GEOTHERMAL ENERGY UTILIZATION IN ETHANOL PRODUCTION

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The Geo-Heat Center conducted an evaluation of using geothermal energy in ethanol production, funded and completed under a grant from Midwest Research Institute, National Renewable Energy Laboratory (NREL) Task Order No. KLDJ-5-55052-01. Presented here is a summary of the results of that study.

OVERVIEW OF ETHANOL USES AND PRODUCTION

Ethanol is also referred to as ethyl alcohol or grain alcohol. According to BBI International (2003), ethanol's primary uses in the U.S. are: as an octane extender for gasoline; as a clean-air gasoline additive in the form of an oxygenate; as a product to foster rural economic development; and as a domestic fuel source to aid in the reduction of U.S. dependence on imported oil. Ethanol blended fuels currently represent more than 12% of U.S. motor gasoline sales, and ethanol blends of up to 10% are approved under the warranties of all the major automobiles sold in the U.S.

At the time of completion of this report, there are currently about 100 ethanol plants in the U.S., producing over 4.2 billion gallons of ethanol annually (www.bbiethanol.com/). Over 20 new plants are planned or are under construction, with an estimated combined annual production of over 1.1 billion gallons of ethanol. As of 2003, approximately 95% of the U.S. fuel ethanol was manufactured from corn (BBI International, 2003).

ETHANOL PRODUCTION PROCESS AND ENERGY REQUIREMENTS

Prior to examining the feasibility of utilizing geothermal energy in ethanol production, it is necessary to detail the process, along with the associated energy and temperature requirements at each step. First of all, there are two types of processes used to produce ethanol: wet-mill process and dry-mill process. In the wet-mill process, corn is soaked or steeped and then separated into its component parts, which are recovered prior to fermentation, and only the starch fraction is processed. In the dry milling process, corn is ground into flour (meal) and processed without separation of component parts. Wet-milling plants have much higher up-front costs and operating expenses than dry-milling plants, and thus are not as common. Consequently, this study only deals with dry-milling process plants.

There are basically eight steps in the dry-milling ethanol production process as summarized below and shown schematically in Figure 1.

1. Milling: The corn (or barley or wheat) is first processed through hammer mills, which grind it into a fine powder the industry refers to as "meal".
2. Cooking and Liquefaction: The meal is then mixed with water and enzymes, which passes through cookers where the starch is liquefied. Cooking is generally accomplished at temperatures of 150-180˚F (65-80˚C). The meal is exposed to a high temperature stage of 250-300˚F (120-150˚C) for a short period of time to reduce bacterial growth in the mash.
3. Saccharification: The process of saccharification involves transferring the mash from the cookers where it is cooled, and a secondary enzyme (glucoamylase) is added to convert the liquefied starch to fermentable sugars (dextrose).
4. Fermentation: Yeast is then added to the mash to ferment the sugars to ethanol and carbon dioxide. Using a continuous process, the fermenting mash will be allowed to flow, or cascade, through several fermenters until the mash is fully fermented. In a batch fermentation process, the mash stays in one fermenter for about 48 hours before the distillation process is started.

