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# USING GEOTHERMAL ENERGY TO PRODUCE ETHANOL FOR AUTOMOTIVE FUEL

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## ABSTRACT

The Raft River KGRA in south-central Idaho is known to have extensive low-salinity geothermal fluid, and the agricultural region around the KGRA is a major producer of wheat, sugar beets, and potatoes. A conceptual alcohol production facility was designed to convert these local crops to 76 million-liters-per-year of anhydrous ethanol with flashed geothermal fluid as the primary energy source. Three levels of geothermal steam are extracted from the assumed 138$^{o}$C fluid resource. All of the steam is indirectly used with the exception of a small amount of cooking steam (direct injection). Condensate and unflashed geothermal fluid are reinjected into the formation.

The alcohol facility can process any of the three crop materials and would operate as long as possible on the lowest cost crop. The estimated capital cost for the plant is $64 million. The geothermal facility capital cost is an additional $18 million. Economic analyses indicate the alcohol production cost is very sensitive to the feed crop costs. Reasonable returns on investment can be realized with an alcohol selling price of less than 53¢ per liter ($2 per gallon). The cost of geothermal-derived steam is equivalent to about 8.5 mills/kJ ($2.50 per million Btu's). Geothermal resources can be used not only to provide reasonably priced energy, but also to produce a form of mobile energy — alcohol.

## INTRODUCTION

Ethanol is currently being produced from renewable resources for use as a fuel. However, the production of ethanol is energy intensive. If ethanol can be produced with geothermal resources supplying the heat input, then the geothermal resource would be converted in a sense from an immobile energy form to a mobile form that can supplement our automotive fuel requirements.

The Raft River geothermal resource area in south-central Idaho is known to have extensive low-salinity geothermal fluid. It has been established that this formation can yield 143$^{o}$C geothermal fluid at a well depth of 1500 m. Test wells drilled in this KGRA have the typical fluid properties shown in Table 1. The temperature conditions and the fluid properties appear to meet the needs of an ethanol production facility.

Table 1. Typical Raft River KGRA geothermal fluid properties

| Constituent | Analysis Range, mg/l |
|---|---|
| Sodium | 300 - 1000 |
| Potassium | 30 - 100 |
| Calcium | 30 - 130 |
| Strontium | 1 - 5 |
| Magnesium | 0.5 - 1.0 |
| Lithium | 1.0 - 3.5 |
| Chloride | 500 - 2000 |
| Fluoride | 4 - 6 |
| Sulfate | 30 - 50 |
| Bicarbonate | 25 - 50 |
| Silica | 125 - 150 |
| pH | 7.0 - 7.5 |

The south-central agricultural region of Idaho is a major producer of wheat, sugar beets, and potatoes. Over the past few years, the total production of each crop in the counties around the Raft River KGRA has been sufficient to support a commercial-scale ethanol production facility. The following shows the average annual crop production in a five-county area within 60 miles of the Raft River KGRA:

| | |
|---|---|
| • Wheat (winter) | - 10 million bushels |
| • Wheat (summer) | - 8 million bushels |
| • Sugar Beets | - 1.3 million tons |
| • Potatoes | - 24 million cwt |

Based on our discussions with property owners and farm groups, it appears that the Raft River area can accommodate a 76-million-liter-per-year (20-million-gallon-per-year) ethanol plant. Therefore, we selected this size facility at a specific site as the basis for our technical and economic evaluation. Because of the feedstock supply situation, we decided to use a multi-crop feedstock concept for the design of this facility. The facility would nominally process potatoes for five months, sugar beets for four months, and wheat for three months of the year. In each year, crop productions and prices would dictate the actual processing mix and run duration of each, so that the feedstock yielding the lowest cost per gallon of production would be purchased on the open market. Sugar beet acreage would be contracted a year in advance through the growers association, so the process run time on sugar beets is essentially fixed before planting time.

