately 15 million acres in Idaho are so designated. Figure 2 shows the location of known geothermal resource areas and areas classed as potentially valuable for geothermal exploration. Figure 3 shows the temperature ranges of these areas in the Western U.S. and Figure 4 shows the water quality in these areas.

Investigations of geothermal sites within the state of Idaho are numerous. The most recent and complete reports for Idaho are published by the Idaho Department of Water Resources, as Water Information Bulletin No. 30(28) (three parts). In this report, over one-third of Idaho's known geothermal sites
EXPLANATION

- Known geothermal resource area
- Lands classified as potentially valuable for geothermal exploration

Land classification generalized from Godwin and others (1971)

FIGURE 2. Location of known geothermal resource areas and areas classed as potentially valuable for geothermal exploration. Ref. (24)
FIGURE 3. Temperature ranges of the major known geothermal resource areas in the Western United States. Ref. (25)
FIGURE 4. Water quality of the major known geothermal resources areas in the Western United States. Ref. (26)
were sampled and analyzed. The report includes a table with the geologic environment of selected springs and wells in Idaho, a table of the chemical analysis of the sources, and a table of the estimated aquifer temperatures and atomic ratios of selected chemical constituents of the sources. The water temperatures, calculated using the silica and sodium-potassium-calcium geochemical thermometers, range from 5°C to 370°C and averaged 110°C. The quality of the waters sampled was generally good. Dissolved-solids concentrations ranged from 14 to 13,700 mg/l and averaged 812 mg/l, with higher values occurring in the southeastern part of the State. Figure 5 shows the locations of known springs and wells in Idaho.

Idaho possesses a geothermal resource which has the potential to alleviate a large portion of current conventional energy demands. Five incentives for the prospective for geothermal energy in Idaho have been summarized by Ross(27).

1. Idaho lacks most conventional fuels.

2. Idaho can use large blocks of additional power to increase irrigation, for phosphate production and to stimulate industrial growth.

3. Chemical and geologic data indicate that several areas may have the potential to produce steam suitable for power generation.

4. Increased drilling for thermal water to be used for space heating will probably result in the discovery of steam sources.

5. Since large portions of the State which are owned by the Federal Government contain known geothermal anomalies, the Geothermal Steam Act will act as a stimulus for exploration of geothermal sources.
• Spring and well sites
■ Recreation developments
▲ Recreational or commercially developed sites studies

FIGURE 5. Thermal springs and wells in Idaho. Ref. (27)
Approach to Geothermal Development

The development of geothermal energy is inhibited by the narrow scope of known geothermal sources and by the absence of data which are required for the economic assessment of this development. Programs are currently underway to explore for and to investigate suspected geothermal areas in order to define the magnitude and characteristics of these areas. However, the economical impact of the application of geothermal energy to industrial processes has not been studied extensively. This report is an attempt to develop a framework and data for assessing the economics of eventual geothermal development.

The basic approach of this report is to define a range of temperatures of geothermal sources that might be found in Idaho and to study the possible applications of these sources in various Idaho industries. The study will develop a list of possible applications with required geothermal source parameters and locations. This type of study will also give indications as the relative economics of the application of geothermal energy versus conventional energy sources.

Investigation Procedure

This study is based on several assumptions. The initial assumption is that geothermal sources are available over a wide range of temperatures. Source temperatures are assumed well beyond the range which is probably available to show the relative contribution of such sources as compared to higher
source temperatures. It is assumed that the quality of the water is such that corrosion and scaling will not pose a problem. Finally, it is assumed that the technology required to obtain and utilize the source is available.

The initial step of this study was to perform an exhaustive literature search to obtain all pertinent information. Available information proved to be scarce and many publications merely recounted previous publications.

Upon completion of the literature search, the industries in Idaho which appeared to have possible uses for geothermal energy were defined. Two criteria were used to select an industry for possible geothermal application. One criterion was that the industry have a large demand for low temperature energy. The second criterion was that the industry have a large economic impact around the areas in which it is located. Any industry which satisfied both of the above criteria was included in the study.

Once the industries were selected, each industry was visited in an attempt to identify the energy requirements for the various steps in their processes. The results obtained were not always sufficient to establish a complete energy picture. In some cases, data were not available, and in other cases, proprietary considerations prevented the data from being released. In these cases estimates were made based on other available information to obtain energy use data.

With the data in hand, energy balances were calculated to estimate possible geothermal energy applications. The economics
were studied over a wide range of source temperatures and overhead costs to produce general results which could be applied to many different situations. The economics for conversion to geothermal energy are strongly affected by source location, source of capital, etc. This study is intended to present a range of the expected economic return on the capital (ROC) investments for conversion to geothermal energy. Return on Investment (ROI) is a standard criterion used to estimate the economic feasibility of an investment. The before tax ROI is the annual capital return on the investment divided by the investment, minus 10 percent for depreciation and 10 percent for capital recovery (29).

The ROI results of this study should not be considered as absolute values but as indicators of the relative merit of the application of geothermal energy. Large ROI values and small ROI values indicate good and bad economic returns for geothermal development respectively. However, there is a large area between the high and low ROI values in which the economics of geothermal application is uncertain. The impression that should be obtained from such results is that more detailed analysis than is possible in this report must be performed in order to ascertain the true economics of each application.

During this study some costs were found to be quite variable in magnitude. The cost estimate for the geological exploration which is required to locate a geothermal source varied from $50,000 (50) to $1.5 million (31). The difference
between these costs results from the size of the areas to be investigated and the previous knowledge of geothermal activity in the area. Areas with known geothermal reserves such as Klamath Falls, Oregon, and Boise, Idaho, require considerably smaller exploration costs than areas in which little information is available on possible geothermal source locations. As the study progressed it became apparent that no private industry in Idaho could afford to risk $1.5 million in an attempt to locate a geothermal site. Therefore, it is reasonable to assume that these industries would only consider geological explorations in areas with known geothermal reserves. For this reason, the geological investigation cost used in this study is $50,000.
Farming constitutes the bulk of Idaho's economy, with the major crops being potatoes, wheat, sugar beets and peas. There appears to be very little application for geothermal energy in growing these crops other than for irrigation. However, each year more of these crops are being processed and packaged prior to being sold. This trend has spurred expansion in Idaho's food processing industries and an increase in their energy consumption.

One of the largest food processing industries in the Northwest is the potato processing industry. Between 1959 and 1970 the Northwest's share of U.S. potato production rose from 24 to 42 percent. In 1970 Idaho produced 7 billion pounds of potatoes which amounted to 60 percent of the total Northwest production. Figure 6 shows the approximate distribution of potato production in Idaho as of 1969. The bold lines in the figure show the general geothermal areas in the state. The circles show the location of the potato processing plants in Idaho. The figure indicates that the location of potato production and processing and geothermal areas are somewhat coincidental. The importance of this coincidence will be shown in the economic analysis for geothermal conversion later in the thesis.

The energy demand for potato processing is continually increasing as potato production increases and as the percentage of potatoes processed increases. Table 2 shows a projection
FIGURE 6. Potato production in Idaho. Ref (33)
Table 2  
Potatoes  
Production, Frozen Pack  
Idaho, Oregon, and Washington  
1959 - 1990  
(000 lbs.)

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Production</th>
<th>Sold from Farm</th>
<th>Processed Production</th>
<th>Frozen Pack</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(000 lbs.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Idaho</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1959</td>
<td>4,049,600</td>
<td>3,685,400</td>
<td>1,546,600</td>
<td>165,000</td>
</tr>
<tr>
<td>1963</td>
<td>5,346,600</td>
<td>4,932,800</td>
<td>2,572,000</td>
<td>365,000</td>
</tr>
<tr>
<td>1965</td>
<td>6,169,500</td>
<td>5,534,900</td>
<td>3,569,700</td>
<td>475,000</td>
</tr>
<tr>
<td>1968</td>
<td>5,950,500</td>
<td>5,251,400</td>
<td>3,735,700</td>
<td>615,000</td>
</tr>
<tr>
<td>1970</td>
<td>7,391,500</td>
<td>6,431,000</td>
<td>4,672,900</td>
<td>905,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8,450,000</td>
<td>7,435,000</td>
<td>6,208,500</td>
<td>1,212,000</td>
</tr>
<tr>
<td>1990</td>
<td>9,530,000</td>
<td>8,380,000</td>
<td>7,551,000</td>
<td>1,533,500</td>
</tr>
<tr>
<td>Oregon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1959</td>
<td>869,200</td>
<td>736,200</td>
<td>43,200</td>
<td>40,000</td>
</tr>
<tr>
<td>1963</td>
<td>923,000</td>
<td>824,300</td>
<td>148,800</td>
<td>70,000</td>
</tr>
<tr>
<td>1965</td>
<td>918,000</td>
<td>829,700</td>
<td>181,800</td>
<td>105,000</td>
</tr>
<tr>
<td>1968</td>
<td>1,200,800</td>
<td>1,082,000</td>
<td>272,800</td>
<td>155,000</td>
</tr>
<tr>
<td>1970</td>
<td>1,605,600</td>
<td>1,400,000</td>
<td>382,300</td>
<td>185,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1,930,000</td>
<td>1,700,000</td>
<td>626,000</td>
<td>320,500</td>
</tr>
<tr>
<td>1990</td>
<td>2,320,000</td>
<td>2,045,000</td>
<td>841,000</td>
<td>426,500</td>
</tr>
<tr>
<td>Washington</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1959</td>
<td>986,000</td>
<td>873,900</td>
<td>80,200</td>
<td>30,000</td>
</tr>
<tr>
<td>1963</td>
<td>1,172,000</td>
<td>1,076,700</td>
<td>169,200</td>
<td>65,000</td>
</tr>
<tr>
<td>1965</td>
<td>1,808,800</td>
<td>1,719,200</td>
<td>428,500</td>
<td>140,000</td>
</tr>
<tr>
<td>1968</td>
<td>2,417,300</td>
<td>2,301,600</td>
<td>731,500</td>
<td>285,000</td>
</tr>
<tr>
<td>1970</td>
<td>3,359,000</td>
<td>2,959,000</td>
<td>1,144,800</td>
<td>445,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3,620,000</td>
<td>3,185,000</td>
<td>1,465,500</td>
<td>571,500</td>
</tr>
<tr>
<td>1990</td>
<td>4,050,000</td>
<td>3,555,000</td>
<td>1,818,000</td>
<td>709,000</td>
</tr>
</tbody>
</table>
of potatoes produced and processed through 1990\(^{(35)}\). These figures show that potato production is expected to rise to 9.5 billion pounds \((4.32 \times 10^9 \text{ kg})\) by 1990 and that at least 73 percent of the potato crop will be processed. The following sections investigate the economic implications of applying geothermal energy to various potato processes.

The majority of potato processing involves freezing or dehydration of the potato. Freezing results in products such as frozen french fries, while dehydration results in potato flakes or potato granules. The flakes or granules can be packaged as instant mashed potatoes or reconstituted to produce other products such as potato chips. The following sections review the processes used to produce potato granules, flakes and frozen french fries. The general process is outlined and the energy requirements defined. Estimates of possible geothermal applications are then made.

**Potato Granule Production**

Potato granule production is a dehydration process in which the raw potatoes are prepared, cooked and dehydrated. The Add-Back process, so named because dried potato granules are added back to freshly cooked potatoes, results in potato granules which are actually individual potato cells. The process of adding back dried granules to freshly cooked potatoes changes the texture of the material so that it can be handled more easily. This product is used for instant potato mix or is reconstituted to produce potato chips and french
fries. The following information on this process was provided by Lyle Parks of the American Potato Company in Blackfoot, Idaho(36).

After the raw potatoes are washed, they are steam peeled (see Figure 7 for process outline). The potatoes are exposed to steam at 80 psi for five to six seconds. The loosened skin is then removed by abrasion. The peeling process uses six to eight pounds of steam for 100 pounds (45.45 kg) of raw potatoes. None of this steam is recovered. Due to the nature of a continuous piston type steam peeler which is primarily used in large operations, recovery of this energy would be very difficult.

The peeled potatoes are then trimmed and sliced. Cooking the potatoes is a two-step procedure. The first step is a blanching process which partially cooks the potato and allows the cells to expand so that they will not rupture during the final cooking step. Blanching is performed under an atmospheric steam blanket using a live steam source at 100 psi. Ten to twelve pounds of steam are required for each 100 pounds of raw potatoes in the blanching step. The water in the cooker is maintained at 82°C, and the potato reaches a temperature of 71°C in the cooker. Approximately 2 pounds of water per 100 pounds of raw potatoes are added to the cooker to make up for water lost during the cooking.

The partially cooked potatoes are then sent to the main cooker in which the water temperature is maintained between 99°C and 104°C. Again, live steam at 100 psi is used as the heat source. Cooking takes 35 to 45 minutes and requires 11 to
15 pounds of steam per pound of raw potatoes. At this point in the process, the potatoes are completely cooked and contain 80 percent moisture. The potato slices are then mashed and cooled to $15.6^\circ C - 26.7^\circ C$. Potato granules which contain 10 percent moisture are then added to the freshly cooked potatoes. The ratio of add-back to freshly cooked potatoes is approximately 2.5 to 1.0. This results in a mixture with approximately 30 percent moisture which is conditioned for one hour.

The product is then dried from a moisture content of 30 percent to 7 percent. Drying takes place in three stages. The first stage involves a flash dryer which uses $260^\circ C$ to $287.8^\circ C$ air, heated by natural gas, to reduce the moisture from 30 to 15 percent. The drying air exits this stage at $76.7^\circ C$ to $82.2^\circ C$. The second stage is a fluidized bed which also uses air heated by natural gas to $121^\circ C$ and supplemented with steam to reduce the moisture from 15 to 10 percent. The resulting material is screened and separated. The fraction of material that is to be packaged as product is sent to the final drying stage while the remaining portion is used as add-back. The final drying stage is also a fluidized bed and uses $43.3^\circ C$ air to reduce the moisture to 7 percent. The last two drying stages use large quantities of low temperature air so that the vaporization of the water from the granule is gradual and does not rupture the cell. The entire drying process requires 0.9 to 1.0 therm per 100 pound of raw potatoes.
RAW POTATO

WASH

STEAM PEELER
80 PSI
6-8# S/100# RAW

SLICE

BLANCHER
100 PSI
10-12# S/100# RAW
WATER TEMP= 180°F

FLASH DRYER
500-550°F
30-15% MOISTURE

MIX

+ CONDITION
30% MOISTURE

MASH + COOL

COOKER
100 PSI
10-12# S/100# RAW
210-220°F

FLUIDIZED BED
250°F
15-10% MOISTURE

ADD BACK

SCREENING

FLUIDIZED BED
110°F
10-7% MOISTURE

PACKAGED

FIGURE 7
Energy Requirements for Potato Granule Production

The energy requirements for potato granule production can be divided into two categories. One category is preparation and cooking of the potato and the other category is drying the potato. The following is a list of the energy requirements for these steps.

<table>
<thead>
<tr>
<th>Process</th>
<th>BTU (Natural Gas)/100 pounds raw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peeling</td>
<td>18360</td>
</tr>
<tr>
<td>Blanching</td>
<td>27638</td>
</tr>
<tr>
<td>Cooking</td>
<td>34546</td>
</tr>
<tr>
<td>Drying</td>
<td>90,000 - 100,000</td>
</tr>
</tbody>
</table>

The energy (natural gas) consumption on a yearly basis is as follows:

<table>
<thead>
<tr>
<th>Process</th>
<th>BTU (Therms)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space heating</td>
<td>57,000</td>
<td>0.7</td>
</tr>
<tr>
<td>Direct drying</td>
<td>4,600,000</td>
<td>55.0</td>
</tr>
<tr>
<td>Steam generation</td>
<td>3,700,000</td>
<td>44.3</td>
</tr>
</tbody>
</table>

From the above data it can be seen that over 44 percent of the gas used at American Potato goes into steam generation which is primarily used for peeling and cooking.

Due to the nature of the process, there is no energy reclamation in the peeling or cooking portion of the process. At this time there is no energy reclamation in the drying portion of the process. Recycling waste heat from the drying units was considered but was rejected due to the possibility of bacteriological contamination. A system in which the exhaust from the flash dryer is used as an energy source for the two fluidized bed dryers is currently under consideration by American Potato.
Geothermal Energy Applications

Geothermal sources of varying temperature could be adapted to the production of potato granules. The higher the temperature of the source, the more significant the contribution to the energy requirements of the process. However, the quality of the geothermal water is a major consideration. The peeling process is the only step in which geothermal water could be in direct contact with the potatoes. This restriction is due to the contaminants contained in most geothermal waters.

Although direct steam is generally used in this process, this is not a requirement. As long as the correct temperature can be maintained, the integrity of the product will not decline. It may be possible to perform the cooking operation in a jacketed container in which the outer jacket uses geothermal water as the energy source. This technique would require a major equipment modification since current kettles are not jacketed. With this method, it is possible for a geothermal source (250°F) to supply the bulk of the energy in the blanching and cooking operations.

It is unlikely that any geothermal source in Idaho would be able to supply a significant amount of energy to the drying stages in this process. Very few (2.5%) geothermal sources in Idaho are expected to exceed 150°C, much less the 260°C required for the flash dryer. The temperature requirements for the two fluidized bed dryers are significantly lower (121°C and 43.0°C). However, the large volumes of air that are used in these dryers would require heat exchangers of such size and expense as to be prohibitive.
Figure 8 shows the percentage of energy requirements supplied versus the temperature of the source. The following assumptions were made in the construction of this graph:

1. It is assumed that the peeling process will remain a steam peeling process and not a lye process which would probably be more applicable for geothermal use. Lye peeling is carried out at approximately 95°C and does not require steam injection.

2. It is assumed that no geothermal energy will be applied to the drying process.

3. It is assumed that geothermal energy greater than 38°C could supply 100 percent of the space heating requirements.

4. No consideration of the electrical requirements, which amount to approximately 24 x 10^6 kw hours per year, will be made.

