# INDUSTRIAL PROCESSES AND THE POTENTIAL FOR GEOTHERMAL APPLICATIONS

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## INTRODUCTION

Industrial applications constitute the smallest sector of direct use and the only one which has experienced a decline in recent years (-7% annual growth 1995-2000). Despite this performance, the industrial sector, at least in theory, offers a very attractive target for geothermal use. Industrial processes operate at high load factor relative to other geothermal applications, offer a concentrated load at a single location and in some cases are characterized by energy as a significant portion of production cost. Together these qualities suggest attractive conditions for geothermal application.

Historically this has not translated into extensive use however. In fact, over the past 20 years, only a handful of projects have been initiated and several of these have ceased operation. The single remaining large application, food dehydration, has been very successful with two large facilities currently operating in northern NV. Another large industrial user was formerly gold mining. These operations also located in northern NV, used the geothermal to heat a solution sprinkled on low-grade ore to remove remaining gold. From a practical standpoint, the mining applications were very successful but due to a combination of downturn in the gold market and high federal royalty costs for the geothermal, all of these operations have ceased.

The issues that have prevented wide-scale use of geothermal in the industrial sector relate to the high temperature requirements for most processes, the use of steam rather than hot water and the fact that geothermal resources tend to be dominated by low-temperature hot water production. Though it is unlikely that large potential exists in the industrial sector there may be some niche opportunities which to date have not been capitalized upon.

## THE DELIVERED COST OF HEAT

A pivotal factor in the economics of a specific direct-use project is the extent to which the resource is used on an annual basis--often expressed as load factor. High load factor correlates with lower cost of delivered heat and industrial applications often exhibit higher load factors than most other geothermal applications.

In direct-use systems, heat is only supplied to the process, the building, the greenhouse, etc., when it is needed and in most cases, this is driven by climate. In warmer portions of the year, little or no heat is required. As a result, the load factor, the ratio of the actual heat used divided by the heat delivered if the system ran at full capacity 8760 hrs/yr, can vary from about 15% to 75% depending on the application. Load factor is normally expressed as the decimal

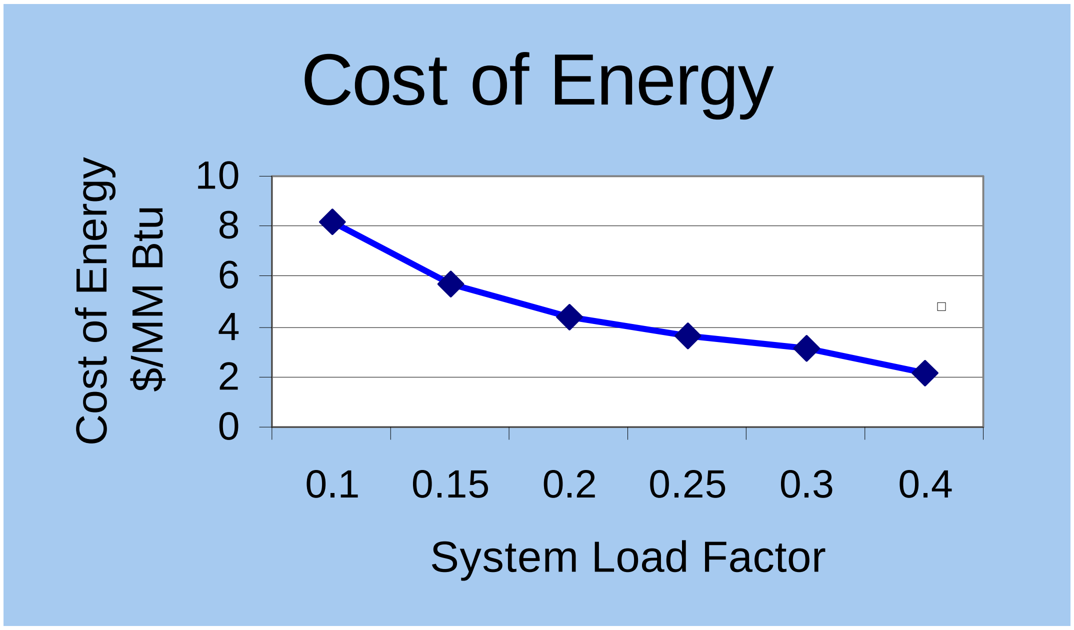

*Figure 1. The influence of load factor on energy cost.*

equivalent such as 0.15 for 15%. Geothermal power plants operate in the range of 0.90 to 1.0. In direct-use, a space heating only application might have a load factor of 0.15 to 0.20, greenhouses 0.18 to 0.24, aquaculture (outdoor open ponds) 0.50 to 0.80 and industrial applications 0.30 to 0.75 (depending on the number of shifts and the nature of the process). Since the cost of the well and pump is related to the peak heating requirement rather than the annual, the greater the quantity of heat over which the capital cost is spread and the lower the unit cost of delivered heat. The cost of delivered heat is a function of the load factor which in turn is a function of the application. The typically high load factor of industrial applications makes them an attractive target for geothermal energy use.