## FACILITY DESIGN BASIS

As a basis for the design of the facility, we decided to use conventional technology so that such a plant may be installed with no developmental effort involved. This conventional technology approach applies to both alcohol production and geothermal energy extraction.

Although the Raft River geothermal fluid is low in salinity, it still has the potential to deposit scale on heat transfer surfaces. Much of the process equipment in the ethanol production plant incorporates heating surfaces that may be extremely difficult to descale. As a result, the direct use of hot geothermal fluid was considered unsuitable for this operation. Instead, we decided to use steam flashed from the geothermal fluid as the heating medium. Any scaling in the flash step can be controlled by proper design of the flash vessels and by the use of scale-suppressant additives. Multiple-temperature steam heating systems are routinely used in chemical process plants. Heat transfer rates with condensing steam are uniformly high, and steam is less susceptible to fouling. In addition, control of heat to individual users is simple and uses equipment already familiar to the industry. Balanced heat flow at the various temperature levels required can be done in such a way as to minimize geothermal fluid flow. The multi-stage flash system selected provides saturated steam at approximately 121°C, 107°C, and 96°C, starting with the geothermal fluid at 138°C.

The design of the extraction system is shown in Figure 1. Geothermal fluid from each well is pumped individually to the energy extraction system. Here a scale control additive is metered into the brine by a positive displacement pump and mixed in a static mixer. The fluid then flows to the first flash vessel where the pressure is reduced to produce steam at 121°C. The flow of geothermal fluid is adjusted to maintain the 121°C steam temperature. The flashed liquid then flows to the second-stage flash vessel where it is again flashed to produce steam at 107°C. A small amount of steam is vented to the atmosphere from the second stage for control purposes. In the third stage the liquid is flashed to produce steam at about 96°C. The third-stage temperature is allowed to float depending on the steam demands. Process condensate is returned to this stage. From the third flash stage the brine is withdrawn by a transfer pump and routed through parallel multi-media filters for removal of any suspended solids. After filtration the liquid is routed to the individual reinjection wells where high-pressure pumps force the liquid back into the receiving strata. The flash vessels, as well as major system piping, are constructed of mild steel. That portion of the flash vessel that is in contact with the aqueous portion of the geothermal brine is clad with stainless steel. Each vessel is equipped with a two-stage entrainment separator which can be washed with condensate to reduce the potential for plugging.

## ALCOHOL PRODUCTION FACILITY

Alcohol production involves several basic steps: (1) feed preparation, (2) saccharification