The calculations used to obtain the data represented in Figure 8 are in Appendix A. Figure 8 shows that a potato granule processing plant using geothermal water can expect an energy savings from 1.9 percent for 38.0°C water to slightly less than 12 percent for 177°C water. If a geothermal steam source (212°F) is available from a vapor dominate hydrothermal source or from flashing superheat geothermal water, approximately 45 percent of the total energy (natural gas) requirements in the potato granule process can be saved. Figure 8 also shows that little advantage is derived from having a steam source higher than 100°C. A steam source of 176.7°C provides only an additional 0.4 percent savings in the energy requirements.

The above calculations do not include any refrigeration requirements. The refrigeration requirements for the potato
Percent Energy Savings Versus Source Temperature
(Potato Granules)

FIGURE 8.
granule process are relatively minor. The potatoes are stored in cellars at approximately 4.4°C. In the months of May and June, it is sometimes necessary to provide some refrigeration to maintain this temperature. The refrigeration is provided by freon compression systems. Approximately 50 tons of refrigeration are required for each 7500 tons of potatoes. Data on the average quantity of stored potatoes present during this time are not available. The fraction of the total electrical energy requirement used for this refrigeration is also not available. However, it is most likely that this energy demand could technically be provided by a geothermal source in excess of 93.3°C.

**Economic Analysis of Conversion to Geothermal Energy**

The basic assumption in this work is that there is a geothermal source of usable temperature near the potato granule processing plant. Transportation of geothermal energy over an extended distance is expensive and inefficient. Therefore, it is preferred that the plant site be in the proximity of the geothermal source. At present, data on possible geothermal locations are scanty and surface exploration techniques are not totally reliable. It is unlikely that an existing plant is close enough to an existing geothermal site to convert to geothermal energy. As prospecting techniques progress, this situation will probably improve, and some present industries might find themselves within a reasonable proximity to a geothermal source.
The capital outlay required for conversion to geothermal energy can be divided into five categories.

**Geological Investigation.** The cost of a geological investigation to find a geothermal source represents the initial and minimum investment required for conversion to geothermal energy. The current cost of a geological investigation of this nature is approximately $50,000 (30) (see introduction on geological investigation costs). This investment pays off only if the investigation is successful in locating a geothermal source of usable temperature and capacity. If the results of this investigation are negative, the investment yields zero returns.

**Well Cost.** Due to the nature of the material in which geothermal sources are generally found, the cost of drilling a geothermal well is substantially greater than the cost of drilling an oil well. A drilling rig can drill 17 oil wells per year versus 7 geothermal wells per year (38). The cost of the well depends upon the depth to which the well must be drilled. Cost estimates for a geothermal well drilled in Idaho are as follows. Assuming a production hole with 7 inch casing, a geothermal well supplying 120°C water costs approximately $150,000 (39). This assumes that 120°C water can be found at a depth of 3000 feet and cost of the well is $54/ft. A well producing 150°C water costs $300,000, and a well with 350°F water costs $400,000. These costs correspond to wells of 3000, 5000, and 7000 feet respectively and do not include pumps or extensive well head equipment. These are rough drilling costs and local geology
can cause significant variations in cost, productivity and temperature in depth.

**Conversion Cost.** Conversion of an existing plant to geothermal energy would require that the present cooking equipment be replaced with jacketed kettles, or existing kettles would have to be jacketed. A potato cooker which can handle 30,000 pounds of potatoes per hour is 42 inches in diameter and 20 feet long with a cost of approximately $15,000 unjacketed\(^{36}\). The cost of an installed jacket is approximately $50 per square foot. The above cooker has a surface area of 220 square feet. Therefore, jacketing would cost approximately $11,000. Similar costs can be expected for jacketing the blanchers. Assuming three processing lines with one cooker and one blancher per line, the total conversion cost is $66,000. If space heating and cooling were to be provided by the geothermal source, the present system would have to be adapted to the new source. It is impossible to make a general estimate of the expense of this operation due to the variety of the present systems in use.

**Piping Cost.** Piping cost is the most variable of the conversion expenditures. The pipe cost are determined by the size of the pipe required to transport the water. For applications to potato granules, this study assumes that geothermal water with an enthalpy content below that required for the processing step is piped into a boiler where the enthalpy content is increased. Therefore the pipe size depends upon the mass of
steam currently used in the process and not on the enthalpy contained in that steam.

A typical potato granule plant processing 40 tons of potatoes per hour requires approximately 28,000 pounds of steam per hour (see Appendix A) or 8 ft$^3$/min of water. Piping this quantity of water could be accomplished in a 4 inch schedule 40 welded steel pipe for an approximate cost of $14.15 per linear foot (installed). The cost of one mile of such pipe is $75,000[^{40}]. The magnitude of this expenditure illustrates the advantages of a short piping distance. Other material might be used to reduce cost.

**Miscellaneous Conversion Costs.** The above figures do not include conversion costs within the plant other than the labor of jacketing the kettles. They also do not include the cost of pumping the materials. From available figures on pump and labor costs, it is estimated that the miscellaneous conversion cost is approximately $30,000. While there is room for a large percentage error in this number, the magnitude of this number as compared with the other costs will render such an error insignificant.

**Summary Of Conversion Costs.** Assuming that the conversion is carried out during a normally scheduled maintenance period so that there is no production loss, the costs of conversion to geothermal energy are as follows:

- Geological investigation: $50,000
- Well cost: $150,000
- Conversion cost: $66,000
Piping cost 75,000/mi.
Miscellaneous conversion cost 30,000

In order to ascertain the economic feasibility of such an investment, an estimate can be made of the return on the investment. Return on Investment (ROI) is a standard criterion used to estimate the economic feasibility of an investment. The before tax ROI is the general capital returns on the investment divided by the investment minus 10 percent for depreciation and 10 percent for capital recovery(79) times one hundred.

\[ \%ROI = \frac{\text{Energy Savings}}{\text{Investment}} \times .2 \times 100(79) \]

The minimum ROI value which indicates a good investment is not fixed. It depends upon the economy, projected growth of the industry, the availability of capital and the associated risk. Under normal conditions, the minimum before tax ROI which is considered for an investment is approximately 40 percent. However, as discussed in the introduction, it is not possible for a study such as this to define a given number as the boundary between good and bad economical results. The ROI values obtained in this report are only indicators of the relative economics of the application of geothermal energy to these industries. ROI's which are not clearly good or bad indicate that closer study is required to obtain the true economic impact of geothermal application.
Figure 8 indicates that a 121°C water source can provide 7.7 percent of the total energy (natural gas) requirements in the granule process. At 15 cents per therm, this results in a natural gas energy cost of $96,520. If the geothermal source is in close proximity to the plant so that piping costs are minimal, the investment required to convert to geothermal energy is $296,000, yielding an ROI of 12.6 percent. ROI values versus piping distances are calculated in Appendix A and the results on Figure 9. Two outstanding features are seen in Figure 9. Figure 9 shows that there is a steep decline in ROI as piping distance increases and also that a large economic advantage is possible if a geothermal steam source is available rather than a water source.

The above data assume the conversion of an existing plant to geothermal energy. The economics of building a new plant near a geothermal source should be considered. All of the basic costs remain approximately the same except the piping cost. Assuming that the plant location is determined by the geothermal site, the piping cost should approach zero miles. This corresponds to an ROI of 29.9 percent for 180°C water and 168.8 percent for 160°C steam which are the values obtained for the conversion of an existing plant with zero miles piping distance (see Appendix A). However, the location of the processing plant in relation to the potato crops must be considered. It is estimated that the average distance potatoes are trucked to the processing plant is 25 miles at a rate of $.13/100 pounds (36). If the location of the plant
ROI Versus Piping Distance
(Potato Granule - 121°C Source)

FIGURE 9.
were such that the average shipping distance was 50 miles, the rate would be approximately $.19/100 pounds and $.245/100 pounds for 100 miles. As the shipping distance increases, transportation costs rise and the ROI decreases accordingly. Figure 10 shows how ROI varies with shipping distance. Figure 10 indicates that locating a new plant near a geothermal site which is further from the potato crops than the 25 mile average distance should only be considered when the geothermal source is steam.

**Disposal of Geothermal Water**

The cost of disposal of the geothermal water is not considered for single industrial users. A basic assumption in considering conversion to geothermal energy is that the geothermal water is of usable quality. In this regard, it is assumed that the quantity and quality of the water is such that disposal will not add significantly to the cost. Therefore, present conventional disposal systems could be used to dispose of the geothermal water.

The cost for disposal of geothermal water for very large users such as industrial parks and large space heating developments cannot be ignored due to the very large quantities of water involved. The standard disposal method for large geothermal systems is reinjection of the water back into the geothermal area. Water reinjection is not considered for single industrial users because the quantity of water used is relatively small. Reinjection reduces the impact on the environment which results
ROI Versus Shipping Distance

FIGURE 10.
from exposure to large quantities of warm water and also serves to increase the life span of the geothermal source. Reinjection costs includes return piping, pumps and reinjection well and are considered in the space heating portion of the multiple use section.

Conclusions

The application of geothermal water to the production of potato granules on an individual basis is economically marginal. ROI calculations indicate a clear economic advantage only in the best possible cases. The economics of conversion of an existing plant depends upon several factors including the source temperature, piping distance and equipment conversion cost. The minimum risk involved in conversion to geothermal energy is the cost of the geological investigation to locate a geothermal site which currently costs approximately $50,000\(^{(30)}\). While building a new plant near a geothermal site reduces piping costs substantially, the economics of transporting potatoes to the plant must be considered.

It should be noted that the production well which was considered has a larger capacity than required by the granule process. Therefore, the capital expenditure is paying for unused capacity which makes the ROI values less favorable. If the well is used to full capacity the cost per unit of energy is reduced and the ROI becomes more favorable. This possibility is considered in the multiple use section and in the report conclusion which appears later in the thesis.
Potato Flakes

The processing of potato flakes is a dehydration process which closely parallels potato granule production. There are approximately 40 dehydrated potato processing plants in the U.S. (41). Most of this production is in Idaho and Washington. The largest concentration of these plants is between Idaho Falls and American Falls in Idaho, with the remainder split between the Moses Lake, Washington, area and the Caldwell, Nampa, and Burley, Idaho, areas. Approximately 11 percent of the 270 million hundred weight of potatoes grown in the U.S. is dehydrated. Estimates are that the demand for dehydrated potato products will double in the next eight years.

The following information on potato flake production is supplied by Bill Weaver of Rogers Brothers Company in Idaho Falls, Idaho (42). Raw potatoes are washed and then steam peeled. The peeling process consists of subjecting the potatoes to 80 psi steam for 5 to 6 seconds. This step uses 11.7 pounds of steam per 100 pounds of raw potatoes. There is no energy recovery in this step. (See Figure 11 for the simplified schematic of the process.) The potatoes are then peeled by abrasion, washed and sliced. To prevent rupture of the potato cell, the cooking process is carried out in two steps. The potatoes are first cooked in a precooker at 76.67°C for 30 minutes. Direct steam injection is used to maintain the correct water temperature. This step uses 34 pounds of steam per 100 pounds of raw potatoes. During this process 20 gallons per minutes of 80°C water is
Simplified Schematic of Potato Flake Process

RAW POTATOES
11000 hr

STEAM PEELER
11.7 ft
100 lb Raw

PEEL AND WASH

SLICE

Cooker
16.5 ft
100 lb Raw

COOLER
80-90°F

DEWATER

RICER

DRYER
82 ft
100 lb Raw

POTATO FLAKES
2000 lb hr

FIGURE 11.
allowed to overflow to maintain the correct water level. This water is not recovered.

The potatoes leave the precooker and are dewatered and cooled to 27°C - 32°C prior to entering the cooker. The potatoes are cooked in the cooker for 30 to 45 minutes at 95°C. Direct steam injection (16.5 pounds of steam per 100 pounds of raw potatoes) is used to maintain the cooking temperature. There is no water overflow in this step. The cooked potatoes are sent to a ricer and after being riced, are sent to the dryers where the moisture in the potatoes is reduced from 80 percent to 7 percent. The potatoes are applied to the drum dryers and are scraped from the drum as they dry. The dryers require 83 pounds of 125 psi steam per 100 pounds of raw potatoes. The condensate from this process is recovered and returned to the boiler.

Energy Requirements for Potato Flake Processing

The energy requiring steps in potato flake production are peeling, precooking, cooking and drying. This does not include electrical energy necessary to run motors, etc. The following table gives the approximate energy demand for each step.

<table>
<thead>
<tr>
<th>Process</th>
<th>BTU/100 #Raw</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peeling</td>
<td>13842</td>
<td>0.082</td>
</tr>
<tr>
<td>Precooking</td>
<td>39127</td>
<td>0.231</td>
</tr>
<tr>
<td>Cooking</td>
<td>19000</td>
<td>0.112</td>
</tr>
<tr>
<td>Drying</td>
<td>97580</td>
<td>0.576</td>
</tr>
</tbody>
</table>

The above table does not take into account the efficiency of the boiler which results in a BTU expenditure of natural gas greater
an the indicated BTU requirements. The Roger's Brothers company estimates that 2.05 therms are required to process 100 pounds of raw potatoes. When this correction is applied to the above table, the following data results.

<table>
<thead>
<tr>
<th>Process</th>
<th>BTU/100# Raw</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peeling</td>
<td>16736</td>
<td>0.082</td>
</tr>
<tr>
<td>Precook</td>
<td>47308</td>
<td>0.231</td>
</tr>
<tr>
<td>Cook</td>
<td>22973</td>
<td>0.112</td>
</tr>
<tr>
<td>Dry</td>
<td>117983</td>
<td>0.576</td>
</tr>
</tbody>
</table>

The drying process is the only step in which the steam condensate is recycled to the boiler. All of the energy used in the peeling, precooking and cooking is lost.

**Geothermal Energy Applications**

The application of geothermal energy to the potato flake process has similar restrictions in regard to the quality of the geothermal source as does the potato granule process. Jacketed vessels are required in the precooking and cooking steps. Geothermal energy (steam) can be applied directly to the peeling process. The steam source is separated from the potato flakes in the drying process and therefore little equipment change is required in this step.

Due to the difference in drying techniques between granule and flake production, it is possible for a geothermal source (steam 180°C) to supply approximately 100 percent of the energy requirements (natural gas) in the flake process. This energy requirement constitutes approximately 20(41) percent of the total cost of potato flake production. Figure 12 shows the per-
percentage of the energy requirement supplied versus the temperature of the geothermal source. The following assumptions are made in the construction of this graph.

1. Steam peeling is used rather than lye peeling.
2. Geothermal energy is applied to all steps in the process including the drying process.
3. The graph does not reflect space heating and cooling requirements.
4. No consideration of the electrical requirements is made.
5. The minimum geothermal energy applied to the drying and peeling process is water at 100°C. The water will be converted to steam at 100°C. It is assumed that the condensate in the dryer is water at 100°C and is recycled to the boiler.

Figure 12 shows that a 38°C geothermal source can provide approximately 14 percent savings of the natural gas consumption. A 100°C water source could provide approximately 43 percent and a 180°C water source could provide over 50 percent of the energy requirements. A 100°C steam source can provide in excess of 96 percent of the energy demand (natural gas) in the potato flake process and a steam source at 180°C can provide 100 percent of the natural gas requirements in this process.

The calculations (see Appendix B) used to obtain the above estimates do not take electrical requirements, space heating and cooling or refrigeration into account. The refrigeration requirement in the potato flake process is minimal. As in the potato granule production, refrigeration is used to maintain a 4.4°C temperature in the potato cellars. This refrigeration is only required for a short period each year. Space heating and cooling
Recent Energy Savings Versus Source Temperature
(Potato Flake Production)

![Graph showing energy savings versus source temperature.]

FIGURE 12.
typically account for less than one percent of the natural gas demands and could be supplied by geothermal energy.

**Economic Analysis**

The same basic parameters as in potato granule production are considered in an economic analysis of potato flake production. The two approaches to be considered are conversion of an existing plant to geothermal energy and construction of a new plant near a geothermal source. The Return on Investment criterion is used to indicate the economic feasibility of conversion under conditions of various source temperatures and piping distances. The effect of potato transportation cost is considered for ROI in the construction of a new plant near a geothermal source.

**Conversion Cost.** A large potato flake facility can process approximately 40 tons of potatoes per hour. New, large capacity cookers can process approximately 15(36) tons of potatoes per hour which means that three processing lines are required. In potato flake production it is assumed that the precookers and cookers must be jacketed while the peelers and dryers require only slight or no modification. Modification of the dryers to use hot water rather than steam would be extensive and no data is available indicating that this procedure would produce an acceptable product. Therefore, this analysis will assume a steam input with no modification of the dryers.

The cost of jacketing the precookers and cookers is approximately $11,000(36) each. Considering three lines with one cooker and one pre-cooker in each line, the cost of the equipment...
is $66,000. This cost includes the jacket and its installation but does not include any refitting inside the plant or connecting the jackets to the steam source. These procedures will be included in the pump, labor and miscellaneous cost.

Geological Investigation. Currently, the cost of a geological survey is approximately $50,000\(^{(30)}\). The exploration costs are viewed as the minimum investment in considering conversion to geothermal energy.

Well Cost. Currently, a 7-inch diameter well can be drilled to 6000 feet for approximately $50\(^{(39)}\) per foot. Therefore, a 3000-foot well which would probably be required to find a 120°C water source costs $150,000. This cost is subject to large variations due to local geology and flow capacity requirements.

Piping Cost. Pipe costs are determined by the size of pipe required to transport the water. This study assumes that geothermal water with an enthalpy content below that required for the processing step is piped into a boiler where the enthalpy content is increased. Therefore, the pipe size depends upon the mass of steam currently used in the process and not on the enthalpy contained in that steam.