Figure 1 provides an example of the influence of load factor. The plot of cost of delivered heat vs load factor is based upon a system designed for a peak load of 20,000,000 Btu/hr using three 1500-ft production wells and a single injection well. The cost of heat includes capital, maintenance and operating components. Referring to Figure 1, the same geothermal system would produce the following cost of delivered heat for various applications.

| | |
|---|---|
| Space heating application (load factor 0.15) | \$5.50 per $10^6$ BTU |
| District heating system (load factor 0.20) | \$4.30 per $10^6$ BTU |
| Greenhouse (load factor 0.22) | \$4.05 per $10^6$ BTU |
| Industrial application (load factor 0.40). | \$2.10 per $10^6$ BTU |

For comparison, natural gas at \$0.60 per therm and 75% efficiency amounts to approximately \$8.00 per million Btu. Clearly, industrial applications stand out among other applications types in terms of potential savings.

The economics of direct-use is a strong function of the type of application to which the heat is applied. There is no pressing need to reduce the costs of resource development to reduce the cost of direct-use delivered heat. Those costs are already low. The strategy necessary is identifying applications with naturally high load factors (such as industrial applications) or configuring the design to artificially increase the load factor.

Base load (geothermal)/peak load (conventional fuel) design of some systems, though not widely practiced in the U.S., can have a powerful impact on the load factor of the geothermal component. The extent to which it improves overall economics, however, is variable with the type of application. The specifics of the strategy was explored in some detail for greenhouses in (Rafferty, 1996).

## TEMPERATURE REQUIREMENTS OF INDUSTRIAL PROCESSES

Part of the reason for the general lack of industrial applications is the nature of the way industry uses heat. An evaluation of industrial energy use (Brown, et al., 1985) found that of 108 industrial processes surveyed (representing 80% of U.S. industrial energy usage) 97% of all processes required heat input in the form of steam at 250ºF or higher. An examination of direct-use wells in eight states (Figure 2) reveals that 99% of all wells are 250ºF or less. In the context of geothermal, temperatures above 250ºF are in the range of resources that would be used for electric power generation rather than direct-use.

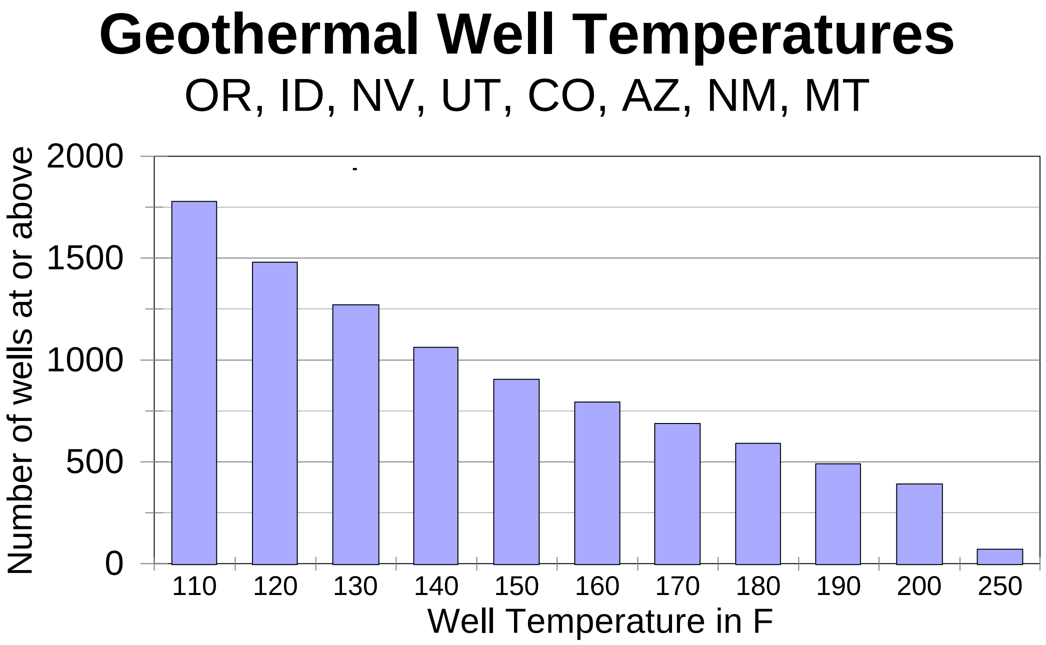

*Figure 2. Geothermal well temperatures in eight western states.*

In most industrial processes, opportunities for lower temperature heat input are satisfied through heat recovery within the process itself and unless the steam is consumed in the process, no boiler make-up water heating is required.