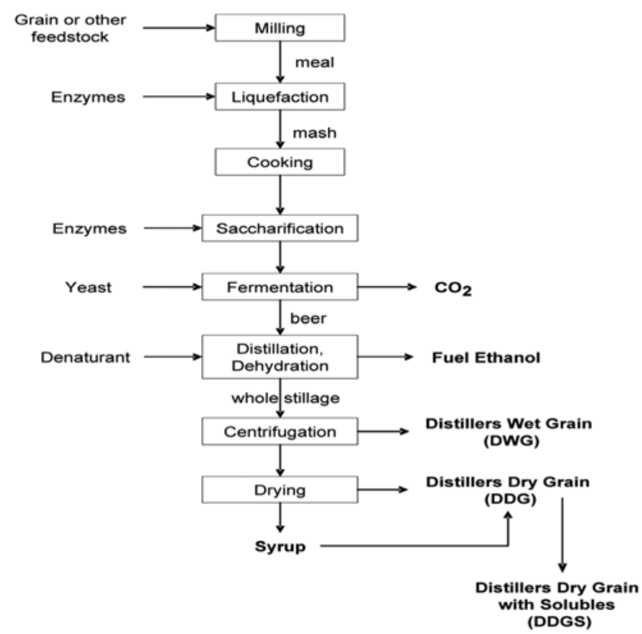

Figure 1. Process schematic of ethanol production using the dry milling process.

5. Distillation: The fermented mash, now called "beer," at this stage contains about 10% alcohol, as well as non-fermentable solids from the corn and the yeast cells. The mash is then pumped to the continuous flow, multi-column distillation system where the alcohol is removed from the solids and the water. Ethanol boils at a temperature of 173˚F (78.3˚C) at sea level pressure, allowing the distillation separation of the ethanol from water, which boils at 212˚F (100˚C) at sea level. The alcohol will leave

the top of the final column at about 95% purity (190 proof), and the residual mash, called stillage, gets transferred from the base of the column to the co-product processing area.

6. *Dehydration*: The alcohol from the top of the column is then passed through a dehydration system where the remaining water is removed. At this point, distillation has diminishing effect, and the remaining water must be removed chemically. Most commercial ethanol plants use a molecular sieve to capture the remaining water in the ethanol. The alcohol product at this stage is called anhydrous ethanol and is approximately 200 proof.

7. *Denaturing*: Ethanol to be used for fuel is then denatured with a small amount (2-5%) of a product (usually gasoline) to make it unfit for human consumption.

8. *Co-Products*: There are two main co-products created in the production of ethanol: carbon dioxide and distillers' grain. Carbon dioxide is given off in significant quantities during fermentation, and many ethanol plants collect this carbon dioxide, clean it of any residual alcohol, compress it, and sell it for use in carbonated beverages or in the flash freezing of meat. Distillers' grain is sold in two forms: distillers' wet grain (DWG) and distillers' dried grain (DDG). Both are high in protein and other nutrients, and are a highly valued livestock feed ingredient. DWG seems to be preferred by dairy and beef cattle (BBI International, 2003), but if a cattle feed lot is not within 100 miles of the ethanol plant, storage and transportation can become problematic. DDG requires a high amount of input energy to dry the grain to 10-12% moisture. The main advantage of DDG over DWG is better "flowability" and longer storage life. Some ethanol plants also create a "syrup" that contains some of the leftover materials, and can be sold as a separate product in addition to the distiller's grain, or combined with it to form so-called "distillers' dried grain with solubles" (DDGS).

According to BBI International (2003), about 85% of the ethanol plants in the U.S. use natural gas as a source of thermal energy. The remainder use propane, fuel oil, or coal. In general, about 20,000 to 40,000 Btu of energy is required to produce a gallon of ethanol and associated co-products. The highest energy requirements are needed when dry distillers grain (DDG) is a co-product. For comparison, the energy content of ethanol is about 85,000 Btu/gal.

Geothermal utilization opportunities exist in three stages of the production process: cooking, distillation, and drying of the distillers grain. In addition, geothermal energy could be used for space heating.

ECONOMIC ANALYSIS

For the economic analysis, an ethanol plant producing 10 million gallons of ethanol annually was considered. According to BBI International (2003) a small plant would be one producing about five million gallons per year. The fraction of the peak load met by geothermal energy was assumed at 75%, and the remaining 25% was assumed to be met by natural gas.

The peak heating load of the fictitious plant is estimated at 26.8 million Btu/hr and the annual heating requirement is approximately 3.0x1011 Btu (operating 350 days per year). The annual energy cost of a conventional ethanol plant using 100% natural gas is estimated at $3.22 million while the annual energy cost of the fictitious ethanol plant using 75% geothermal energy is estimated at $1.19 million.