The energy requirements of a plant which processes 40 to 45 tons of potatoes per hour during a 16-hour work day is slightly in excess of 2 million pounds of steam per day. (See Appendix B for calculations.) This is equivalent in mass to 0.56 cubic feet of fluid per second which can be transported in a 4-inch diameter pipe at a velocity of 6.5 ft/sec. The cost of 4-inch
schedule 40 welded steel pipe is $14.15 per linear foot or approximately $75,000 per mile. The total piping distance depends upon the distance the fluid must be pumped.

**Miscellaneous Conversion Cost.** As previously described in the potato granule process, this cost includes the in-plant labor for refitting pipe systems to new equipment, pump cost which can vary greatly and unforeseen expenditures. This cost is estimated to be approximately $30,000.

**Summary of Costs.** In summary, the costs of conversion to geothermal energy are as follows:

<table>
<thead>
<tr>
<th>Cost</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological investigation</td>
<td>$50,000</td>
</tr>
<tr>
<td>Well cost</td>
<td>150,000</td>
</tr>
<tr>
<td>Conversion cost</td>
<td>66,000</td>
</tr>
<tr>
<td>Miscellaneous conversion cost</td>
<td>30,000</td>
</tr>
<tr>
<td>Pipe cost</td>
<td>75,000/mi.</td>
</tr>
</tbody>
</table>

Return on the capital investment (ROI) depends upon the investment made and upon the capital savings resulting from conversion. The basic conversion costs amount to $296,000 plus piping cost. As the piping distance increases, the capital investment increases and the ROI decreases. Figure 13 plots the ROI for various water sources versus piping distance. A large potato flake plant requires approximately 8.6 million therms per year at a cost of $1.25 million. Figure 12 shows that a 100°C water source can provide 13.8 percent of the energy requirements in the flake process. This saving results in an ROI varying from 40.2 for zero miles to 14.2 for 3 miles piping distance. Figure
ROI Versus Piping Distance
(Potato Flake Production)

FIGURE 13.
13 shows that an ROI of 92.9 can be expected from a 176.7°C source at zero miles.

Figure 14 plots ROI versus piping distance for a 100°C steam source which could be available by flashing superheated geothermal water. It shows that the ROI varies from 400 at zero miles to 166 at 5 miles piping distance. A comparison of the above figures shows the advantage of a steam source versus a water source.

As the geothermal water or steam is piped from the well to the plant, energy is lost to the surroundings. Calculations (Appendix B) indicate that water flowing in a 4-inch steel pipe at the required rate (6.5 ft/sec) will lose 3 BTU's per pound of water per mile. This heat loss is very small as compared to the heat content of the water and is not considered in the ROI calculations.

The previous calculations are also valid for the construction of a new plant near a geothermal site. It is assumed that a new plant which is designed to use geothermal energy will be located at a distance approaching zero miles from the source. With this assumption, the ROI's vary from 400 for a 100°C steam source to 93 for a 180°C water source and 40 for a 100°C water source. This assumes that the source and plant are in close proximity to the potato crops (average 25 miles). If this is not the case, increased transportation cost will decrease the ROI. Figure 15 is a plot of the ROI versus the crop transportation distance. Figure 15 shows that ROI values drop rapidly with increased shipping distances. However, shipping distances up to 100 miles can be considered with 100°C steam sources.
ROI Versus Piping Distance
(Potato Flake Production - 100°C Steam Source)

FIGURE 14.
ROI Versus Shipping Distance
(Potato Flake Production)

FIGURE 15.
Conclusions

The economics for conversion of a potato flake process to geothermal energy are more favorable than those found for the conversion of a potato granule process. Although both processes are approximately equal in energy consumption, the flake process allows better use of geothermal energy in the drying process. This is reflected in higher ROI values.

It should be noted that the production well which was considered has a larger capacity than required by flake process. Therefore, the capital expenditure is paying for unused capacity which results in a less favorable ROI value. If the well is used to full capacity the cost per unit of energy is reduced and the ROI becomes more favorable. This possibility is considered in the multiple use section and in the report conclusion which appears later in this thesis.

Frozen French Fries

The production of frozen french fries has increased each year since the inception of the product. In 1970, 905 million pounds of frozen french fries were produced in Idaho\(^\text{43}\). It is estimated that the production of frozen french fries will continue to rise and reach approximately 1.5 billion pounds produced in Idaho by 1990.

The following process information was furnished by Mr. Shah Kazemi of Pride Pak Foods in Richland, Washington\(^\text{44}\). After washing (see Figure 16 for simplified schematic of process), the raw potatoes (50,000 pounds per hour) are placed in a
caustic solution for 25 to 35 seconds. After the skin is loosened by the hot (91°C - 96°C) caustic solution, the potato skin is removed by an abrasive peeler. The skinned potatoes are trimmed to remove defects, sliced and then sent to a pre-heat bath while the nubbins and trimmings are sent to the potato-flour processor. The potatoes are kept in the preheat bath (57 - 66°C) for 6 to 9 minutes to allow the potato core temperature to rise to approximately 27°C. The potatoes are then sent to the blanchers.

The blanching process takes place in a series of steps so that the potato is not heated too rapidly and to allow the stabilization of the sugar content in the potato. The potatoes are kept in Blancher #1 for 4 to 10 minutes (57 - 66°C). They are then placed in Blancher #2 to which no heat is applied in order to equilibrate and cool slightly. In Blancher #3 the potatoes are again heated (54 - 67°C) from 4 to 10 minutes. During the first three blanching steps excess sugar is removed from the potatoes to prevent yellowing of the final product. The potatoes are heated for one minute in Blancher #4 (77°C) during which time sugar and additives are added to produce a uniform product. The potatoes are then sent to the dryer where they are steam dried for 4 minutes (77 - 93°C) using direct steam injection. After the excess moisture is removed from the potatoes in the dryer, the potatoes are sent to the first frier. Cooking oil enters the first frier at 190°C and leaves at 170°C. The potatoes are then sent to the second frier in which the oil enters at 200°C and leaves at 180°C. The potatoes are in the friers
Simplified Schematic of Frozen French Fry Production

42,000 to 50,000 Raw

CAUSTIC
750 lbs/hr

ABRASIVE PEELER

TRIM

POTATO FLOUR
10,000 lbs/hr

PREHEAT

BLANCHER
1 2 3 4

DRYER

Fryer
1 2
15,000 lbs/hr

PRECOOL
195 ton

FREEZING TUNNEL
390 ton

STORAGE
145 ton

PACKAGE

FIGURE 16.
for a total of 25 to 45 seconds. The potatoes are taken from the friers and sent to a precooling unit which takes the potatoes from 90°C to 20°C. This precooling unit is a 195 ton mechanical ammonia system. From the precool unit, the potatoes enter the freezing tunnel where the temperature of the potato is reduced to approximately -20°C. From the freezing tunnel, the potatoes are sent to the packaging room and from there to cold storage. The entire process results in the production of 21,000 pounds of frozen french fries and 12,000 pounds of potato flour per hour.

**Energy Requirements for Frozen French Fries**

All heating steps in this process are carried out with direct steam injection except the frying process in which the oil is heat exchanged with steam. The following table lists the energy required in each process step.

<table>
<thead>
<tr>
<th>Process Step</th>
<th>Energy Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caustic peeling</td>
<td>7,500 #steam/hr</td>
</tr>
<tr>
<td>Potato flour production</td>
<td>10,000</td>
</tr>
<tr>
<td>Preheating, blanching and drying</td>
<td>7,500</td>
</tr>
<tr>
<td>Frying</td>
<td>15,000</td>
</tr>
</tbody>
</table>

The boiler produces 40,000 pounds of 280 psi steam per hour. At the rate of $.15 per therm, this results in an annual fuel cost of approximately $581,000. (See Appendix C.)

Except for the caustic peeling step, the geothermal water cannot contact the potatoes due to the contaminants normally found in the geothermal water. If the preheater and blanchers were jacketed, geothermal water of sufficient temperature could supply the required energy in these steps. No heating breakdown
is available for the preheating, blanching and drying steps. This analysis therefore makes an order of magnitude estimate that 5000 pounds of steam is required per hour for the preheating and blanching steps and that 2500 pounds of steam is used per hour in the drying step.

Approximately 830 tons of refrigeration are required in the frozen french fry process. This refrigeration is furnished by mechanical ammonia systems at an annual energy cost of approximately $53,000 per year (see Appendix C).

Application Of Geothermal Energy

Northwest geothermal sources are not expected to be hot enough to supply energy to the frying process. Since the oil never drops below 170°C, geothermal energy cannot even be used in a preheat step except in the initial warming of the oil. To redesign the potato flour production machine so that geothermal water can be used in place of steam is very difficult. Even if such a design is possible, no cost figures are available for such a device and therefore the application of geothermal energy to this step is not considered in this analysis. Since steam is mandatory in the dryer and comes into direct contact with the potatoes, geothermal water cannot be used in this step.

Assuming that geothermal water is used in the caustic peeler and in a jacketed preheater and blanchers, approximately 12,500 pounds of steam can be saved every hour in this process for an annual fuel savings of approximately $181,000. This assumes a geothermal source in excess of 93°C is available. Assuming that such a source is available and that the water can
furnish 20 BTU's per pound, the caustic peeler and blanchers require $7.5 \times 10^5$ pounds of geothermal water per hour or $3.341 \text{ ft}^3/\text{sec}$ in order to receive the energy equivalent to 12,500 of steam (see Appendix C for calculations).

Geothermal energy can be applied to absorption refrigeration units to provide the refrigeration required in the process. However, the economic analysis in the Fish Production, Section V, will show that such an application is not economically feasible.

**Economic Analysis**

The basic assumptions and considerations in performing an economic analysis have been previously outlined in the potato granule and flake processes. The costs for conversion of a frozen french fry plant to geothermal energy are as follows:

- **Well Cost.** A 7-inch production well costs approximately $50 per linear foot$^{39}$. Assuming that a 3000-foot well is required to obtain geothermal water in excess of 93°C, the cost of the well is $150,000. This is a rough cost estimate and is dependent upon local geology, productivity and temperature at depth.

- **Conversion Cost.** The cost of jacketting the preheater and blanchers is approximately $11,000 each$^{36}$. Since Blancher #2 does no heating and requires no jacket, the conversion cost is $44,000.
Piping Cost. A 6-inch pipe can supply the required amount of water at a velocity of 17 ft/sec (see Appendix C). A 6-inch schedule 40 welded steel pipe costs $25 per linear foot or $132,000 per mile\(^4\). The piping cost depends upon the distance the plant is from the source.

Miscellaneous Conversion Cost. As previously described in the potato granule process, this cost includes the in-plant labor for refitting pipe systems to new equipment, pump cost and unforeseen expenditures. This cost is estimated to be approximately $30,000.

While there is room for a large percentage error in this number, the magnitude of this number as compared with the other costs will render such an error insignificant.

Summary of Conversion Costs. Assuming that the conversion is carried out during a normally scheduled maintenance period so that there is no production loss, the costs of conversion to geothermal energy are as follows:

<table>
<thead>
<tr>
<th>Cost Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological investigation</td>
<td>$50,000</td>
</tr>
<tr>
<td>Well cost</td>
<td>150,000</td>
</tr>
<tr>
<td>Conversion cost</td>
<td>44,000</td>
</tr>
<tr>
<td>Piping cost</td>
<td>132,000/mi</td>
</tr>
<tr>
<td>Miscellaneous conversion cost</td>
<td>30,000</td>
</tr>
</tbody>
</table>

Considering the best possible case in which the piping distance is approximately zero, an expenditure of $274,000 results in a savings of $181,000. This results in an ROI of 46%. If the source is one mile from the processing plant the
expenditure is $406,000 which results in an ROI of 25%. As the piping distance continues to increase, the ROI is reduced accordingly.

Conclusions

The application of geothermal water to the production of frozen french fries on an individual basis is economically marginal. Therefore, a more detailed economic analysis on a case-by-case basis is required to determine the advisability of the investment.

It should be noted that the production well which was considered has a larger capacity than required by the french fry process. Therefore, the capital expenditure is paying for unused capacity which makes the ROI values less favorable. If the well is used to full capacity the cost per unit of energy is reduced and the ROI becomes more favorable. This possibility is considered in the multiple use section and in the report conclusion which appear later in the thesis.
SUGAR BEET PRODUCTION

The primary sources of processed sugar throughout the world are sugar cane and sugar beets. Sugar beets are a major crop in the Pacific Northwest. Figure 17 shows the production data for sugar beets in the Northwest through 1970 and the projected production for 1980 and 1990\(^{(45)}\). It is estimated that the output of sugar beets should more than double in the next two decades, reaching 10.7 million tons by 1990. The majority of this increase should take place in central Washington and in the Idaho counties along the central Snake River\(^{(46)}\). It is estimated that the present processing plants are adequate to handle the increased production\(^{(48)}\). Figure 18 shows the three major processing areas in Idaho and illustrates the estimated geothermal potential of these areas\(^{(47)}\).

Processing

Sugar beet processing is seasonal with the length of the season depending upon the geographic location. The processing season in the Northwest generally begins in early October and continues approximately 130 days. During the processing season the processing plants operate 24 hours a day, seven days a week\(^{(49)}\).

Two basic sugar processes are used in the U.S., either the "Straight Houses" (used by 33 plants) or the "Steffen Houses" (used by 20 plants). Molasses is produced as an end product in the Straight Houses while the molasses is further processed to recover additional sugar in the Steffen Houses procedure.
FIGURE 17

Sugar Beets
Total Harvest; Acreage
Idaho, Oregon and Washington
1959 - 1990

<table>
<thead>
<tr>
<th>Year</th>
<th>Production (tons)</th>
<th>Acreage Harvested</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Idaho</td>
</tr>
<tr>
<td>1959</td>
<td>1,886,000</td>
<td>87,600</td>
</tr>
<tr>
<td>1963</td>
<td>3,212,000</td>
<td>145,600</td>
</tr>
<tr>
<td>1965</td>
<td>2,818,000</td>
<td>156,700</td>
</tr>
<tr>
<td>1969</td>
<td>3,383,000</td>
<td>186,900</td>
</tr>
<tr>
<td>1970</td>
<td>3,087,000</td>
<td>169,600</td>
</tr>
<tr>
<td>1980</td>
<td>4,475,000</td>
<td>223,800</td>
</tr>
<tr>
<td>1990</td>
<td>5,725,000</td>
<td>260,100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oregon</td>
</tr>
<tr>
<td>1959</td>
<td>504,000</td>
<td>19,300</td>
</tr>
<tr>
<td>1963</td>
<td>532,000</td>
<td>19,300</td>
</tr>
<tr>
<td>1965</td>
<td>454,000</td>
<td>18,800</td>
</tr>
<tr>
<td>1969</td>
<td>552,000</td>
<td>23,300</td>
</tr>
<tr>
<td>1970</td>
<td>432,000</td>
<td>20,400</td>
</tr>
<tr>
<td>1980</td>
<td>650,000</td>
<td>26,500</td>
</tr>
<tr>
<td>1990</td>
<td>800,000</td>
<td>30,200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Washington</td>
</tr>
<tr>
<td>1959</td>
<td>763,000</td>
<td>34,100</td>
</tr>
<tr>
<td>1963</td>
<td>1,548,000</td>
<td>59,400</td>
</tr>
<tr>
<td>1965</td>
<td>1,356,000</td>
<td>55,600</td>
</tr>
<tr>
<td>1969</td>
<td>1,628,000</td>
<td>64,600</td>
</tr>
<tr>
<td>1970</td>
<td>1,260,000</td>
<td>63,000</td>
</tr>
<tr>
<td>1980</td>
<td>2,925,000</td>
<td>111,200</td>
</tr>
<tr>
<td>1990</td>
<td>4,200,000</td>
<td>146,200</td>
</tr>
</tbody>
</table>
FIGURE 18. Potato processing in Idaho. Ref. (47)
Since most sugar processing plants were built in the 1920's and 1930's when electricity production was not abundant, the capability of producing needed electric power was built into the plants. All sugar manufacturing plants currently produce high pressure steam in their boilers which is expanded through a reciprocating engine or a turbine to furnish electrical power to their processing operations. The exhaust steam is then used in the sugar refining process as process heat. The resultant condensate is pumped back to the boilers or used in making syrups. This dual utilization of steam results in boiler efficiencies of approximately 85 to 90 percent\(^{(50)}\).

Figure 19 is\(^{(51)}\) a material and energy flow for a typical sugar beet processing plant (Straight House). The energy input is in units of thousands of BTU/ton beets sliced. The manufacturing process may be divided into the following sequences:\(^{(52)}\)

1. The beets are brought into the factory by means of canals filled with warm water which serves to wash and thaw the beets. Approximately 10-16 percent sucrose is present in the raw beet.

2. The beets are washed further, weighed and sliced into long, narrow strips.

3. These strips are dropped into a specially designed continuous countercurrent diffuser or into a connected series diffuser. The water used for extracting the sugar has a temperature of 70°C to 80°C. This step yields a raw juice of 10 to 12 percent sucrose solution and remaining pulp which is dewatered in presses and dried in a rotary dryer. The dried product is sold as cattle feed.

4. The juice is screened and impurities are precipitated. Any calcium saccharate is decomposed in carbonators by passing carbon dioxide from the lime kiln through the juice for 10-15 minutes.
Simplified Schematic of Beet Sugar Production  Ref. (51)

BEETS → FLUMING WASHING → SLICERS → DIFFUSORS

PULP FEED → PELLETIZER → DRIER 120 BTU/ton → PULP SCREENS AND PRESS

JUICE HEATER → SULFONATION → LIME CARBONATION → JUICE HEATER

EVAPORATOR 120 BTU/ton → VACUUM PANS → CRYSTALLIZER MIXER

SUGAR → GRANULATOR → CENTRIFUGE

1730 BTU/ton → MOLASSES

FOSSIL FUEL → BAILER → PROCESS

640 BTU/ton

FIGURE 19.
5. The sludge produced by carbonation is removed by thickening and filtering.