The opportunities in the industrial sector, though attractive from an energy use perspective, are fundamentally mismatched to direct use geothermal in terms of temperature (assuming higher temperature resources are used for electric power generation).

Using information from the Brown, et al., work, an evaluation of the 108 industrial processes was done to identify those processes most applicable to geothermal use. The individual processes were ranked first by the percentage of the heating requirements that were at or below 250°F and secondarily by the energy use per unit of production. This approach was based on the assumption that industries most likely to use geothermal would be those that could displace all or most of existing energy requirements and do so at

**TABLE 1**

| **Process** | **SIC** | **Heat Requirement Btu/Unit** | **% Steam/HW** | **Temp °F** | **% of Heat Input <250°F** | **Notes** |
|---|---|---|---|---|---|---|
| Rayon | 28231 | 46892 | 92/2 | 250/200 | 100 | per lb.rayon produced |
| Acetate | 28232 | 34305 | 96/4 | 250/140 | 100 | per lb. acetate produced |
| manmade fabric fnsh | 22621 | 13,000 | 100 | 250 | 100 | per lb. product |
| polypropylene | 28242 | 9766 | 100 | 260 | 100 | per lb. product |
| dipped latex | 30691 | 7563 | 100 | 230 | 100 | per lb. latex product |
| molded latex | 30692 | 7563 | 100 | 240 | 100 | per lb. latex product |
| acetelyene | 28133 | 5970 | 100 | 250 | 100 | per lb. acetelyene |
| acrylics | 28243 | 5064 | 0/100 | 180 | 100 | per lb. ac fibre 30wet/70dry |
| paper finishing | 26211 | 4900 | 100 | 250 | 100 | per lb. paper produced |
| bldg paper and board | 26611 | 4360 | 100 | 250 | 100 | per lb. building paper |
| bldg paper/brd intgrtd | 26612 | 4215 | 100 | 250 | 100 | per lb. building paper |
| alk/chlorine-mercury | 28121 | 4000 | 100 | 250 | 100 | per lb. chlorine product |
| alk/chlorine-soda ash | 28124 | 3690 | 100 | 250 | 100 | per lb. NaCO3 product |
| SBR rubber | 28221 | 3097 | 100 | 250 | 100 | per lb. product |
| wet corn milling | 20461 | 2853 | 100 | 250/200 | 100 | per lb. corn input |
| canned fruit | 20331 | 2521 | 76/24 | 250/140 | 100 | per can (24/case) |
| butyl rubber | 28222 | 2500 | 46/54 | 250/180 | 100 | per lb. rubber |
| saw mills | 24211 | 2475 | 100 | 250 | 100 | per lb. lumber produced |
| polybutadiene | 28223 | 2264 | 100 | 250 | 100 | per lb. polybutadiene |
| polyisoprene | 28224 | 2252 | 100 | 250 | 100 | per lb. product |
| meat packing | 20111 | 2184 | 88/12 | 250/140 | 100 | per lb. |
| phosphoric acid | 28693 | 1915 | 100 | 250 | 100 | per lb. |
| canned drinks | 20333 | 1763 | 70/30 | 250/140 | 100 | per can (24/case) |
| potash | 28194 | 1100 | 100 | 250 | 100 | per lb. potash product |
| malt beverages | 20821 | 901 | 52/48 | 250/185 | 100 | per lb. beverage produced |
| photographic film | 38611 | 878 | 62/38 | 250/180 | 100 | per lb. film product |
| pharmaceut preps | 28341 | 582 | 100 | 250 | 100 | per $ of sales |
| fluid milk | 20261 | 555 | 100 | 250 | 100 | per lb. |
| cakes/pies | 20512 | 530 | 89/11 | 250/180 | 100 | per lb. product |
| alk/chlorine-soda ash | 28123 | 470 | 100 | 250 | 100 | per lb. NaCO3 product |
| bread/cake | 20511 | 465 | 94/6 | 250/185 | 100 | per lb. product |
| cement | 32731 | 6.5 | 0/100 | 140 | 100 | per lb. cement product |
| canned vegetables | 20332 | 2708 | 88/12 | 250/140 | 90 | per can (24/case) |
| cane sugar | 20621 | 2317 | 72/28 | 300/145 | 87 | per lb. sugar, various temps |
| inorganic pigments | 28162 | 18645 | 100 | 350/250 | 72 | per lb. TiO2 |
| beet sugar | 20631 | 1011 | 94/6 | 280/140 | 67 | per lb. input |
| cumine phenol | 28652 | 9483 | 100 | 500/250 | 56 | per lb. phenol |
| nylon 6 | 28245 | 9987 | 100 | 550/250 | 46 | per lb. nylon product |
| EP rubber | 28225 | 3595 | 100 | 420/250 | 30 | per lb. product |
| PVC suspension | 28211 | 1269 | 100 | 370/250 | 30 | per lb. PVC |
| sodium | 28195 | 2092 | 100 | 275/250 | 27 | per lb. sodium |
| car bodies | 37111 | 1264 | 77/23 | 250/180 | 23 | per lb. finished product |
| styrene | 28651 | 14360 | 100 | 400/230 | 20 | per lb. styrene prod |