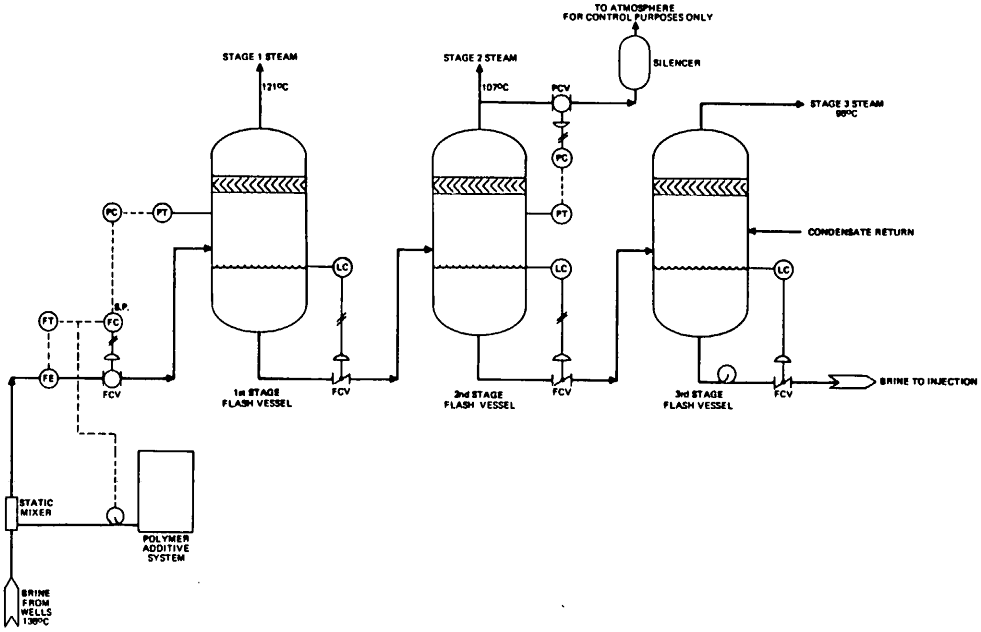

Figure 1. Geothermal Steam Extraction System

to produce sugars (where applicable), (3) fermentation of the sugar solution to ethanol, (4) alcohol recovery and dehydration, (5) stillage drying and evaporation, and (6) by-product drying. The basic steps for wheat processing are shown in Figure 2. These steps consist of cleaning and dry grinding with no separation, followed by slurrying with water to a 30 percent starch dry solids (DS) content that is suitable for fermentation to yield approximately 10 percent ethanol. The pH of the crude starch slurry is adjusted to 6.5 in preparation for gelatinization and enzymatic liquefaction. Potato preparation and sugar beet preparation also involve simple, well-established physical processes. Beet processing yields a fermentable sugar solution directly.

Both potato and wheat starches must be converted into fermentable sugars. Enzymatic schemes were selected for liquefaction and saccharification, based on starch conversion practices currently employed. The processing steps for wheat and potato starches are nearly identical, so the same equipment can be used for both. These steps are as follows:

- Addition of the liquefying enzyme (alpha-amylase) to the raw starch slurry
- Cooking of the slurry by injection of geothermal steam to liberate the starch molecules (gelatinization) to allow enzymatic breakdown of the starch bonds (liquefaction)
- Cooling the slurry and pH adjustment to 4.5
- Conversion of starch to glucose (saccharification) by addition of the saccharifying enzyme (glucoamylase) and holding the solution for about 48 hours prior to fermentation

A batch fermentation approach was chosen because of its relative simplicity and its proven reliability. Batch fermentation consists of charging the fermentation tanks with the sugar solution, and addition of brewers yeast and nutrients. Holding the mash for about 48 hours allows completion of the sugar conversion to ethanol. The mash temperature is maintained at about 30°C by using an external cooling loop to remove the heat of reaction. By-products of the reactions include yeast, carbon dioxide, fusel oils, and aldehydes. After the fermentation period the tank is emptied, cleaned, and sterilized. The tank is then ready to receive another charge of sugar solution. Multiple fermentation tanks are employed to avoid enormous tank sizes and to reduce the total cycle time needed to turn around a tank (fill, ferment, empty, and clean).

Conventional distillation schemes are employed to concentrate the 10 percent alcohol solution (beer) produced in the fermentation process. The beer is first fed to a beer still where an ethanol-water stream below the azeotropic composition is taken overhead. The stillage, leaving the bottom of the column, contains all of the residual solids from fermentation. The concentrated overhead alcohol-water solution is fed to an azeotropic distillation column. Benzene is used in this column to form a ternary azeotrope with the ethanol-water mixture. Water is removed in the overhead stream. The overhead is condensed, cooled, and collected in a phase separator. The benzene-rich layer is recycled to the top tray of the azeotropic column. The water-rich layer is fed to a hydrocarbon stripper. The azeotropic column bottoms stream is virtually 200-proof ethanol. The hydrocarbon stripper, which is the third column, is used to recover the residual benzene and ethanol from the water-rich feed, yielding an aqueous bottom stream containing only about 0.3 percent weight ethanol. Geothermal-derived steam is used as the heat source in the reboilers of all three distillation columns.