6. Lime is added and the juice again carbonated, this time while hot.

7. Sulfur dioxide is bubbled through the solution in sulfur towers to remove calcium ions. The process also bleaches the juice.

8. Pressure or plate-and-frame filters are used to remove the calcium sulfite precipitate.

9. Multiple-effect evaporators are used to concentrate the purified juice. The calcium ions are concentrated again and must be removed by a repetition of the treatment with sulfur dioxide and filtration.

10. The juice is now crystalized in vacuum pans, centrifuged, washed, dried, screened and then packed.

11. The remaining syrup is used to make molasses by boiling and crystallizing it twice more.

12. The molasses at this point is either sold for animal feed or processed further by the Steffen House method.

13. For the Steffen House method, the molasses is diluted, cooled, and treated with lime to precipitate sugar as a saccharate.

14. The saccharate is returned to the basic system at Step 4 after it is separated by filtration.

15. The Steffen filtrate is normally precipitated to remove calcium carbonate and evaporated.

16. The concentrated filtrate may be either dried as beet pulp or processed further into monosodium glutamate or potash fertilizer.

A review of the energy flow diagram (Figure 19) shows that 2,370,000 BTU's of fossil fuel are required per ton of beets processed. In addition, 116,000 BTU's of coke are required in the liming process per ton of beets processed. The fossil fuel is distributed as 1,750,000 BTU's per ton to the boiler and 640,000 BTU's per ton to the dryer. The steam from the boiler
is sent to a turbine to generate electricity, and the exhaust steam is then used as process heat. Following is a list of the energy requiring steps and the fraction of energy consumption each step required:

<table>
<thead>
<tr>
<th>Beets Sliced</th>
<th>Electricity</th>
<th>Dryer</th>
<th>Slicer</th>
<th>Diffusor</th>
<th>Juice Heater</th>
<th>Evaporators</th>
<th>Liming Process</th>
<th>Boiler Efficiency Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTU's/ton of beets sliced</td>
<td>83</td>
<td>640</td>
<td>25</td>
<td>72</td>
<td>120</td>
<td>1200</td>
<td>116</td>
<td>230</td>
</tr>
<tr>
<td>Fraction of Total Energy</td>
<td>0.033</td>
<td>0.257</td>
<td>0.010</td>
<td>0.029</td>
<td>0.048</td>
<td>0.483</td>
<td>0.047</td>
<td>0.093</td>
</tr>
</tbody>
</table>

Approximately 10 percent of the steam is lost in the process. The rest of the condensate is recycled to the boiler.

**Geothermal Energy Application**

Since 90 percent of the process steam is recycled to the boiler, this process can be considered to have an initial energy input of water at 100°C. Therefore, there is no need to consider the application of geothermal water at a temperature less than 100°C since its contribution would be trivial. Neither is there any need to consider the direct application of geothermal energy to the processing steps while eliminating the boiler system. Even though the boiler would no longer be needed to generate steam for the processing system, it would still be needed to generate electricity for the plant.
The application of geothermal steam in excess of 100°C is economically possible. Seventy-two percent of the energy which goes into steam production in the sugar beet process could be saved if the input to the boiler were geothermal steam in excess of 100°C. This would result in a savings of almost 6.5 million therms per year, approximately $1 million at $.15/therm, for a plant which processes 4,000 tons of beets per day for 130 days per year. The savings constitutes approximately 50 percent of the total energy costs for the beet sugar process. As stated before, it is very unlikely that a geothermal steam source is available in Idaho.

The possible energy savings obtained from geothermal water will not be considered since the following section indicates the economics of conversion are not favorable even for a geothermal steam source.

Economics of Conversion

The cost of converting a sugar beet processing plant to geothermal energy depends upon the quality of the geothermal source. If the geothermal steam were pure enough to use in the processing steps in which the steam would come in contact with the sugar, the cost of conversion would be substantially reduced as compared to a system in which the geothermal steam must be heat exchanged with clean water. Even though it is very unlikely that such a geothermal source would be available, both possibilities are considered in the economic evaluation of conversion.
Conversion Cost. Assuming that the geothermal steam is pure enough to use directly in the process, the conversion cost is essentially zero. The only in-plant conversion would be the connection of the geothermal pipe line to the boiler.

If contaminants in the steam prevented its use directly in the process, it would be necessary to heat exchange the geothermal steam with clean water. A conservative estimate of the size of the heat exchanger required is 14,500 sq. ft. (See Appendix D for calculations). Assuming the exchanger is constructed of a nickel alloy at $30 per square foot, the cost of the exchanger is $435,000 (53). The cost of the exchanger installed is approximately $1 million. This estimate does not take a fouling factor into account since scaling would depend upon the source. However, if scaling proved to be a problem (as it has in the past), the estimated cost would have to be increased.

Geological Exploration. The initial well cost is allocated to exploration. Currently, the cost must be considered the minimum investment in considering conversion to geothermal energy.

Well Cost. Currently, a 7-inch diameter well can be drilled to 6,000 ft for approximately $50/ft (39). Therefore, $150,000 is required to drill the 3,000-foot well which would probably be required to find geothermal water around 121°C. This cost is subject to large variations due to local geology and flow capacity requirements.
Piping Cost. A beet sugar plant which processes 170 tons of beets per hour requires approximately 250,000 pounds of geothermal water per hour (see Appendix D). This quantity of water can be transported in a 4-inch pipe at a velocity of 12.8 ft/sec and will lose approximately 2 BTU's/lb of water/mile. The cost of schedule 40 welded steel pipe is $14.15/linear ft., or approximately $75,000/mile\(^{(40)}\). The total piping costs will depend upon the distance which the fluid must be pumped.

Summary of Conversion Cost. A summary of conversion costs is as follows:

<table>
<thead>
<tr>
<th>Costs</th>
<th>Without Heat Exchanger</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological Investigation</td>
<td>$50,000</td>
<td></td>
</tr>
<tr>
<td>Well Cost</td>
<td>150,000</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous Conversion Cost</td>
<td>30,000</td>
<td></td>
</tr>
<tr>
<td>Piping Cost</td>
<td>75,000/mile</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>$230,000 + pipe</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Costs</th>
<th>With Heat Exchanger</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conversion Cost</td>
<td>$1,000,000</td>
<td></td>
</tr>
<tr>
<td>Geological Investigation</td>
<td>50,000</td>
<td></td>
</tr>
<tr>
<td>Well Cost</td>
<td>150,000</td>
<td></td>
</tr>
<tr>
<td>Miscellaneous Conversion Cost</td>
<td>35,000</td>
<td></td>
</tr>
<tr>
<td>Piping Cost</td>
<td>75,000/mile</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>$1,235,000 + pipe</td>
<td></td>
</tr>
</tbody>
</table>

Figure 20 is a plot of ROI versus piping distance for both cases. The calculations are based upon a savings of $1 million/year. For the first case (no heat exchanger), the ROI varies
ROI Versus Piping Distance
(Beet Sugar Production - 120°C Source)

No Heat Exchanger

With Heat Exchanger

FIGURE 20.
from 431 at 0 miles to 80 at 10 miles. For the second case, the ROI varies from 58 at 0 miles to 40 at 5 miles.

The above calculations do not consider the trivial energy loss that occurs in piping the water. There is no need to consider the possibility of locating a new plant near a geothermal site since no significant expansion of this industry in the way of new plants is likely in the next 15 years. As in previous cases, the cost of water disposal is not considered since it is assumed that present disposal methods are adequate.

Conclusions

Calculations indicate that application of geothermal energy to beet sugar processing is economically favorable if the geothermal source is steam which is pure enough to use directly in the process. ROI values vary from 431% at 0 miles, which is very good economically, to 80% at 10 miles, which is still economically favorable. However, the probability of finding steam pure enough to use without heat exchange is almost zero. Therefore, the ROI would most likely vary from 58 at 0 miles to 40 at 5 miles due to the need for a heat exchanger, and the application of geothermal energy to the sugar beet process under this condition would be economically marginal.
Approximately 90 percent of the production of the malt beverage industry consists of lager beer\(^{(67)}\). Other products include malt liquors, draught beer, ale, porter and stout beer. The production of the malt beverage industry in 1973 was over 148 million barrels or \(4.6 \times 10^9\) gallons of product.

The following description of the brewing process was furnished by H. Gerards of the Blitz-Weinhard brewery of Portland, Oregon\(^{(68)}\). The initial step in the process consists of cooking the barley and cereal in order to extract the starches (see Figure 21). The cooking is carried out by direct steam injection and consumes approximately 2,000 pounds of steam per hour in the masher and 1,100 pounds of steam per hour in the cooker. When the cereal cooking is completed, the contents of the cooker is added to the masher, and the resulting mixture is cooked together. When the cooking is completed in the masher, the contents is pumped to a lauter tub which filters the mixture and passes the liquid to a holding kettle. The spent barley and cereal are removed from the lauter tub and sold as animal food. Although Blitz-Weinhard does not dry this material, many breweries do. This drying constitutes approximately 24 percent of the entire process energy demand.

The holding kettle is a jacketed vessel. Steam is injected into the jacket to heat the liquid so that it approaches the boiling point. After this preheating step is completed, the liquid is pumped to the brew kettle which is also jacketed, and
Simplified Schematic of Malt Beverage Production

MALTED BARLEY

MASHER
200 # S/hr

LAUTER TUB

HOLDING KETTLE

BREW KETTLE

HOT WORT RECEIVER

HEAT EXCHANGER
H₂O: 35-170°F
WÖRS: 210-53°F

CEREAL GRITS

COOKER
1100 # S/hr

PACKAGE
11,000 #S/hr

FINAL FILTER

AGE 21 DAYS

PRIMARY FILTER

FERMENTING CELLAR
7 DAYS

FIGURE 21.
the liquid is brought to boil. The liquid is boiled to achieve the "hot wort break" which is a term denoting the coagulation of small solids contained in the liquid. A total of 10,400 pounds of steam per hour is required in the holding and brew kettles. The condensate from this step is recycled back to the boiler. After achieving the "hot wort break," the liquid is pumped to the hot wort receiver where the coagulated solids are swirl-separated. The hot liquid is then pumped through a heat exchanger and is reduced in temperature from 100°C to 12°C. The hot liquid is exchanged with water which is heated from 2°C to 77°C in the exchanger.

The cool wort is pumped to the fermenting cellars where it is kept for days at approximately 12°C while it undergoes alpha and beta fermentation. The fermenting tanks are in a cooler which helps maintain the temperature at 12°C. This cooling is supplemented with a circulating glycol system which is activated when the fermenting temperature exceeds 12°C. At the end of this time, the liquid is pumped through a primary filter to remove the yeast, which is sold as animal food, and then pumped to the aging tanks. After aging for 21 days, the liquid is pumped through a final filter and bottled. Approximately 11,000 pounds of steam per hour is used in the bottling process. Of this amount, approximately one-half is used for cleaning the bottles and barrels, and one-half is used for pasteurizing the beer.

The production of beer is a batch process and approximately 480 barrels of beer are produced per brew. Blitz-Weinhard pro-
duces one million barrels of beer per year. Since the processing steps for all breweries are very similar, the energy requirements for larger or smaller breweries can be estimated.

**Energy Requirements**

The energy requiring steps in the brewing process are as follows:

<table>
<thead>
<tr>
<th>Step</th>
<th>Lbs. steam/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masher</td>
<td>2,000</td>
</tr>
<tr>
<td>Cooker</td>
<td>1,100</td>
</tr>
<tr>
<td>Holding Kettle</td>
<td>10,400</td>
</tr>
<tr>
<td>Brew Kettle</td>
<td>11,000</td>
</tr>
<tr>
<td>Packaging</td>
<td>11,000</td>
</tr>
<tr>
<td>Clean-up and Misc.</td>
<td>2,500</td>
</tr>
</tbody>
</table>

The boiler produces a total of 27,000 pounds of steam (125 psi) per hour. The boiler feed gas fill in 1975 was $325,000 which corresponds to approximately 2.2 million therms per year (see Appendix H for calculations).

The brewing process also requires a large amount of refrigeration. The refrigeration requirements are as follows:

<table>
<thead>
<tr>
<th>Refrigeration</th>
<th>Tons (12000 Btu/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling water</td>
<td>150</td>
</tr>
<tr>
<td>Glycol</td>
<td>50</td>
</tr>
<tr>
<td>Cellar</td>
<td>400</td>
</tr>
<tr>
<td>Cooler</td>
<td>200</td>
</tr>
<tr>
<td>CO₂ Condenser</td>
<td>20</td>
</tr>
</tbody>
</table>

All refrigeration is furnished by a mechanical refrigeration system. The total electrical energy cost in 1975 was $112,000 of which approximately $57,000 was for refrigeration (calculated on the basis of $0.0107/Kwhr). (Appendix H)
Economic Assessment of Geothermal Energy Application

Geothermal energy applied to absorption refrigeration units could be used to furnish the refrigeration required in the brewing process. However, the economics previously discussed in the section "Fish Production" shows that such an application is not economically feasible. Neither is there enough recoverable waste heat in the brewing process to run such units.

The obvious place to apply geothermal energy is in the holding and brewing kettles. These vessels are jacketed, and the conversion cost would be minimal. Geothermal energy cannot be applied directly to the masher, cooker or packaging steps due to the contaminants normally found in the geothermal water. If the cooker and masher were jacketed, the geothermal energy process could be applied to these steps too. The costs of jacketing these vessels are not available. However, calculations in Appendix H show that the conversion cost would have to be less than $62,000 in order to obtain an acceptable ROI for the energy savings of these two vessels. While figures are not available, the size of these vessels make achievement of such a conversion cost unlikely.

The application of geothermal energy to the holding and brewing kettles results in an energy savings of 38.9 percent (see Appendix H) which amounts to $126,000. In order to achieve an ROI of .4, the minimum acceptable value in this study, the maximum investment possible to obtain a geothermal source is $210,000. The following costs are encountered in obtaining a geothermal source.
Geological Investigation. Currently, the cost of geological investigation is approximately $50,000\(^{(30)}\).

Well Cost. A 7-inch production well costs approximately $50/foot\(^{(39)}\). Assuming that a 3,000 foot well is required to find 121°C water, the cost of the well is $150,000. This cost is subject to large variations due to local geology.

Conversion Cost. Since the kettles are jacketed, the conversion costs are approximately zero.

Piping Cost. In order to supply the energy required by the holding and brewing kettles, approximately 2.7 ft\(^{3}\) of geothermal water (121°C) must be supplied per second (see Appendix H for calculations). A 6-inch pipe can supply this volume of water at a velocity of 14 ft/sec. Six-inch, schedule 40 welded steel pipe costs approximately $25/linear foot or $132,000 per mile\(^{(40)}\). The cost of the pipe depends upon the distance the brewery is from the source.

Miscellaneous Conversion Cost. This cost includes the fitting of pipes inside the brewery, pump cost and unforeseen expenditures. The amount is estimated to be $30,000.

In summary, the costs of the geothermal source are as follows:

<table>
<thead>
<tr>
<th>Cost</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological investigation</td>
<td>$ 50,000</td>
</tr>
<tr>
<td>Well cost</td>
<td>150,000</td>
</tr>
<tr>
<td>Conversion cost</td>
<td>---</td>
</tr>
<tr>
<td>Piping cost</td>
<td>132,000/mile</td>
</tr>
<tr>
<td>Miscellaneous conversion cost</td>
<td>30,000</td>
</tr>
</tbody>
</table>
Assuming the best possible case in which the piping distance is zero, the cost of the geothermal energy is $230,000. The maximum investment allowed in order to achieve an ROI of 40% is $210,000. (Appendix H)

Conclusions

The application of geothermal energy to the brewing process on an individual basis is economically marginal. Therefore, a more detailed economic analysis on a case-by-case basis is required in order to determine the advisability of investing in geothermal energy.

It should be noted that the production well which was considered has a larger capacity than required by the brewing process. Therefore, the capital expenditure is paying for unused capacity which makes the ROI values less favorable. If the well is used to full capacity the cost per unit of energy is reduced and the ROI becomes more favorable. This possibility is considered in the multiple use section and in the report conclusion which appears later in the thesis.
GEOTHERMAL APPLICATIONS FOR SPACE HEATING

The utilization of geothermal energy for space heating could prove to be the single largest application of this energy source. Residential and commercial space heating accounted for approximately 18 percent of the U.S. fuel consumption in 1968 (approximately $10,857 \times 10^{12}$ BTU's)$^{(54)}$. Assuming that geothermal sources are located near the areas of high energy usage, the bulk of this energy requirement could be supplied by geothermal energy.

As mentioned previously, large scale use of geothermal energy for space heating began in Iceland around 1928. Through the years this use of geothermal energy expanded from heating a handful of homes in a pilot project to providing heat for 99 percent of Reykjavik's population (88,000)$^{(55)}$. Currently, seven countries are reported to be using geothermal hot water for space heating. This application amounts to approximately 400 megawatts of thermal energy or, in heating energy, to three million barrels of oil per year. Table 3$^{(56)}$ lists the countries presently using geothermal water for space heating and gives an estimate of the average annual thermal power usage.