temperatures closest to those commonly available from geothermal. Table 1 presents the results. The first column identifies the industry and the second column the Standard Industrial Code (SIC) associated with it. Column three provides the unit heat requirement of the process. This is most often expressed in Btu per pound of product. Industries with the highest unit energy use would be most likely to consider geothermal use. Column four indicates the percentage of steam versus hot water used in the process. Industrial processes are heavily dominated by steam as the heating medium, but there are a few that have significant hot water use (acrylics, butyl rubber, malt beverages and concrete). Column five provides key process temperature requirements. Most industries have heat inputs at multiple temperatures in different stages of the process and in the column the highest and lowest values are indicated. Column six is a key value--the percentage of the process heat requirement that is at or below 250°F. In most cases, the requirement is at 250°F (15 psi steam).

Column 6 indicates the unit upon which the heat requirement is based. In most cases this is per pound of product.

Most the industries with favorable heat use characteristics are in the plastics, rubber, chemical and paper sectors. Interestingly of the 108 processes evaluated, dehydration was not included (though several other food processes were). Based on the energy use per pound of product for geothermal dehydration facilities (Lund, 1994), onion and garlic dehydration would rank just below Acetate in Table 1 in terms of heat energy consumed per unit of production. The success of geothermal dehydration applications suggests that the unit energy approach to industry ranking may have some merit.

The amount of energy consumed in the industrial sector is substantial. For just the two top processes (Rayon and Acetate), according to Chemical and Engineering magazine, the total U.S. production in 2001 was 235,000,000 lbs. At an average of 40,000 Btu per pound of product, the energy consumed amounts to $9.4 \times 10^{12}$ Btu--roughly equivalent to the annual energy supplied by all existing direct use projects in the U.S. combined.

## AN UNTAPPED OPPORTUNITY?

One of the opportunities we have not taken adequate advantage of in the U.S. is combining direct-use with electric power production. This strategy has very attractive features relative to stand-alone development of geothermal resources for direct-use--particularly in the industrial sector. Effluent from geothermal electric power production, especially that from flash plants (flash tanks) is:

- At relatively high temperature,
- Devoid of risk relative to drilling for similar temperature resources,
- Characterized by far lower cost than developing a resource from scratch, and
- Available in substantial quantity

Hurdles would remain in the areas of land access, agreement with the resource/plant owner, location acceptability for the industrial concern, fluid chemistry, etc., but it is strategy that warrants greater attention and promotion than has been accorded it in the past. With the use of vapor recompression technology, it would be possible to boost low pressure steam from flash effluent to higher pressure for industrial uses. In some cases, generation of low pressure steam from hot (190+ °F) fluid streams may also be possible. This could significantly enhance the utility of power plant effluent heat.

Binary plant effluent owing to its typically lower temperature would be a secondary source appropriate for use but more likely for the lower temperature applications (greenhouse/aquaculture) than for industrial purposes.

## VAPOR RECOMPRESSION

Vapor recompression is a technology used in various industries in which low pressure steam exiting from one part of a process (often a cooking or evaporation process)is directed to a compressor where the pressure of the steam is raised so that it can be used in a higher temperature/pressure part of the process. There are limitations in terms of the amount of pressure that can be added at the compressor (most applications are at compression ratios of less than 2:1). This translates into a minimum geothermal fluid temperature requirement of approximately 190°F.