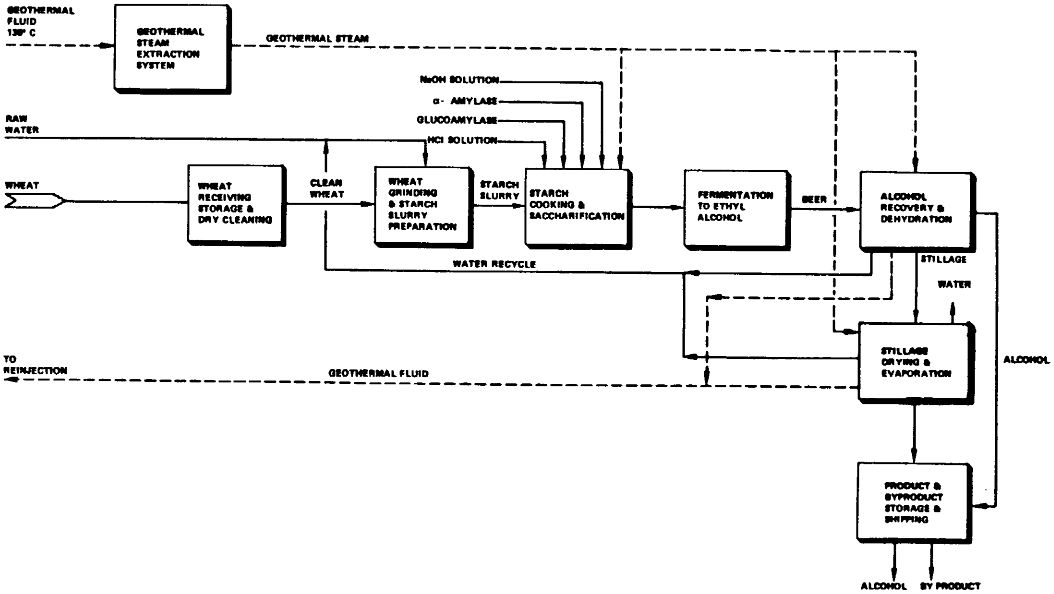

Figure 2. Block flow diagram - wheat processing
76 MM liters/year ethanol plant

The whole stillage from each feed material contains yeast, other insolubles, and dissolved solids from which a single type of by-product animal feed can be recovered. The by-product processing scheme selected involves:

- Centrifugal separation of the whole stillage into a sludge and a thin liquor containing the dissolved solids
- Evaporation of the thin liquor to a syrup-like by-product
- Blending the syrup with the sludge and drying it with geothermal-derived steam as the heat source
- Grinding the dry solid for storage and sale as dry animal feed

## GEOTHERMAL ENERGY REQUIREMENTS

Table 2 shows the geothermal energy requirements for the three feedstock cases. The beet by-product recovery section is a particularly large energy consumer. The higher (gross) heating value of ethanol is about 6.72 kJ per liter (86,700 Btu's per gallon). The geothermal energy input represents a fairly large part of the thermal energy value of the product ethanol.

## CAPITAL COSTS AND ECONOMIC ANALYSIS

The capital cost of the overall ethanol production facility described herein has been estimated. In order to provide a comparison, the three feedstock cases were also costed as separate plants, each with its own handling, fermentation, and processing facilities sized individually to produce 76 million liters (20 million gallons) per year of anhydrous ethanol. The cost of the geothermal production facility including production wells, reinjection wells, and energy extraction facilities is presented separately. Table 3 summarized the estimates, which are based on first-quarter 1980 dollars.