The advantages of geothermal application to space heating have been discussed in the introduction of this report. The main disadvantage for the application of geothermal energy to space heating is the initial investment. The major installation cost is for drilling and casing the well. In Klamath Falls,
<table>
<thead>
<tr>
<th>Country</th>
<th>Number of Locations and Estimated Usage</th>
<th>Estimated Average Annual Thermal Power Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iceland</td>
<td>12 (101,000 people)</td>
<td>250 MW</td>
</tr>
<tr>
<td>USSR</td>
<td>8 (40,000 people)</td>
<td>100</td>
</tr>
<tr>
<td>Japan</td>
<td>4 (20,000 people)</td>
<td>10</td>
</tr>
<tr>
<td>Hungary</td>
<td>3 (3,000 people)</td>
<td>10</td>
</tr>
<tr>
<td>USA</td>
<td>4 (3,000 people)</td>
<td>10</td>
</tr>
<tr>
<td>New Zealand</td>
<td>3 (3,000 people)</td>
<td>20</td>
</tr>
<tr>
<td>France</td>
<td>1 (10,000 people)</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>35 (180,000 people)</td>
<td>404 MW</td>
</tr>
</tbody>
</table>

The average usage is based on a utilization factor that varies from 10 percent to 53 percent (New Zealand and Iceland) (Howard, 1975; Pearson, et al., 1975).
Oregon, this cost will run from $3,000 to $10,000 depending upon the depth\(^{(55)}\). The annual operation cost for pumps, repair, etc., is nearly $50/year. While the high initial cost has deterred some homeowners from converting to geothermal energy, others have joined together to share the cost of the well and, therefore, have lowered individual installation costs.

The economics of conversion cannot be generalized because it depends upon, among other things, geographic location of the site to be heated, the distance from the well to the site, the temperature of the water, and the insulation at the site. However, a representative example of institutional use of geothermal energy for space heating can be found in Klamath Falls, Oregon, where the campus of the Oregon Institute of Technology is heated by direct use of geothermal hot water\(^{(57)}\). This water is provided by three hot water wells which have been drilled adjacent to the campus. Their depths vary from 400 to 600 meters and can be individually pumped up to 1700 l/m (450 gal/min) at 89°C. This provides ample heat for eight buildings which contain approximately 500,000 square feet of floor space. If the temperature outside drops below 20°C, two wells are required pumping up to 28000 l/m (750 gal/min). Deep hole centrifugal pumps are used to pump the water which is in most cases used directly in the heating systems (consisting of both hot water radiators and forced air systems). A map of the campus heating system is given in Figure 22\(^{(58)}\). The annual operating cost for the system is $12,500, and the capital recovery on the present cost for the system is $12,500, amounting to a total of
FIGURE 22. O.I.T. Geothermal heating system. Ref. (58)
$25,000 or 5¢/ft$^2$. Under a conventional fuel system the estimated annual heating cost would be over $250,000 or 50¢/ft$^2$.

In summary, the potential for application of geothermal energy for space heating purposes is very good. This is especially true in areas with KGRA designation since costly exploration can generally be avoided. The economics of conversion differ with each different situation but the development of community heating districts would probably be a favorable economic investment.
Fish production is a rapidly expanding industry across the country. Catfish and trout are the major species of fish grown commercially in the U.S. Of the 16 million pounds of trout raised annually in the U.S., approximately 95 percent of this amount is raised in the vicinity of Buhl, Idaho (59).

The method of raising these fish is straightforward. After the eggs are milked from the fish, they are placed in hatching containers until hatching occurs. The fish are then placed in large tanks and fed until they reach an appropriate size. They are then killed, cleaned and sold as fresh or frozen fish. Approximately 95 percent of the fish processed are frozen (60).

The energy requirements for freezing the fish constitute one of the major energy costs in this process. However, refrigeration costs are well below the costs of food and labor in this industry.

**Energy Requirements for Fish Production**

Refrigeration constitutes the largest energy requirement in this industry for which geothermal energy is applicable (60). Thousand Springs Fish Farms produce 15,000 to 17,000 pounds of trout per day (60). This production requires 125 tons of refrigeration which, at current rates, costs approximately $9,000 per year (see Appendix F). Other energy expenditures are for pumping and transportation. These are not applicable for geothermal energy.
Economic Analysis

The costs for converting from an ammonia compression system to an ammonia absorption system are as follows:

**Conversion Cost.** Lewis Refrigeration estimates that an ammonia absorption refrigeration system costs approximately $4,000 to $5,000 per ton for a 100T system and $1,000 to $1,500 per ton for a 500 T or greater system\(^{(61)}\). Therefore, the cost of a 125T system is $500,000 using the lower figure.

**Geological Exploration.** Currently, the cost for a geological investigation to locate geothermal water is approximately $50,000\(^{(30)}\).

**Well Cost.** A 5,000 foot well is generally required to obtain a 150°C source\(^{(39)}\). The 7-inch diameter well costs approximately $50 per linear foot which results in a cost of $250,000 for the required 5,000 foot well.

**Piping Cost.** A single stage Lewis RWH Aqua Ammonia Absorption System (0°F) requires 430 BTU/min/tr\(^{(61)}\). This is usually furnished by steam at 53.2 psia (140°C). However, since water-dominated systems are being considered, it is assumed that a 150°C source will be dropped 20 degrees to furnish the required energy. At this rate, 45 pounds of 150°C water is required per second (see Appendix F for calculations). This quantity of water can be delivered in a 4-inch schedule 40 welded steel pipe at a velocity of approximately 9 feet/second. This pipe costs approximately $14.15 per linear foot, or approximately $75,000 per mile\(^{(40)}\).
Miscellaneous Conversion Cost. This cost includes the fitting of pipes to the refrigeration system, pump cost, and unforeseen expenditures. It is estimated to be $30,000.

Summary of Conversion Costs. From the above data the costs of conversion to geothermal energy are as follows:

- Geological Investigation: $50,000
- Well Cost: $250,000
- Conversion Cost: $500,000
- Miscellaneous Conversion Cost: $30,000
- Piping Cost: $75,000/mile

Assuming the best possible case in which the geothermal site is located at the plant site, the total cost of conversion for a 125T plant is $830,000. For an energy savings of $9,000, the ROI would be -.19.

The above calculations indicate that absorption refrigeration is not economically feasible for the fish production industry. Furthermore, calculations indicate that the ROI does not increase appreciably as the size of the refrigeration unit increases. For example, in order to save 1 million dollars in energy costs, it would be necessary to have a refrigeration unit in the order of 14,000 tons. Assuming the unit costs $1,000/ton, the conversion cost would be approximately $14 million, and would result in an ROI of -.13. Even if the cost of the unit were $250/ton, the ROI would only be .06.

It is apparent that the conversion of present refrigeration equipment to an absorption system is not economically feasible. However, the economics of building a new refrigeration-
tion plant should be considered. The following table compares the cost of a 500T refrigeration unit for both compression and absorption systems.

<table>
<thead>
<tr>
<th></th>
<th>Absorption</th>
<th>Compression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological investigation,</td>
<td>$330,000</td>
<td>---</td>
</tr>
<tr>
<td>well, pump, labor, and</td>
<td>$330,000</td>
<td>---</td>
</tr>
<tr>
<td>miscellaneous costs</td>
<td>$330,000</td>
<td>---</td>
</tr>
<tr>
<td>Equipment cost</td>
<td>500,000</td>
<td>$500,000*</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$830,000</td>
<td>$500,000</td>
</tr>
</tbody>
</table>

*Mechanical ammonia systems cost approximately $1,000/ton for 500T or greater systems. (61)

Considering that the operating cost for the absorption system is zero (which it is not) and the energy cost for the compression system is $45,000 per year, the compression plant could operate 7.3 years before the sum of its equipment and energy cost equals the initial cost of the absorption plant. (See Appendix F).

The above calculations indicate that geothermal energy cannot currently be used economically for refrigeration. The question arises as to whether the economics of this situation will change in the future. Calculations in Appendix F show that energy cost per unit of energy for an absorption refrigeration system must be one-fifth to one-sixth that of the energy cost per unit of energy for a mechanical energy system in order to achieve the same operating cost per ton of refrigeration. This is not presently the case. However, the situation could change in the future as conventional energy rates rise and as technological advances reduce the cost of geothermal energy.
At the present time the costs of mechanical and absorption refrigeration equipment are approximately equal for large systems (500 tons and larger)\(^{(61)}\). Therefore, the only difference in the construction cost of an absorption system versus a mechanical system is the cost of locating and obtaining the geothermal source. For this reason, the geothermal energy must be available at a cost somewhat less than one-fifth that of conventional energy in order to pay off the geothermal source cost.

**Waste Utilization.** It should be kept in mind that the above information is concerned with the application of geothermal energy as an energy source for an absorption refrigeration system. The economics of an absorption refrigeration system could be quite favorable for an industry which has a large quantity of waste heat available in its processes and also has a large cooling requirement. The economics of this situation are quite complex and must be considered separately.

**Conclusions**

Currently, the application of geothermal energy for absorption refrigeration is not economically feasible. The economics of converting an existing refrigeration system to a geothermal absorption system are very unfavorable yielding negative ROI's. While it is not presently economical to build a new refrigerating system using absorption refrigeration with geothermal energy, this could change in the future. When the cost of a unit of geothermal energy is less than one-fifth that of conven-
tional energy, the economics of this possibility should be reviewed. Industries which possess large quantities of waste heat and which also have a large cooling demand should consider the economics of an absorption refrigeration system.
MEAT PACKING

Meat packing plants are primarily engaged in slaughtering cattle, hogs, sheep, lambs, horses and other animals for meat and for the purpose of selling these meats or using them in canning, curing, and the production of sausage, lard and other such meat products. A meat packing plant can be divided into the slaughtering and the processing function. This section deals with the slaughtering process only. Some aspects of the processing function are covered in the "Animal Fats and Oils" section.

In 1973, approximately 51 billion pounds of beef and hogs were slaughtered in the 2,000 meat packing plants throughout the United States\(^{(62)}\). Although no figures are available for the production in Idaho, a rough approximation can be made. There are 40 meat packing plants listed in the 1973 Idaho Manufacturing Directory\(^{(63)}\). Assuming that these plants processed the national average per plant, the Idaho production was approximately one billion pounds of meat. This estimate is probably high due to the relatively small population density in the Northwest. However, the magnitude of the number indicates that meat production is quite considerable even if Idaho produces only one percent of the calculated amount.

Slaughtering Process

The following process and energy data were furnished by A. R. Burattdof, Idaho Meat Packers, Inc., in Caldwell, Idaho\(^{(64)}\).
The slaughtering process begins with the immobilization of the animal by chemical, mechanical or electrical means. The animal is then hoisted to a vertical position to be bled. Following the bleeding, cattle hides are removed by mechanical means. The carcass is then opened by hand knives and the animal is eviscerated. The heart, liver, tongue, head meat, brains and kidneys are removed and washed. The carcass is then halved and cooled. After inspection, the carcass may be shipped out by the half or be broken down into smaller sections and then shipped out. The edible organs are sold for food or used in meat products. The intestines are used in edible products or rendered along into the viscera. The blood is either discarded or dried and used as animal feed.

**Energy Requirements for Slaughtering Process**

The energy requirements for the rendering of viscera and the drying of blood are considered in the section of animal fats and oils. Therefore, the major expenditure of energy is for refrigeration. Idaho Meat Packers, Inc., slaughter approximately 225 head of cattle per day on the average. The process requires 200 tons of refrigeration which is distributed throughout the process. The refrigeration is supplied by a mechanical ammonia system.

**Economic Analysis of Geothermal Application**

The economics of absorption refrigeration using geothermal energy are covered in the section on fish production. The conclusions are that absorption refrigeration using geothermal
energy is not an economically feasible alternative at this time. See "Fish Production" for details.
Rendering is a process which converts animal by-products obtained from the slaughtering process into fats, oils and proteinaceous solids. Heat is applied to the by-products to melt the fats out of tissue, to coagulate cell proteins and to evaporate the material moisture. Approximately 9.7 billion pounds of raw by-products were rendered in the U.S. in 1973\(^{65}\). No figures have been located for Idaho production.

The process begins by grinding the by-products prior to cooking (see Figure 23). The material is cooked for approximately two hours and then discharged from the cooker into a percolation pan where it stands until all free draining fat has run off. The solids are then pressed to remove adhering fat. The solids are ground, screened and sold as animal feed. Blood is dried and added to the solids which are used as animal feed. The fat goes through a clarification and refining step and is sold as grease and tallow.

**Energy Requirements**

The following information was supplied by Idaho Meat Packers, Inc., of Caldwell, Idaho\(^{64}\). Approximately 225 head of cattle are slaughtered per day at the Caldwell plant. Processing the by-products from the slaughtering operation requires approximately 300 boiler horsepower or 10 million BTU's per house. Assuming an eight hour operation per day, this results in an energy consumption of \(2.9 \times 10^{10}\) BTU's per year.
Simplified Schematic for Rendering Process

RAW MATERIAL → CRUSHING AND GRINDING → COOKING AND EVAPORATION

REFINING → CLARIFICATION → SCREEN AND PRESS

GREASE AND TALLOW

MEAL GRINDING

BLENDING

STORAGE AND PACKAGING

ANIMAL MEAL

FIGURE 23.
Considering that gas costs 15 cents per therm, this energy cost is approximately $44,000 per year. (See Appendix G for calculations).

Conclusions

The above calculations indicate that if all heat requiring processes are furnished by a geothermal source, the total dollar savings is only $44,000 per year. Previous economic analysis indicates that the cost to develop a geothermal source is considerably greater than the possible savings and results in an unfavorable ROI. However, as pointed out previously, the geothermal source which is considered has a much larger capacity than is required by this industry. If the source was used to full capacity, the cost per unit of energy is reduced and the ROI values become more favorable. This possibility is considered in the multiple use section and in the report conclusion which appears later in the thesis.
The following information is supplied by the Frontier Leather Company of Sherwood, Oregon. The tanning process begins by soaking the hide (usually dried) in water for one or two days to cool and swell the hide. The excess flesh is removed from the hide and sold to the animal oil and fat market. The hide is then placed in a lime vat for one day to remove the hair. Following this process, the hide is placed in a tanning vat for eight hours. After tanning is complete, the hide is wrung out, split, colored and dried. The hides are dried for 16 hours in a room maintained at 43.3°C. At the end of the drying process, the hide contains 15 percent moisture. This completes the tanning process, and the hides are finished in various ways.

Energy Requirements

A breakdown of energy consumption was not available for this process. The major energy consumption in the tanning process results from the drying of the hides. Some energy is expended in maintaining the processing vats at the correct temperature, but this consumption is small in comparison to the drying process. The Frontier Leather Company processes approximately 400 hides per day and has a gas bill of approximately $2,000 per month.

Conclusions

Due to the low temperature requirements of the tanning process, geothermal energy should be able to supply a large
percentage of the energy demand. However, if 100 percent of
the present gas demand is supplied, the cost savings is only
$24,000 per year which is not sufficiently large to warrant
the expenditure required to develop the geothermal source.

Therefore, this system must be part of a multiple use
system in order to reduce the geothermal development cost and
improve the economics of geothermal energy application.
GEOTHERMAL WATER FLASHING

The introduction stated that this report would consider only liquid-dominated hydrothermal systems since vapor-dominated systems were not numerous and had not been found in Idaho. However, energy savings estimates in the potato and sugar beet processes considered the contribution which could be made by a 100°C steam source. Figures of the percent energy savings versus source temperature showed a dramatic increase in percent of energy saved when a 1000°C steam source was available as compared to a 212°C water source. The energy savings for the potato granule process increased from approximately 20 to 45 percent and the savings for the granule process increased from 43 percent to over 90 percent. It was shown in the sugar beet processing section that geothermal application should not even be considered unless geothermal steam was available.

Since vapor-dominated hydrothermal systems have not yet been found in Idaho, it might appear that considering energy savings from a steam source is merely academic. However, 100°C steam is available from liquid-dominated hydrothermal systems through a flashing process. Flashing is a process in which the pressure exerted on superheated water (temperature in excess of 100°C at 760mm Hg) is reduced. The reduction in pressure causes the water to flash and produce steam. Using this process, it is possible to convert water to a mixture of water and steam.

Flashing results in a fraction of the superheated water being converted to steam. The fraction of the water that goes
to steam depends upon the initial temperature of the superheated water and the final pressure that is exerted on the steam-water mixture. The following indicates the friction of water at various temperatures that becomes steam at 212°F. (See Appendix E.).

<table>
<thead>
<tr>
<th>Initial Temperature</th>
<th>Percent of Water to Steam (100°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>120°C</td>
<td>3.8</td>
</tr>
<tr>
<td>150°C</td>
<td>9.2</td>
</tr>
<tr>
<td>180°C</td>
<td>14.5</td>
</tr>
<tr>
<td>200°C</td>
<td>20.0</td>
</tr>
</tbody>
</table>

The figures show that in order to obtain a given quantity of 100°C steam, a much larger quantity of geothermal water is required. For example, over 20 pounds of 150°C water are required to produce one pound of 100°C steam.

The availability of steam in the previously studied processes results in much larger energy savings. However, larger equipment is required to handle the increased quantity of water and a throttling valve and separation tank is required for the flashing process. Therefore the ROI's indicated in the previous sections for 212°F steam will be much lower for hot water sources.

Calculations on the potato flake process (Appendix B) indicated that 100°C steam could supply 96.6 percent of the natural gas energy requirements for a savings of $1,243,000 per year. The conversion costs totalled 296,000 plus pipe cost and this resulted in an ROI at zero miles of 400. The ROI decreased as the distance from the source of the processing plant increased due to the pipe cost which was $75,000 per mile.
The flake process requires 2 million pounds of steam per day. The previous study assumed that 2 million pounds of geothermal water was pumped to the boiler in the plant and then the enthalpy was increased to the required level. If a flashing technique is used instead, 40 million pounds of 300°C water is required per day. This is equivalent to 694 pounds of water per second or 11.13 cubic feet per second. (See Appendix E). The previous study assumed a 7-inch production well. However, a 7-inch well is not capable of delivering 11.13 cubic feet of water per second and therefore the diameter must be increased to 13-3/8 inches. The cost of 13-3/8 inch production well is 225,000\(^{(39)}\).