The attractiveness of recompression is that only that energy required to boost the steam to the higher pressure is added at the compressor. This amounts to only a fraction of the energy required to generate equivalent pressure steam at the same pressure with a boiler. Figure 3 presents an example of the recompression strategy for a geothermal application. A flow of 1000 gpm of 230°F water is delivered to a flash tank maintained at 0 psig (atmospheric pressure). Approximately, 8800 lb/hr of steam is liberated in the tank (slightly less than 2% of the inflow) and the remainder is discharged as 212°F water. The compressor raises the pressure of the steam to15 psig and a small flow of water is sprayed into the discharge to control superheat. A total of approximately 9000 lb/hr of steam is delivered at 252°F for use in an industrial process.

The economics of the steam generation are the compelling feature of a process such as this. To produce the flow of steam in the example a 30 hp motor would be required to drive the compressor. At $0.07 per kWh, the energy cost of the steam would amount to approximately $1.68 per million Btu. To generate the equivalent flow of steam using a boiler (75% efficiency, $0.60 per them gas and 200°F condensate return) would amount to $8.57 per million Btu. The compressor supplied steam costs (energy only) just 20% of boiler supplied steam.

The values in the example are not suggested to be the optimum configuration for a recompression design but only to illustrate the potential of the technology. It is potentially one method of capturing moderate pressure/temperature, steam based, industrial applications with low-temperature geothermal water resources.

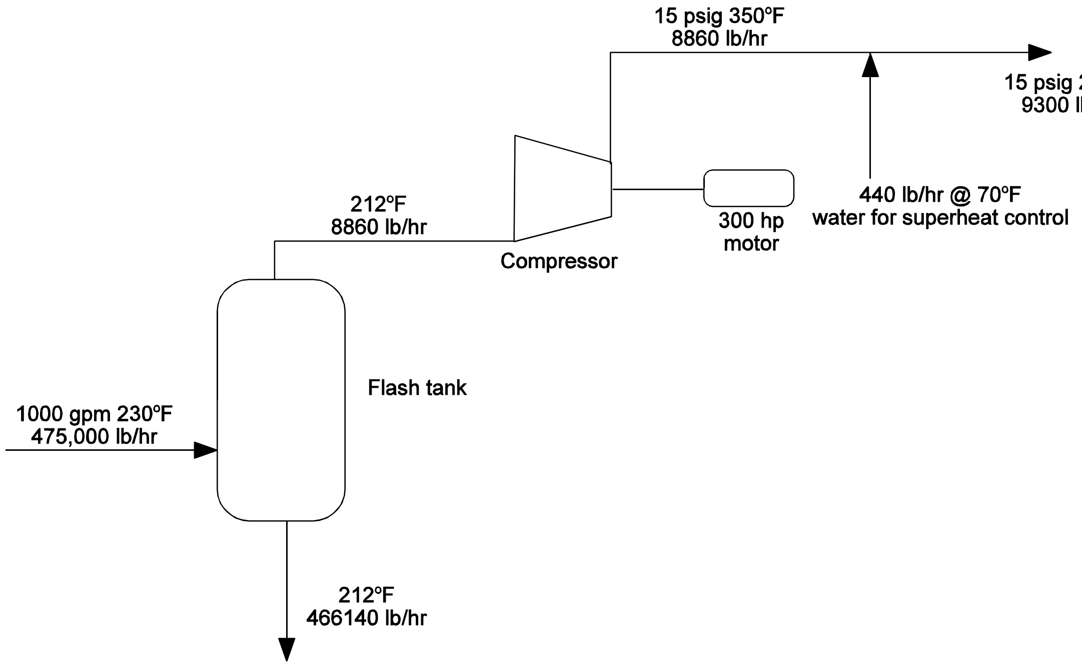

*Figure 3. Vapor recompression using geothermal.*

## CONCLUSION

Although industrial processes consume substantial amounts of heat, the temperatures at which the heat is required are far above the typical range encountered in low-temperature geothermal resources. As a result, it is unlikely that most industries will be able to take advantage of geothermal resources. By carefully targeting those processes characterized by the lower temperature heat input requirements, possibly taking advantage of power plant effluent and technologies such as vapor recompression, there may be niche applications which can yield attractive savings.

Although the industrial processes in Table 1 have been sorted by energy use and temperature level, many other issues can impact the ability to use geothermal resources and the ranking should be considered very preliminary. Geographic limitations would be a critical factor. For paper, celluose fibre and chemical based industries, proximity to feed stocks may be a significant consideration. To gain a more realistic picture of the potential, a more detailed evaluation of the most favorable processes addressing such issues as geography, production volume, transportation costs and other issues would be necessary. In parallel an evaluation of the role, if any for vapor recompression would be useful. An examination of hardware requirements, availability, costs, performance of existing systems in industry and suitability for geothermal fluids (materials) would help to bring clarity to the prospects for this technology.

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