Capital costs of the fictitious plant using geothermal energy included: design and engineering fees, land acquisition and construction of roads and services to a possibly remote location, exploratory drilling, and final well construction. The capital cost of a comparable conventional ethanol plant is estimated at $21.15 million, while the cost of an ethanol plant using geothermal energy is estimated at $25.72 million. Thus, the incremental cost of the geothermal ethanol scenario above the conventional is approximately $4.57 million or 21.6%

Annual costs considered include all costs associated with ethanol production. For this feasibility study, relative values were taken from BBI International (2003). For both plants, the greatest annual cost item is that associated with acquiring the feedstock (typically corn) and related chemicals and enzymes. For the conventional natural gas ethanol plant, energy costs account for 22.3% of total annual costs, while only 9.6% of the total annual cost is attributed to energy use in the 75% geothermal, 25% natural gas ethanol plant scenario. For the geothermal case, an additional well maintenance cost was assumed at $15,000, or 0.1% of the annual costs.

Annual income was estimated from relative values from BBI International (2003). Income is generated through sale of ethanol, CO_2, and some type of distillers grain. As described previously, the distillers grain is sold as animal feed and can be wet, dry, or mixed with solubles. For the ethanol plant scenario considered here, gross sales of $18.5 million are realized.

For the scenarios examined here, the conventional natural gas ethanol plant yields an annual profit before taxes of approximately $4.1 million, while the 75% geothermal, 25% natural gas ethanol plant yields an annual profit before taxes of approximately $6.1 million. This results in a pre-tax profit margin of $0.41/gal. for the conventional plant and $0.61/gal. for the geothermal scenario.

Thirty-year life-cycle economics were compared using present value comparison. Given the uncertainty of the cost of items, a sensitivity analysis was conducted in order to observe the effects of various cost items on the present value. The items varied in the sensitivity analysis were: natural gas costs, energy required per gallon of ethanol, fraction of energy provided by geothermal, geothermal initial costs, ethanol market price, feedstock price, and electricity costs. Results of the sensitivity analysis are shown in Figure 2. Present values are expressed as a ratio of the geothermal scenario to the conventional scenario. A discount rate of 8% was assumed.

A review of the data presented in Figure 2 shows that, for the base case described above, the geothermal case has a 54% greater present value than the conventional case. The most sensitive item to the present values is the ethanol selling price. As ethanol selling price is decreased, the ratio of the present value of the geothermal case to the conventional case rises dramatically as operating costs become very important. As the ethanol selling price is increased by up to 25%, the present value of the geothermal case relative to the conventional case decreases to about 1.2.

Following the market price for ethanol, the next most sensitive item on the project economics is the feedstock price. An increase in feedstock price of 10% increases the ratio of the present value of the geothermal case to the conventional case up to a value of 2.0. A further increase in the feedstock price up to 25% results in operating costs exceeding profits (and thus resulting in a negative present value) for the conventional case, while the geothermal case remains profitable. Lowering the feedstock price has a similar effect to lowering the natural gas price and the energy required per gallon of ethanol, the next most sensitive items.

The next most sensitive items to the present value ratio, each having a nearly identical impact, are the natural gas price and the energy required per gallon of ethanol. Increasing each by 25% increases the ratio of the present value of the geothermal case to the conventional case to about 2.2. Decreasing these items by 25% has less of an impact, lowering the ratio of the present value of the geothermal case to the conventional case increases to about 1.25.

The next most sensitive item to the present value ratio is the initial geothermal cost, followed closely by the fraction of energy provided by geothermal. As the initial geothermal cost is decreased by 25%, the ratio of the present value of the geothermal case to the conventional case increases to about 1.8. Conversely, as the initial geothermal cost is increased by up to 25%, the ratio of the present value of the geothermal case to the conventional case decreases to about 1.25. When the fraction of energy provided by geothermal is increased by 25% (i.e. up to 93.75%), the ratio of the present value of the geothermal case to the conventional case increases to about 1.76. When the fraction of energy provided by geothermal is decreased by 25% (i.e. down to 56.25%), the ratio of the present value of the geothermal case to the conventional case decreases to about 1.35. The project economics are relatively insensitive to the electricity cost.