The conversion cost for the plant is the same as in the previous study since it is still necessary to separate the geothermal steam from the potatoes. However, a throttling valve and separation tank must be added to control the flashing process. The cost of this equipment is not available. This analysis will assume the cost of this equipment is $100,000. There is probably a large error in this figure. However, this error will only have a great effect on the zero mile ROI since it will be shown that the magnitude of the pipe cost will dampen this error as the source to plant distance increases.

A 4-inch diameter pipe was used in the previous study to transport the water from the well to the plant. However, a 4-inch pipe is not adequate to deliver 11.13 cubic feet per second of water. A twelve-inch diameter pipe can deliver the required quantity at a velocity of 14 feet per second. A
12-inch diameter schedule 40 welded steel pipe costs $75(40) per linear foot or $396,000 per mile. The size of this cost will tend to decrease the significance of the error on the ROI due to the estimated flashing equipment cost.

The summary of the conversion cost for a geothermal flash system is as follows:

<table>
<thead>
<tr>
<th>Cost Code</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well cost</td>
<td>$225,000</td>
</tr>
<tr>
<td>Conversion cost</td>
<td>166,000</td>
</tr>
<tr>
<td>Geological exploration</td>
<td>50,000</td>
</tr>
<tr>
<td>Piping cost</td>
<td>396,000/mile</td>
</tr>
<tr>
<td>Miscellaneous Conversion cost</td>
<td>30,000</td>
</tr>
</tbody>
</table>

The cost of conversion is $471,000 plus piping cost. This expenditure results in an energy savings of $1,243,000 per year for an ROI of 244 at zero miles piping distance. Figure 24 is a plot of ROI versus piping distance for the flake process.

Figure 24 shows that the ROI drops quickly from 244 to 40 in a distance of 4 miles. A comparison of this figure with Figure 13 shows that there is a significant difference between the economics of a geothermal flash system and a vapor-dominated system even though both systems produce 100°C steam. The ROI for the vapor-dominated system ranges from 400 at zero miles to 90 at 10 miles piping distance. A comparison of the ROI figures for the flash system and the 121°C water system in the flake section shows that there is a small advantage in the flash process if the shipping distance is short, but that the high cost of pipe in the flash system quickly reverses this
ROI Versus Piping Distance
(Flashing Process)

FIGURE 24.
situation so that the water system has a higher ROI for longer distances. Similar results can be expected in the potato granule process.

This study assumes a 150°C source is being flashed. The economics of this flashing process will change as the temperature of the source varies. If the geothermal source is 180°C or 200°C the economics of the flash system becomes more favorable because less water is required to produce the steam, the equipment cost to handle the water is less and the ROI values are higher.

Due to the large number of possible combinations of source temperatures and processes to which the flash process may be applied, a detailed economic analysis will not be given for each case. However, this study shows that the flash process can be an economical alternative to conventional energy in some cases. The economics of the flash process depends upon many variables and therefore, each case must be studied individually.
Vegetable processing, which includes the canning and freezing of vegetables, amounted to 334 million pounds of processed vegetables in Idaho in 1970\(^{69}\). The quantities of vegetables processed are projected to increase and reach approximately 615 million pounds in Idaho by 1990. Approximately three-fourths of the Pacific Northwest's vegetable crop is currently being processed. Virtually all of the snap beans, green peas and sweet corn are being processed. The Pacific Northwest produces approximately two-thirds of the national output of frozen peas, about 60 percent of the frozen sweet corn and half of the frozen snap beans. Approximately one-fifth of the canned output of these vegetables is produced in the Pacific Northwest.

Since the canning operations for all these vegetables are approximately the same, the canning of vegetables is taken as one section. Mr. Elvin Smith of General Foods Corporation in Nampa\(^{70}\) and Mr. Vetter of the Green Giant Company\(^{71}\) in Buhl, Idaho, were visited to obtain processing energy data. The vegetables are washed and separated from their containers (husked or peeled). They are then sealed in cans under vacuum and sent to continuous cookers which heat the vegetables to 250°F to sterilize the product. After 20 minutes in the cooker, the cans are removed, labelled and packaged.

Sufficient energy data were not available from either company to allow a detailed economic analysis. In order to
obtain 100 percent of the energy requirements for this process a geothermal source (65.6°C) must be available. It is doubtful that such a source will be available in Idaho and the actual savings will be approximately 20 percent of the indicated values. (See Appendix I.) Such a small cost savings does not justify the capital expenditures required to convert to a geothermal source on an individual basis. The economics improve when this industry becomes part of a multiple use unit for reasons previously discussed. This possibility is considered in the multiple use section and in the report conclusion which appear later in the thesis.

The freezing of vegetables can be accomplished with absorption refrigeration equipment which is powered by geothermal energy. However, the economics of this type of operation has been considered previously under "Fish Production" and is shown to be economically infeasible.
MULTIPLE USE OF GEOTHERMAL ENERGY

To this point, the economics associated with the application of geothermal energy has been studied for each industry individually. Also, as mentioned in the introduction, the cost of a geological investigation required to find the geothermal source has been estimated to be $50,000\(^{30}\) for use in the calculations. This cost estimate is quite low and is applicable only in proven geothermal areas such as Boise. The cost to explore a 100 mile\(^2\) area is approximately $1.5 million\(^{31}\). Since no company studied could economically afford such a risk, it was assumed that these companies would only consider such exploration in proven geothermal areas, resulting in a risk of only $50,000. However, if several industries were to combine their efforts in developing geothermal energy, or if the cost were supported by large space heating then the exploration of larger areas is economically possible. This section considers the economics of the application of geothermal energy to an industrial park and to large scale space heating.

Space Heating

The potential impact of the application of geothermal energy for space heating in Idaho is substantial. Approximately 30 percent of Idaho's space heating requirements can be supplied by geothermal energy. This figure was obtained by estimating the fraction of the population in Idaho which is within 50 miles of a known geothermal area (see map Figure 25).
FIGURE 25. Population density in the Western United States

- Known geothermal source location (90 - 150°C)
An economic assessment for the application of geothermal energy to space heating must be preceded by a definition of the geothermal source and an estimate of the cost of this source. The wide variations of the resource make it impossible to define a "typical" geothermal source. However, use of assumptions from previously gathered data will allow a reasonable cost estimate to be made.

Table 4 lists the assumptions made in this economic analysis. Where possible, cost estimates were solicited from individual vendors. Extrapolations were used to obtain cost data when such information was not otherwise available. Cost estimates for the geological investigation required to locate the source assumes that preliminary work narrows the area under study to 100 sq. mi. (118). The well, pump, maintenance, and replacement costs were taken directly or extrapolated from documents and correspondence provided by Aerojet Nuclear in Idaho Falls.

It is assumed that the geothermal supply system consists of 100 wells. Exploration costs are a major factor in a single well system that does not require long transmission distances. For large transmission distances, or for a multiple well system the exploration costs are relatively minor. The geological exploration cost constitutes the minimum investment required in conversion to geothermal energy for any supply system. While this $1.5 million is readily available in large metropolitan areas, it represents a considerable risk for small communities.
TABLE 4

Assumptions for Geothermal Supply System

1. Preliminary data narrows exploration area to 100 sq. mi. (31)
2. 13-3/8 inch production well.
3. Well depth of 5000 ft. for 120°C water. (30)
4. Twelve inch schedule 40 steel pipe. (72)
5. Ten wells in supply system.
6. Water velocity of 10 ft./sec.
7. Piping distance of 50 miles.
8. 20 year capacity.
9. 100 BTU's usable per pound of water.
10. 0.5% of total investment for replacement cost. (72)
11. Distribution costs equals convestion cost\(^1/\).

\(^1/\) This cost is quite variable and this represents a very rough approximation.
Table 5 lists the estimated costs for this geothermal supply system. The total cost of the system is approximately $492 million. During a 20 year life span this system can supply approximately $3 \times 10^{14}$ BTU's or 90 million MWHR (thermal). (See Appendix J for supply capacity and total energy supplied.) This results in an energy cost of approximately $5.50 per MWHR (thermal) closely approximating the current cost of gas and coming to one-half the cost of electrical energy. The costs listed in this analysis are estimates and are meant to illustrate the consideration which must be made in such an analysis. Batelle Northwest has performed a similar analysis and calculated that this energy can be supplied at a rate approximately 3 times that estimated here (73).

Assuming that the average residence requires a maximum demand of 50,000 BTU's per hour for space heating, the geothermal supply system described previously can supply approximately 35,000 residences during a maximum demand period. This is calculated as:

\[
\frac{(3500 \text{ gpm}) (60 \text{ min}) (8.35 \text{ lb gal}) (100 \text{ BTU})}{50,000 \text{ BTU/hr}} = 35,070 \text{ residences}
\]

The current energy source costs are approximately $500 per year for gas or $950 per year for electric heat. These were calculated as:

\[
\frac{(50,000 \text{ BTU}) (24 \text{ hr}) (270 \text{ day})}{3 \text{ year}} = 324 \text{ million BTU}
\]
\[
= 3,240 \text{ therms}
\]
<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological Investigation</td>
<td>$1,500,000</td>
<td>(31)</td>
</tr>
<tr>
<td>Supply Well (10)</td>
<td>$3,750,000</td>
<td>1/</td>
</tr>
<tr>
<td>Supply Pump</td>
<td>$3,500,000</td>
<td>1/</td>
</tr>
<tr>
<td>Boost Pump</td>
<td>$350,000</td>
<td>1/</td>
</tr>
<tr>
<td>Pipe Cost</td>
<td>$198,000,000</td>
<td>1/</td>
</tr>
<tr>
<td>Reinjection Pump</td>
<td>$460,000</td>
<td>1/</td>
</tr>
<tr>
<td>Reinjection Piping</td>
<td>$198,000,000</td>
<td>1/</td>
</tr>
<tr>
<td>Reinjection Well</td>
<td>$1,875,000</td>
<td>1/</td>
</tr>
<tr>
<td>Pumping Cost (Energy)</td>
<td>$5,000,000</td>
<td>(72)</td>
</tr>
<tr>
<td>Maintenance</td>
<td>$7,500,000</td>
<td>(72)</td>
</tr>
<tr>
<td>Replacement</td>
<td>$2,000,000</td>
<td>(72)</td>
</tr>
<tr>
<td>Distribution</td>
<td>$70,000,000</td>
<td>2/</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$491,935,000</strong></td>
<td></td>
</tr>
</tbody>
</table>

The above figures reflect the entire cost of a geothermal supply system consisting of 10 wells with a transmission distance of 50 miles over a period of 20 years.

**Calculations:**

1/ Aerojet Pub. #ANCR-1226

Costs were extrapolated from data supplied by Aerojet as the cost estimate of a 50 MW energy and disposal system. Estimates were multiplied by 1.4 since the space heating supply system considered required 1.4 times the flow rate as the 50 MW system.

2/ Distribution cost equals conversion cost. Rough estimate.
Approximate current energy cost is 15¢/therm for gas or 30¢/therm electric, therefore:

\[
(3240) (.15) = \$486 \text{ gas heating} \\
(3240) (.30) = \$972 \text{ electric heating}
\]

The cost of this energy when supplied by geothermal energy is approximately \$1911 per year \([(3240) (.59)]\)\(^{(120)}\). Actual costs are somewhat less since 50,000 BTU/hr represents a maximum average demand expected.

This figure does not include the cost required to convert the residence to a hot water heating system. This will add approximately \$2,000 per residence or \$100 per year over a 20 year life span\(^{(74)}\). While geothermal space heating currently costs approximately 400 percent more than gas heating, the annual rise in gas costs will soon narrow the difference.

The calculations just shown are for the worst possible case. A transportation distance of approximately 50 miles is the greatest distance over which geothermal water could be transported in the Northwest (due to the loss of enthalpy during transportation). Currently, a geothermal area 40 miles from Portland is being considered for space heating. This is the longest piping distance under consideration in the Northwest. For a 50 mile piping distance, the pipe cost constitutes 80 percent of the cost of the geothermal supply system. As the transportation distance decreases, the cost of the supply system will decrease substantially. Assuming a piping distance of 25 miles rather than 50 miles, the cost of the supply
system will drop to $294 million (using this study's figures). The source can still supply the space heating requirements for 35,000 residences but the cost to the resident is reduced approximately $280 per year.

This economic analysis is based on a residence which uses 50,000 BTU's per hour, but this figure is the maximum demand expected by a residence and the average consumption will be less. Therefore 35,000 residences represent the minimum number of residences that could be supported by the geothermal supply. An average demand of 40,000 BTU's per hour would supply an additional 20 percent or 7,000 residences, resulting in a decrease in cost per residence. Maximum loads could then be supplied by conventional energy peaking.

Obviously, many parameters must be considered in an economic analysis of geothermal energy application for space heating. These include source temperature, piping distance, energy demand, and conventional energy costs. The large number of parameters make it impossible to outline general economics that would apply for all systems. This analysis, however, shows that the economics for the worst possible case are still competitive when considered in the context of the continued rise in conventional energy cost. Therefore the application of geothermal energy for space heating should be considered as an economically feasible alternative to conventional energy sources.
Space Cooling

Residential and commercial air conditioning in the United States used $1540 \times 10^{12}$ BTU's in 1969 or 2.5 percent of the total U.S. energy consumption\(^{(75)}\). A portion of the U.S. air conditioning requirements can be provided by the application of geothermal energy to absorption air conditioning units. Commercial and residential size absorption air conditioning systems are readily available off the shelf. The two most popular systems are the ammonia water and lithium bromide water systems. The lithium bromide water is most commonly used because it is simpler and performs better than the ammonia water system. Also, ammonia is mildly toxic and combustable.

Both mechanical and absorption air conditioning systems are available in capacities ranging from small units, meant for residential use, to very large units (1000 tons), used in large buildings and plants. The costs of mechanical systems and absorption systems are approximately the same. The following lists the approximate cost per ton for systems of various capacities\(^{(76)}\).

<table>
<thead>
<tr>
<th>Tons of cooling (One ton = 12,000 BTU)</th>
<th>Cost per ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>$1000</td>
</tr>
<tr>
<td>25</td>
<td>500</td>
</tr>
<tr>
<td>100</td>
<td>320</td>
</tr>
<tr>
<td>1000</td>
<td>80</td>
</tr>
</tbody>
</table>

Since the equipment cost for both systems is approximately the same, the major difference in the cost between the two systems is the investment required to obtain the geothermal source.
Before an economic analysis can be carried out for air conditioning systems, it is necessary to define the term "Coefficient of Performance" (COP) and explain its importance in comparing the two systems. The COP of an air conditioning system is a factor arrived at by dividing the cooling capacity of the system by the energy input to the system. The larger the COP, the less energy required to obtain a given cooling capacity. The COP for mechanical air conditioning systems typically range from 4 to 9. This means that 4 to 9 BTU's of heat are removed from the area to be cooled for every BTU of electrical energy required by the air conditioning system. The COP for absorption systems typically range from .6 to .7. Therefore the removal of one BTU from the cooling area requires 1.4 to 1.7 BTU of energy input. From these numbers it is seen that the least-efficient mechanical systems can provide 36,000 BTU's of cooling for an expenditure of 9,000 BTU's while the same capacity absorption system required 51,430 BTU's. Therefore, the cost of energy supplying the absorption system must be one-sixth that of electricity costs before the absorption system is economically competitive.

Currently electricity costs approximately $.01 per KWHR. Battelle projects that the thermal equivalent of a KWHR can be supplied geothermally for $.017. Therefore electric cost will have to increase ten-fold before energy costs per cooling capacity are equal. Calculations show that the geothermal supply system considered in the space heating analysis could supply enough energy to cool approximately 32,000 residences.
at a cost of $837 per year per residence. In comparison, mechanical cooling systems cost approximately $210 per year per residence.

**Industrial Park**

The application of a geothermal source to an industrial park allows the economic risk to be spread among several industries and therefore reduces the risk for each company. Also using a single source to supply energy for several industries allows full utilization of the source and reduces the development cost per quantity of energy used. If the geothermal source is of sufficiently high temperature, electricity can be generated from the geothermal energy, and the geothermal water can be used as process heat in the park. The concept of cascading temperature requirements allows the geothermal water to be used successively by industries which require successively lower processing temperatures. The multiple use of the geothermal water reduces the cost per quantity of water and therefore reduces the energy cost of each process. A more detailed consideration of the industrial park concept is found in Aerojet Publication Ancr-1260(77). A detailed economic analysis is not presented here due to the large number of possibilities for such application and the lack of required information. However, a table is presented in the report conclusion which summarizes the magnitude of ROI values that can be expected when a geothermal source is used to full capacity and each industry pays for only the percentage of the source that it uses. The reduction of source cost results in increased ROI values in all cases.
This report considers the potential for the application of geothermal energy to various Idaho industries. The industries studied were chosen using criteria explained in the introduction. It was found that the food processing industry was predominant in those industries satisfying the selection criteria. Other industries which satisfy the selection criteria are paper and pulp production, hide tanning, and space heating and cooling. An economic analysis of the application of geothermal energy was performed for each industry when sufficient data were available.

Before summarizing the results of this report, it should be noted that the application of geothermal energy for any use is a very complex subject and does not lend itself to absolute values. The costs required to obtain a geothermal source vary from a few thousand dollars to hundreds of thousands of dollars. The conversion costs can also vary tremendously. In all cases, the major variable is the geothermal source location in relation to the demand. A reduction in the distance from the geothermal source to the point of utilization results in a substantial reduction in the cost of obtaining the geothermal water. This report attempts to apply "typical" values in performing the economic analysis for various industries and to indicate how these values change as operating parameters change.

The initial impression gained while conducting this study was that there is a serious lack of knowledge on the part of
a large percentage of the industries as to the material and energy flows in their processes. This is probably the result of the trial and error method employed by these industries during their formulative years. Once a process is operating satisfactorily and producing an acceptable product, there is no incentive to conduct the laborious task of defining the energy flow of the system. However, as energy and material costs continue to rise, it is necessary that the material and energy flows in the various processes be defined so that logical conservation steps can be performed. Impressive results have been obtained by industries which define their systems and then apply conservation steps on the basis of that information.