Table 3. Construction Capital Cost Estimate Summary

| Type of Facility | $ MM |
|---|---|
| Overall Ethanol Plant | 64.0 |
| Ethanol Plant - sugar beets only | 51.6 |
| Ethanol Plant - potatoes only | 43.1 |
| Ethanol Plant - wheat only | 40.4 |
| Geothermal Facility | 18.0 |

Based on these capital cost estimates, an economic analysis was made assuming as a base case a 20-year operating life, a 15 percent return on equity, and a 60:40 debt-to-equity ratio. The feedstock costs used for the base case were: wheat at $4.20/bushel; potatoes at $1.50/cwt; sugar beets at $25/ton. The analysis also assumes a by-product credit of $120 per ton. In addition to the base case, a sensitivity analysis was also conducted, varying the major parameters affecting the overall ethanol price. An alcohol price of $0.47 per liter ($1.77 per gallon), 1980 dollars, was calculated for the base case. The results of the base case price and the sensitivity analysis are shown in Figure 3. The cost of geothermal-derived steam was estimated at about 8.5 mills per kJ ($2.50 per million Btu's). This estimate indicates a significant energy cost savings from using geothermal resources over conventional sources of steam generation.

The results of this study indicate a geothermal ethanol project using conventional technology will represent a minimal technical risk. The technology for ethanol production is well known. Because of the low salinity of the Raft River geothermal resource, steam can be extracted with minimal scale deposition problems. The overall economic analysis indicates that the price of the ethanol produced is in the range of current

Table 2. Geothermal Energy Requirements

| | Beets | | Potatoes | | Wheat | |
|---|---|---|---|---|---|---|
| | kJ/s | MM Btu/hr | kJ/s | MM Btu/hr | kJ/s | MM Btu/hr |
| Feed Preparation | 10,960 | 37.4 | 5,100 | 17.4 | 3,080 | 10.4 |
| Fermentation & Alcohol Recovery | 24,820 | 84.7 | 24,730 | 84.4 | 24,760 | 84.5 |
| By-product & Stillage Drying | 25,030 | 85.4 | 8,530 | 29.1 | 12,660 | 43.2 |
| TOTALS | 60,810 | 207.5 | 38,360 | 130.9 | 40,500 | 138.2 |
| kJ Consumed per liter ethanol produced | 6.33 | - | 3.97 | - | 4.18 | - |
| Btu's Consumed per gallon ethanol produced | - | 81,180 | - | 51,250 | - | 54,030 |

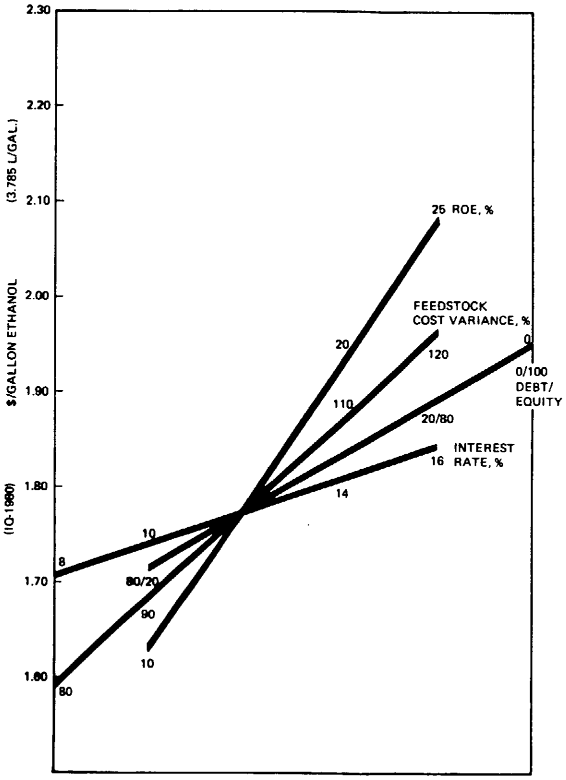

Figure 3. Alcohol Price Sensitivity Analysis

sales prices. Whether this project represents an acceptable economic risk over its 20-year potential life will depend on the relative costs of petroleum derived fuels and on the operating philosophy of the venture group. We believe an ethanol facility of this type should be seriously considered as an alternative fuels project in Idaho, since it will be based totally on renewable resources and energy available in a marginal economic area.

## ACKNOWLEDGMENT

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