SOME POTENTIAL BARRIERS TO GEOTHERMAL UTILIZATION IN ETHANOL PRODUCTION

Although the economics of utilization of geothermal energy can be quite attractive in ethanol production, some barriers to implementation have been identified. One of these is geothermal resource location. If the resource is far from ethanol markets and byproducts markets and/or remote from transportation infrastructure, economics of an ethanol project could become prohibitive. Another challenge in the use of geothermal energy in ethanol production is in the necessary plant design modifications. The majority of ethanol plants use low-temperature steam in their process, but geothermal fluids may be two-phase or single phase liquid, depending on the resource temperatures and pressures.

This will require selection of different heat transfer equipment and modifications to the plant process design (relative to conventional), and will likely incur more design time and cost that may become prohibitive.

Finally, there could be some opportunities in ethanol plants for waste heat recovery that can negatively impact the economics of geothermal energy utilization. This might be the case where thermal oxidation is the best means of destruction of regulated volatile organic emissions and/or odors that could otherwise be released into the atmosphere. Thermal oxidation of air pollutants typically requires destruction temperatures over 1,000°F, resulting in a significant amount of waste heat available for recovery and use in the ethanol production process.

Although some barriers do exist in further development of geothermal utilization in ethanol production, there are some advancements being made as well, particularly with regard to the use of lower temperature resources. New technologies in ethanol production are evolving through research that has been aimed at low-temperature, low-energy chemical process of extracting ethanol from many different types of organic materials.

CONCLUDING SUMMARY

A hypothetical ethanol plant using a dry-milling process was considered for a feasibility study, producing 10 million gallons of ethanol on an annual basis. The energy fraction considered was 75% geothermal and 25% natural gas.

Some specific results of this study are as follows:

- According to BBI International (2003), about 85% of the ethanol plants in the U.S. use natural gas as a source of thermal energy. The remainder use propane, fuel oil, or coal. In general, about 25,000 Btu of energy is required to produce a gallon of ethanol, and the associated dry distillers grain requires an additional 12,700 Btu.
- As of 2003, approximately 95% of U.S. fuel ethanol was manufactured from corn.