A bleach plant in a Southern kraft mill recently spent considerable time and effort in defining the material and energy flows in its process. The results of this study was that a capital expenditure of $500,000 resulted in a savings of $500,000 per year in energy cost (79).

The overall impression which should be left by this study is that the application of geothermal energy to most industries on an individual basis is economically marginal. As discussed previously, the reason for these results is that the standard geothermal production well has a much higher capacity than is required by any single industry and therefore, the capital investment pays for unused capacity. The multiple use section indicated that this situation could be improved by applying one geothermal source to several industries simultaneously. This allows a larger capacity of the geothermal source to be
used and improves the economics for all the industries by reducing the source development cost. Table 6 lists most of the industries which were studied in this thesis and presents ROI data for these industries as part of a multiple use system. (See Appendix K for calculations). It was assumed that a 7-inch production well was used to full capacity and that each industry paid the percentage of the production cost in relation to the industry's consumption of the source. Therefore, an industry which requires 10 percent of the well's capacity pay 10 percent of the development cost. Since the conversion cost and energy savings did not change, the reduction in the source development cost resulted in a drop in overall capital expenditure and in an increase in ROI. Table 6 shows that the majority of industries which were studied have favorable ROI values in a multiple use system.

It is likely that the economics of geothermal energy application to Idaho industries will improve the future. As conventional energy costs continue to rise, the economics of the application of geothermal energy will improve. Boise, Idaho is currently in the process of converting ten state buildings to geothermal energy. An economic study (78) by Aerojet Nuclear in Idaho Falls concludes that the economics of the geothermal system will initially be unfavorable. However, projections indicate that the rise in natural gas prices will be such that the geothermal system will have the same operating cost as the conventional system in approximately three years and will be less expensive in five years. The economic benefits
<table>
<thead>
<tr>
<th>Source</th>
<th>Energy Demand</th>
<th>% Satisfied by 150°C</th>
<th>Energy Satisfied BTU/hr</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potato Granule Production</td>
<td>$1.161 \times 10^8$</td>
<td>9.7</td>
<td>$1.126 \times 10^7$</td>
<td>125</td>
</tr>
<tr>
<td>Potato Flake Production</td>
<td>$1.194 \times 10^6$ BTU/hr</td>
<td>21.5</td>
<td>$2.568 \times 10^7$</td>
<td>121</td>
</tr>
<tr>
<td>Frozen French Fry</td>
<td>$4.8 \times 10^7$</td>
<td>21.5</td>
<td>$1.032 \times 10^7$</td>
<td>160</td>
</tr>
<tr>
<td>Beet Sugar Processing</td>
<td>$4.145 \times 10^8$</td>
<td>4.9</td>
<td>$2.030 \times 10^7$</td>
<td>-.15</td>
</tr>
<tr>
<td>Malt Beverage Production</td>
<td>$4.590 \times 10^7$</td>
<td>5.8</td>
<td>$2.862 \times 10^6$</td>
<td>42.9</td>
</tr>
<tr>
<td>Space Heating</td>
<td>50,000</td>
<td>100%</td>
<td>50,000</td>
<td>--</td>
</tr>
<tr>
<td>Fish Production</td>
<td>318,060 BTU/hr</td>
<td>0</td>
<td>$3.255 \times 10^6$</td>
<td>-18.2</td>
</tr>
<tr>
<td></td>
<td>$3.255 \times 10^6$ Abs.</td>
<td>100%</td>
<td>$3.255 \times 10^6$</td>
<td>-18.2</td>
</tr>
<tr>
<td>Meat Packing</td>
<td>508,896 Mech.</td>
<td>0</td>
<td>$5.11 \times 10^6$</td>
<td>-15.6</td>
</tr>
<tr>
<td></td>
<td>$5.16 \times 10^6$ Abs.</td>
<td>100%</td>
<td>$5.11 \times 10^6$</td>
<td>-15.6</td>
</tr>
<tr>
<td>Animal Fats and Oils</td>
<td>$1.005 \times 10^7$</td>
<td>21.5</td>
<td>$2.161 \times 10^6$</td>
<td>127</td>
</tr>
<tr>
<td>Vegetable Processing</td>
<td>$2.023 \times 10^7$</td>
<td>21.5</td>
<td>$4.349 \times 10^6$</td>
<td>113</td>
</tr>
</tbody>
</table>
of the geothermal system will continue to increase in the following years. It is quite likely that similar results can be expected in industries for which this report finds present application of geothermal energy marginal or unfavorable.

In summary, Idaho possesses an alternate energy source of tremendous potential in the form of geothermal energy. This report indicates the parameters such as source temperature and location which are necessary for the economic application of geothermal energy. In general, geothermal sources in the neighborhood of 148.8°C which are located in close proximity to the user industries are required in order for the economics of geothermal application to be attractive. It is doubtful that these parameters will be met in the near future and indications are that a great deal of work remains to be done if geothermal energy is to make a significant impact on energy consumption in Idaho.
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APPENDICES
APPENDIX A

POTATO GRANULE PROCESS CALCULATIONS
Energy balances for the potato granule process and the other processes to be considered can be calculated in two ways. One method is to calculate the fraction of the total required enthalpy that is supplied by the geothermal water and to consider this fraction to represent the fraction of energy savings. Using this method, the geothermal water is piped into a boiler and the enthalpy is increased to the desired level. The second method is to use geothermal water to heat the process steps so that 180°F water might heat a 160°F processing step. The geothermal water would be heated for processes which require temperatures in excess of the temperature of the geothermal water.

The second approach results in higher energy savings. However, the quantity of water required in the second approach is so much larger than for the first approach that the pipe size required to transport the fluid must be increased with a resultant drop in ROI. Since there is not a large difference in the energy savings between the two approaches, the first approach is used.

**Enthalpy Data**

<table>
<thead>
<tr>
<th>Water temperature</th>
<th>BTU/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>50°F</td>
<td>18</td>
</tr>
<tr>
<td>100°F</td>
<td>68</td>
</tr>
<tr>
<td>180°F</td>
<td>147.9</td>
</tr>
<tr>
<td>212°F (L)</td>
<td>180</td>
</tr>
<tr>
<td>250°F (L)</td>
<td>216.5</td>
</tr>
<tr>
<td>350°F (L)</td>
<td>321.6</td>
</tr>
<tr>
<td>212°F (v)</td>
<td>1150</td>
</tr>
<tr>
<td>328°F (v) (100psi)</td>
<td>1187</td>
</tr>
</tbody>
</table>

The boilers at American Potato produce 100 psi steam. Therefore, these calculations assume that geothermal water is pumped into the boilers and converted to steam (100 psi). This study assumes 50°F water as generally available ground water.
Energy Savings

100°F water: \[
\frac{68-18}{1187-18} = 4.3\% \\
1.9
\]

180°F water: \[
\frac{147.9-18}{1187-18} = 11.1\% \\
5.0
\]

212°F water: \[
\frac{180-18}{1187-18} = 13.9\% \\
6.3
\]

250°F (L): \[
\frac{216.5-18}{1187-18} = 17.0\% \\
7.7
\]

350°F (L): \[
\frac{321.6-18}{1187-18} = 26\% \\
11.8
\]

212°F steam: \[
\frac{1150-18}{1187-18} = 96.8\% \\
44.57
\]

328°F steam: \[
100\% \\
45.2
\]

The first figures above are the percentage of the energy that is used for steam production that is saved. Steam production accounts for 45.2% of the total natural gas consumption. The second figure above is the percentage of total energy savings. \[ \cdot \cdot 4.3\% \text{ of } 45.2\% = 1.9\% \]

Steam Requirements for Granule Plant

The figures for the energy requirements have been corrected to give BTU expenditure of natural gas per 100 lbs. of raw potato. The BTU's of steam per 100 lbs. of potatoes are as follows:

Peeling 9465
Blanching 14248
Cooking 17809
\[ 41522 \text{ BTU/100 lb.} \]
Steam requirements for 40 Ton/hr:

\[
(40 \text{ Ton/hr}) \times (2000 \text{ # Ton}) \times \left(\frac{41522 \text{ BTU}}{100 \text{ #}}\right) \times \left(\frac{1 \text{ # Steam}}{1190 \text{ BTU}}\right) = 27913 \text{ # Steam/hr.}
\]

\[
\frac{27913 \text{ # Steam/hr.}}{hr.} \times \left(\frac{1 \text{ hr}}{60 \text{ min}}\right) \times \left(\frac{1 \text{ ft}^3}{62.4 \text{ #}}\right) = 7.46 \text{ ft}^3/\text{min.}
\]

This can be transported in a 4 inch pipe at a velocity of 1.4 ft/sec.

\[
7.46 \frac{\text{ft}^3}{\text{min}} = 0.1243 \frac{\text{ft}^3}{\text{sec}}
\]

Area of 4" pipe = 0.0873 ft$^2$

Velocity = \[
\frac{0.1243}{0.0873} = 1.4 \frac{\text{ft}}{\text{sec}}
\]

ROI Calculations

A plant which processes approximately 40 tons per hour of potatoes consumes approximately \(8.357 \times 10^6\) therms of gas per year.

\[
\text{ROI} = \frac{\text{Energy Savings}}{\text{Investment}} - .2
\]

Investment = 296,000 + 75,000/mile

Savings = \((8.347 \times 10^6 \text{ therms}) (\%) (\$0.15/\text{therm})

100°F water

\((8.357 \times 10^6)(.019)(.15) = \$23820\)

Pipe distance (miles) \quad ROI

| 0 | -11.9 |

180°F water

\((8.347 \times 10^6)(.05)(.15) = 62680\)

Distance \quad ROI

| 0 | 1.2 |
212°F Water

\[(8.347 \times 10^6)(.063)(.15) = 78970\]

<table>
<thead>
<tr>
<th>Distance</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.7</td>
</tr>
</tbody>
</table>

250°F Water

\[(8.357 \times 10^6)(.077)(.15) = 96520\]

<table>
<thead>
<tr>
<th>Distance</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>12.61</td>
</tr>
<tr>
<td>1</td>
<td>6.02</td>
</tr>
<tr>
<td>2</td>
<td>1.64</td>
</tr>
<tr>
<td>3</td>
<td>-1.47</td>
</tr>
</tbody>
</table>

350°F Water

\[(8.357 \times 10^6)(.118)(.15) = 1.479 \times 10^5\]

<table>
<thead>
<tr>
<th>Distance</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>29.9</td>
</tr>
</tbody>
</table>

212°F Steam

\[(8.347 \times 10^6)(.4457)(.15) = 5.587 \times 10^5\]

<table>
<thead>
<tr>
<th>Distance</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>168.8</td>
</tr>
<tr>
<td>1</td>
<td>130.6</td>
</tr>
<tr>
<td>2</td>
<td>105.3</td>
</tr>
<tr>
<td>3</td>
<td>87.2</td>
</tr>
<tr>
<td>4</td>
<td>73.7</td>
</tr>
<tr>
<td>5</td>
<td>63.3</td>
</tr>
</tbody>
</table>

ROI Versus Shipping Distance

Assume 4 million hundred weight shipper per year. Added for transportation:

- 50 miles: \((4 \times 10^6)(.06) = 240,000\)
- 100 miles: \((4 \times 10^6)(.115) = 960,000\)
- 200 miles: \((4 \times 10^6)(.295) = 1,180,000\)
For 212°F Steam

<table>
<thead>
<tr>
<th>Transportation Distance</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 miles</td>
<td>168.8</td>
</tr>
<tr>
<td>50 &quot;</td>
<td>84.2</td>
</tr>
<tr>
<td>100 &quot;</td>
<td>24.5</td>
</tr>
</tbody>
</table>
APPENDIX B

POTATO FLAKE PROCESS CALCULATIONS
Correction for energy requirements for processing steps. Sum of BTU per 100 pounds of raw potatoes in text:

<table>
<thead>
<tr>
<th>Step</th>
<th>BTU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peeling</td>
<td>13842</td>
</tr>
<tr>
<td>Precooking</td>
<td>39127</td>
</tr>
<tr>
<td>Cooking</td>
<td>19000</td>
</tr>
<tr>
<td>Drying</td>
<td>97580</td>
</tr>
</tbody>
</table>

169549 BTU/100 # Raw

Actual energy (natural gas) consumption = 2.05 therms

Correction factor = \( \frac{2.05}{1.69} \)

\[ (13842) \left( \frac{2.05}{1.69} \right) = 16736 \text{ BTU/100 # Raw for peeling} \]

Precook: 47300 BTU/100 # Raw
Cook: 22973
Dry: 117983

The boilers at Rogers Brothers produce 125 psi steam which has an enthalpy content of 1190 BTU/pound mass.

**Energy Savings**

<table>
<thead>
<tr>
<th>Temperature</th>
<th>ΔH (°F)</th>
<th>ΔH (°C)</th>
<th>% Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>100°F Water</td>
<td>68-18</td>
<td>1190-18</td>
<td>4.3%</td>
</tr>
<tr>
<td>180°F Water</td>
<td>147.9-18</td>
<td>1190-18</td>
<td>11.1</td>
</tr>
<tr>
<td>212°F Water</td>
<td>180-18</td>
<td>1190-18</td>
<td>13.8</td>
</tr>
<tr>
<td>250°F Water</td>
<td>216.5-18</td>
<td>1190-18</td>
<td>16.9</td>
</tr>
<tr>
<td>350°F Water</td>
<td>321.6-18</td>
<td>1190-18</td>
<td>25.9</td>
</tr>
</tbody>
</table>
212°F Steam:  \[
\frac{1150-18}{1190-18} = 96.6
\]

344°F Steam: 100%

Steam Requirements:
- Peeler 11.7 #/100 #R
- Precook 34.0
- Cooker 16.5
- Dryer 82

\[
\text{Capacity} = 14000 \text{ ct/day}
\]

\[
(14000)(144.2) = 2,018,800 \text{ # S/day}
\]

Assume 16 hour day

\[
(2,018,800)\left(\frac{1}{16}\right)\left(\frac{1}{3600}\right) = 35 \text{ # S/sec.}
\]

Assume a 4" pipe:

Area of pipe = 0.087 ft\(^2\)

\[
\frac{0.56}{0.087} = 6.44 \text{ ft/sec}
\]

ROI Calculations

Energy expenditure =

\[
(14,000 \text{ ct/day}) (300 \text{ day/yr}) (2.05 \text{ therm/ct}) = 8,610,000 \text{ Therms}
\]

\[
(8,610,000 \text{ Therms}) (\$.15/\text{Therm}) = $1,291,500
\]

Energy Savings = ($1,291,500)\(\%\)

Investment = $296,000 + $75,000/mile

100°F Water:

<table>
<thead>
<tr>
<th>Mile</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-1.2</td>
</tr>
</tbody>
</table>
### 180°F Water:

<table>
<thead>
<tr>
<th>Mile</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>28.4</td>
</tr>
<tr>
<td>1</td>
<td>18.6</td>
</tr>
<tr>
<td>2</td>
<td>12.1</td>
</tr>
</tbody>
</table>

### 212°F Water:

<table>
<thead>
<tr>
<th>Mile</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>40.2</td>
</tr>
<tr>
<td>1</td>
<td>28.0</td>
</tr>
<tr>
<td>2</td>
<td>19.9</td>
</tr>
<tr>
<td>3</td>
<td>14.2</td>
</tr>
</tbody>
</table>

### 250°F Water:

<table>
<thead>
<tr>
<th>Mile</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>53.7</td>
</tr>
<tr>
<td>1</td>
<td>38.8</td>
</tr>
<tr>
<td>2</td>
<td>28.9</td>
</tr>
<tr>
<td>3</td>
<td>21.9</td>
</tr>
</tbody>
</table>

### 350°F Water:

<table>
<thead>
<tr>
<th>Mile</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>92.9</td>
</tr>
<tr>
<td>1</td>
<td>70.1</td>
</tr>
<tr>
<td>2</td>
<td>55.0</td>
</tr>
<tr>
<td>3</td>
<td>44.2</td>
</tr>
<tr>
<td>4</td>
<td>36.1</td>
</tr>
<tr>
<td>5</td>
<td>29.8</td>
</tr>
</tbody>
</table>

### 212°F Steam:

<table>
<thead>
<tr>
<th>Mile</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>401</td>
</tr>
<tr>
<td>1</td>
<td>316</td>
</tr>
<tr>
<td>2</td>
<td>259</td>
</tr>
<tr>
<td>3</td>
<td>219</td>
</tr>
<tr>
<td>4</td>
<td>189</td>
</tr>
<tr>
<td>5</td>
<td>166</td>
</tr>
</tbody>
</table>

**Temp drop per mile:**

Time to move 1.0 mile \(\frac{5280}{6.44} = 820\) sec.
Surface area = 5526 ft$^2$

\[ \text{.} \cdot \cdot \cdot \frac{(820)(5526)(.0209)}{28664} = 94737 \text{ BTU lost/mile} \]

#water/mile = 28664# H$_2$O

\[ \frac{94737}{28664} = 3.31 \text{ BTU per Water Mile} \]

ROI Versus Shipping Distance

Assume 4 million hundred weight shipped per year.