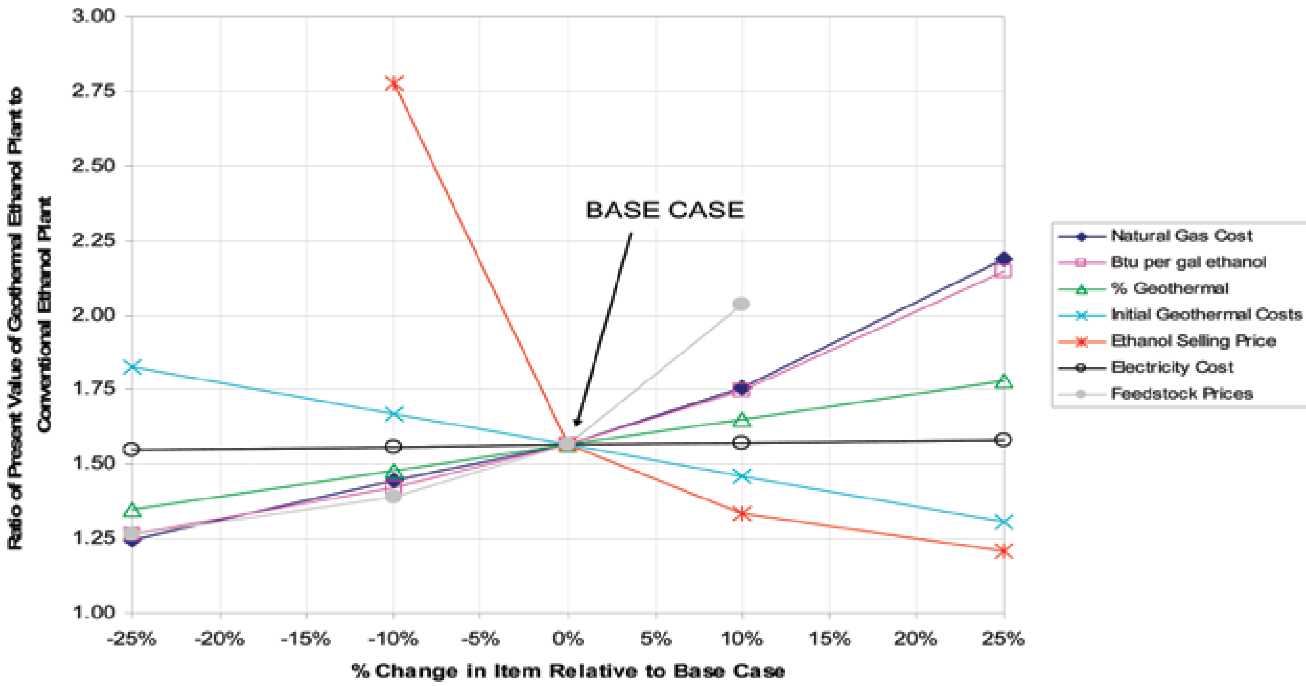

Figure 2. Sensitivity analysis of various cost items on the present value of a geothermal ethanol plant relative to a conventional natural gas ethanol plant.

- Geothermal utilization opportunities exist in three stages of the production process: cooking, distillation, and drying of the distillers grain. In addition, geothermal energy could be used for space heating.
- Cooking is generally accomplished at temperatures of 150-180˚F (65-80˚C). The meal is exposed to a high temperature stage of 250-300˚F (120-150˚C) for a short period of time to reduce bacterial growth in the mash.
- Distillation occurs at temperatures between the boiling point of ethanol (173˚F (78.3˚C) at sea level pressure) and the boiling point of water (212˚F (100˚C) at sea level).
- Grain drying occurs at temperatures exceeding the boiling point of water
- For the base case examined here, the incremental cost of the 75% geothermal plant above the conventional is approximately $4.57 million or 21.6%.
- The estimated annual energy savings with the 75% geothermal plant is $2.03 million or 63.2%. Energy costs account for 22.3% of total annual costs for the conventional plant, while only 9.6% of the total annual cost is attributed to energy use in the 75% geothermal plant.
- The conventional ethanol plant yields an annual profit before taxes of approximately $4.1 million, while the 75% geothermal plant yields an annual profit before taxes of approximately $6.1 million. This results in a pre-tax profit margin of $0.41/gal. for the conventional plant and $0.61/gal. for the geothermal scenario.
- The present value of a 30-year life-cycle of the 75% geothermal plant is 1.54 times greater than the conventional plant.
- A sensitivity analysis of cost items on the present value, shows that project economics are most sensitive to: ethanol selling price, feedstock price, natural gas price, energy required per gallon of ethanol, initial geothermal cost, and fraction of energy provided by geothermal. Project economics are relatively insensitive to electricity cost.
- Some barriers to further development of geothermal energy utilization in ethanol production include: distance of the geothermal resource from markets and/or infrastructure; plant design modifications to account for two-phase or single-phase liquid geothermal fluids; and other waste heat recovery opportunities at an ethanol plant.
- New technologies in ethanol production are emerging that require lower temperature and lower energy per gallon, expanding possibilities for low-temperature geothermal energy utilization.

REFERENCES

BBI International, 2003. Ethanol Plant Development Handbook, 4th Ed. BBI International. Cotopaxi, CO.