Added transportation cost:

- 50 miles $240,000
- 100 miles 960,000
- 200 miles 1,180,000

For 350°F Water:

<table>
<thead>
<tr>
<th>Distance</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 miles</td>
<td>92.9</td>
</tr>
<tr>
<td>50 miles</td>
<td>42.4</td>
</tr>
<tr>
<td>100 miles</td>
<td>6.6</td>
</tr>
</tbody>
</table>

For 212°F Steam:

<table>
<thead>
<tr>
<th>Distance</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 miles</td>
<td>401</td>
</tr>
<tr>
<td>50 miles</td>
<td>212.7</td>
</tr>
<tr>
<td>100 miles</td>
<td>79.3</td>
</tr>
</tbody>
</table>
APPENDIX C

FROZEN FRENCH FRY PROCESS CALCULATIONS
Energy Cost (Natural Gas)

\[
(40,000 \frac{\text{#}}{\text{hr}}) \left(\frac{24\text{ hr}}{\text{day}}\right) \left(\frac{336\text{ day}}{\text{yr}}\right) \left(1200 \frac{\text{BTU}}{\text{#}}\right)
\]

\[
(3.87 \times 10^{11} \frac{\text{BTU}}{\text{yr}}) \left(\frac{1\text{ Therm}}{1 \times 10^5 \text{BTU}}\right) \left(\frac{\$0.15}{\text{Therm}}\right) = \$581,000
\]

Electrical Energy Cost for Cooling:

\[
(830\text{ hp}) \left(\frac{.7457\text{ KW}}{\text{hr}}\right) \left(\frac{24\text{ hr}}{\text{day}}\right) \left(\frac{336\text{ day}}{\text{yr}}\right) \left(\frac{\$0.0107}{\text{KWH}}\right) = 55,390
\]

Cost Savings

\[
\left(\frac{12,500 \text{ #S}}{\text{hr}}\right) \left(\frac{581,000}{40,000 \text{ #S/hr}}\right) = \$181,000
\]

Pipe Size

Assume 250°F is dropped to 230°F

\[
(12,500 \text{ #S}) \left(\frac{1201 \text{ BTU}}{\text{#}}\right) = 1.501 \times 10^7 \frac{\text{BTU}}{\text{hr}}
\]

20 BTU furnished per pound of water

\[
\left(\frac{1.501 \times 10^7 \frac{\text{BTU}}{\text{hr}}}{20 \text{ BTU/#}}\right) = 7.506 \times 10^5 \frac{\text{#}}{\text{hr}} \text{ water } = 3.341 \frac{\text{ft}^3}{\text{sec}}
\]

Area of 6 inch pipe = 0.163 ft²

Velocity = \[
\frac{3.341}{0.163} = 17 \frac{\text{ft}}{\text{sec}}
\]
APPENDIX D

SUGAR BEET PROCESSING CALCULATIONS
Energy Savings using 212°F steam:

Approximately 1334 BTU per pound mass are required to produce 600 psi steam from 212°F water. 364 BTU/lb are required for 212°F steam.

\[
\frac{1334 - 364}{1334} = 72\% \text{ energy savings}
\]

Energy Required per Ton:

\[
\begin{align*}
1,730,000 \\
640,000 \\
116,000 \\
\hline
2,486,000 \text{ BTU/Ton}
\end{align*}
\]

Assume 4000 Ton per day
Assume 130 days per year
\[
(2.486 \times 10^6) \times (4000) \times (130) = 1.29 \times 10^{12} \text{ BTU/yr.}
\]
\[
= 12,900,000 \text{ Therms/yr.}
\]

Heat Exchange Cost:

\[
(1,500,000) \times (170) = 2.55 \times 10^8 \text{ BTU/hr}
\]

\[
Q = UA\Delta T_{\text{in}}
\]

Assume \(T_{\text{steam}} = 250°F\)

\(T_{\text{in}} = 200°F\)

\(T_{\text{out}} = 212°F\)

\(\Delta T_{\text{in}} = 43.7\)

\(U = 400\) (from Thomson and Scheldorf)
\[ A = \frac{Q}{UAT_{ln}} = \frac{2.55 \times 10^8}{(400)(43.7)} = 14588 \text{ ft}^2 \]

Consider Nickel alloy at $30 per ft$^2$.

\[(14588) (30) = \$437,643\]

Labor factor = 2.3

\[(2.3) (437643) = \$1,006,578\]

Cost per year at $.15 per therm = $1,939,000/year

Geothermal Energy Savings:

\[(1,730,000) (.72) (4000) (130) = 6.477 \times 10^{11} = 6477120 \text{ Therms}\]

Cost = $971,568/yr. Saved per year

Percent Cost Savings:

\[\frac{1939080 - 971568}{1939080} = .4989\]

Mass Requirement:

\[(1,500,000 \frac{\text{BTU}}{\text{Ton}}) (170 \frac{\text{Ton}}{\text{hr}}) = 255,000,000 \frac{\text{BTU}}{\text{hr}}\]

Assume average steam is 1192 BTU per pound

\[\text{Mass} = \frac{255,000,000}{1192} = 213,926 \frac{\#}{\text{hr}}\]

This corresponds well to 209,000 (data from Amalgamated)

Piping Requirements:

\[213926 \frac{\#}{\text{hr}} = 59.43 \frac{\#}{\text{sec}} = 0.95 \frac{\text{ft}^3}{\text{s}}\]
Area of 4-inch pipe = 0.087 ft$^2$

Velocity = \[
\frac{0.95}{0.087} = 10.9 \text{ ft/sec}
\]

Time for one mile = \[
\frac{5280}{10.9} = 485 \text{ sec.}
\]

BTU lost per mile:

(5526) (485) (.0209) = 56014 \text{ BTU/mile}

$\frac{\text{Water}}{\text{mile}} = 28664 \# \text{ H}_2\text{O}$

1.95 $\frac{\text{BTU}}{\text{H}_2\text{O}}$ lost per mile
APPENDIX E

FLASHING
Percent of Water to Steam by Flashing:

250°F
\[
\text{fraction} = \frac{216,48-180}{969.74} = 0.038
\]

300°F
\[
\frac{369-180}{969.74} = 0.092
\]

350°F
\[
\frac{321-180}{969.74} = 0.145
\]

400°F
\[
\frac{374-180}{969.74} = 0.20
\]

Water requirements for flashing 300°F water

\[
(40 \times 10^6 \frac{\# H_2O}{\text{day}}) \left(\frac{1}{16} \frac{\text{day}}{\text{hr}}\right) \left(\frac{1}{3600} \frac{\text{hr}}{\text{sec}}\right) = 694 \frac{\#}{\sec}
\]

\[
\frac{694 \#/\sec}{62.4 \#/\text{ft}^3} = 11.13 \text{ ft}^3/\text{sec}
\]

Area of 7-inch pipe = 0.27 ft²

Velocity = \[
\frac{11.13 \text{ ft}^3/\text{s}}{0.27 \text{ ft}^2} = 41.65 \text{ ft/sec} \quad \text{(Velocity too high)}
\]

Area of 12-inch pipe = 0.79 ft²

\[
\frac{11.13}{0.79} = 14.17 \text{ ft/s}
\]
ROI versus piping distance:

Investment = $471,000 + 396,000/mi.

Energy Savings = $1.243 \times 10^6/yr.

ROI = \frac{\text{ES}}{\text{In}} - .2

ROI = \frac{1.243 \times 10^6}{471,000} - .2 = 244 \text{ for zero miles}

<table>
<thead>
<tr>
<th>Miles</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>244</td>
</tr>
<tr>
<td>1</td>
<td>123</td>
</tr>
<tr>
<td>2</td>
<td>78</td>
</tr>
<tr>
<td>3</td>
<td>55</td>
</tr>
<tr>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>31</td>
</tr>
</tbody>
</table>
Refrigeration Requirements:

\( \text{NH}_3 \) System:

5\(^\circ\)F evaporation and 86\(^\circ\)F condensation

\[
\frac{\text{HP}}{T} = 0.989 \approx 1.0
\]

125 HP = 125 Ton of refrigeration

\[
(125 \text{ HP}) \cdot (0.7068 \frac{\text{BTU}}{\text{sec HP}}) \cdot (3600 \frac{\text{sec}}{\text{hr}}) = 318060 \frac{\text{BTU}}{\text{hr}}
\]

\[
(318060 \frac{\text{BTU}}{\text{hr}}) \cdot (2.930 \times 10^{-4} \frac{\text{KW-hr}}{\text{BTU}}) = 93.19 \text{ KWhr}
\]

\[
(93.19) \cdot (24 \frac{\text{hr}}{\text{day}}) \cdot (365 \frac{\text{day}}{\text{yr}}) = 816,344 \frac{\text{KW-hr}}{\text{yr}}
\]

\[
(816,344) \cdot (0.0107 \frac{\$}{\text{KWhr}}) = 8734.88/\text{yr}
\]

Absorption Energy Requirements:

430 \frac{\text{BTU}}{\text{min Ton}} required for 0\(^\circ\)F

\[
(430) \cdot (60) = 25800 \frac{\text{BTU}}{\text{hr Ton}}
\]

\[
(25800 \frac{\text{BTU}}{\text{hr Ton}}) \cdot \left( \frac{1}{3413} \frac{\text{KWhr}}{\text{BTU}} \right) = 7.56 \text{ KWhr}
\]

Assume boiler efficiency = 70%

\[
(7.56) \cdot (0.7) = 5.29 \text{ KWhr}
\]

25800 BTU can produce 7.56 KWhr of electricity which costs \$.057

Mechanical refrigeration requires 1 \frac{\text{KWhr}}{\text{Ton}} for a cost of \$.01.
APPENDIX G

ANIMAL FATS AND OILS
Animal Fats & Oils

\[(300 \text{ bhp}) (33500 \ \frac{\text{BTU}}{\text{bhp}}) = 1.005 \times 10^7 \text{ BTU/hr}\]

\[(1.005 \times 10^7) (8 \text{ hr/day}) (365 \text{ day/yr}) = 2.9 \times 10^{10} \text{ BTU/yr}\]

\[(2.9 \times 10^{10} \ \frac{\text{BTU}}{\text{yr}}) (1/10^5 \ \frac{\text{Therm}}{\text{BTU}}) (0.15 \ \frac{\$}{\text{Therm}}) = 43500/\text{year}\]
APPENDIX H

BREWING PROCESS
Gas consumption based on gas bill:

\[
\frac{\$325,000}{.15} = 2.167 \times 10^6 \text{ Therms/yr}
\]

Maximum Conversion for Masher and Cooker

\[
\frac{2000 + 1100}{27000} = .1148 \text{ fraction of energy savings}
\]

Energy Cost = $325,000

\[
(325,000) (.1148) = \$37,310
\]

ROI = \[
\frac{\text{Savings}}{\text{Investment}} = .2
\]

Minimum acceptable ROI = .4

\[
.4 = \frac{37310}{\text{Investment}} - .2
\]

Investment = $62,190

Geothermal Application to Holding and Brew Kettles

\[
\frac{10500}{27000} = 38.9\% \text{ energy savings}
\]

\[
(325,000) (.389) = \$126,388
\]

Maximum investment to receive ROI if .4 is $210,648.

Quantity of geothermal water required for holding and brew kettles

\[
(10400 \text{ # S/hr}) (1190 \frac{\text{BTU}}{\# \cdot \text{S}}) = 1.238 \times 10^7 \frac{\text{BTU}}{\text{hr}}
\]

Assume geothermal water is dropped from 250 to 230°F

\[
\frac{1.238 \times 10^7}{20} = 6.188 \times 10^5 \frac{\text{# water}}{\text{hr}} = 2.755 \text{ ft}^3/\text{sec}
\]
Minimum pipe diameter required for transportation

Area of 6-inch pipe = 0.1963 ft²

\[
\frac{2.755}{0.1963} = 14 \text{ ft/sec}
\]

Refrigeration Cost:

820 Ton = 820 HP

\[
(820) \left(0.7457 \cdot \frac{\text{kWhr}}{\text{HP}}\right) \cdot (24 \text{ hr/day}) \cdot (365 \text{ day/yr}) \left(\frac{0.0107 \cdot \$}{\text{kWhr}}\right) = 57314/\text{yr}
\]

Energy Data for Brewing Process:

27000 #S/hr consumed

boiler eff. = .70 \[
[(38571) \times (1190) = 4.590 \times 10^7 \text{ BTU/hr}]
\]

\[
4.590 \times 10^7 \text{ BTU/yr}
\]

820 Ton of refrigeration

350°F stack gas temp.

Energy Breakdown:

<table>
<thead>
<tr>
<th>Process</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masher</td>
<td>2000 #S/hr</td>
</tr>
<tr>
<td>Cooker</td>
<td>1000 &quot;</td>
</tr>
<tr>
<td>Holding Kettle</td>
<td>10400</td>
</tr>
<tr>
<td>Brewing Kettle</td>
<td>10400</td>
</tr>
<tr>
<td>Packaging</td>
<td>11000</td>
</tr>
<tr>
<td>Clean Up, Misc.</td>
<td>2500 #S/hr</td>
</tr>
<tr>
<td>Refrigeration</td>
<td></td>
</tr>
<tr>
<td>Cooling water</td>
<td>150T</td>
</tr>
<tr>
<td>Glycol</td>
<td>50</td>
</tr>
<tr>
<td>Cellar</td>
<td>400</td>
</tr>
<tr>
<td>Cooler</td>
<td>200</td>
</tr>
<tr>
<td>CO₂ Cond.</td>
<td>20</td>
</tr>
</tbody>
</table>

Energy Cost:

- Electric $112,000/yr
- Gas (boiler feed) $325,000/yr
- Sewer $13,200/yr
APPENDIX I

VEGETABLE PROCESSING
Energy Expenditure (Green Giant)

\[(\$200/\text{hr}) \times (900 \text{hr}) = 180,800\]

General Foods

\[\left(5.090 \times 10^7 \frac{\#}{\text{yr}}\right) \times (1190 \frac{\text{BTU}}{\#}) \times (1/10^5) \times (0.15) = 89,250\]
APPENDIX J

SPACE HEATING
(3500 gal/min) (60 min/hr) (24 hr/day) (365 day/yr) (20 yr) (100 Btu/#)

\[ (8.35 \text{#/gal}) = 3 \times 10^{14} \text{ Btu} \]
APPENDIX K

REPORT CONCLUSIONS
Cost of 7-inch well:

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geological Exploration</td>
<td>$50,000</td>
</tr>
<tr>
<td>Well Cost</td>
<td>300,000</td>
</tr>
<tr>
<td>Pipe Cost</td>
<td>--</td>
</tr>
<tr>
<td>Miscellaneous Conversion Cost</td>
<td>30,000</td>
</tr>
</tbody>
</table>

$380,000

Cost of each industry in $/BTU plus conversion cost which differs for each industry.

Energy supplied by well per hour:

Assume flow at 10 ft/sec.

Area of 7-inch pipe = 0.27 ft²

\[(10 \text{ ft/sec}) (0.27 \text{ ft}^2) (3600 \text{ sec/hr}) (62.4 \text{ #/ft}^3) (269.6 \text{ BTU/#})\]

= 1.618 x 10⁸ BTU/hr

Energy Produced per year:

\[(1.618 \times 10^8) (24 \text{ hr/day}) (365 \text{ day/yr}) = 1.417 \times 10^{12} \text{ BTU/yr}\]

Energy Cost = \[\frac{1.417 \times 10^{12}}{380,000} = 3.73 \times 10^6 / 1\$

Potato Granule:

\[\text{ES} = (1.121 \times 10^7) (24) (365) = 8.106 \times 10^{16} \text{ BTU/yr} = $1.216 \times 10^5 /\text{yr}\]

Investment = (.046) (380,000) = 1.748 \times 10^4

Conversion Cost = \[\frac{66000}{8.348 \times 10^4}\]

ROI = \[\frac{1.216 \times 10^5}{8.348 \times 10^4} - .2 = 1.26 \text{ or 126}\%\]
Potato Flake:

\[ ES = (2.56 \times 10^7) (24) (300) = 1.849 \times 10^{11} \text{ BTU/yr} = 2.774 \times 10^5 \]

Investment = (.208) (380,000) = $7.904 \times 10^4

Conversion Cost = \[ \frac{66000}{1.450 \times 10^5} \]

ROI = \[ \frac{2.774 \times 10^5}{1.450 \times 10^5} \] - .2 = 1.71 or 171%

Frozen French Fry:

\[ ES = (1.032 \times 10^7) (24) (335) = 8.297 \times 10^{10} \text{ BTU/yr} = 1.245 \times 10^5 \]

Investment = (380,000) (.066) = 2.508 \times 10^4

Conversion Cost = \[ \frac{44000}{6.908 \times 10^4} \]

ROI = \[ \frac{1.245 \times 10^5}{6.908 \times 10^4} \] - .2 = 1.6 = 160%

Sugar Beet:

\[ ES = (2.030 \times 10^7) (24) (130) = 3.214 \times 10^{10} = 4.820 \times 10^4 \]

Investment = (380,000) (.3527) = 1.340 \times 10^5

Conversion Cost = \[ \frac{1 \times 10^6}{1.134 \times 10^6} \]

ROI = \[ \frac{4.830 \times 10^4}{1.134 \times 10^6} \] - .2 = -.15
Malt Beverage:

\[ ES = (2.622 \times 10^6) \times (16) \times (300) = 1.278 \times 10^{10} \text{ BTU/yr} = 1.917 \times 10^4 \]

Investment = (380,000) \times (.0445) = 1.691 \times 10^4

Conversion Cost = \( \frac{62000}{7.891 \times 10^4} \)

ROI = 42.9%

Fish Production:

ES = $9000

Investment = (380,000) \times (.0045) = 1710

Conversion Cost = 500,000

ROI = -18.2

Meat Packing:

ROI = \( \frac{43800}{1,003,420} \) - .2 = -.15 or -15%

Animal Fats and Oils:

\[ ES = (2.161 \times 10^6) \times (8) \times (300) = 5.186 \times 10^9 \text{ BTU/yr} = 7780 \]

Investment = (380,000) \times (.0139) = 5282

Conversion Cost = 0

ROI = \( \frac{7780}{5282} \) - .2 = 1.27 or 127%
Vegetable Processing:

\[ \text{ES} = (4.349 \times 10^6) \times 900 = 3.914 \times 10^4 \text{ BTU/yr} = $5871 \]

Investment = (380,000) \times 0.0116 = 4408

Conversion Cost = 0

ROI = 113\%