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GEOTHERMAL USE IN WYOMING

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A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources

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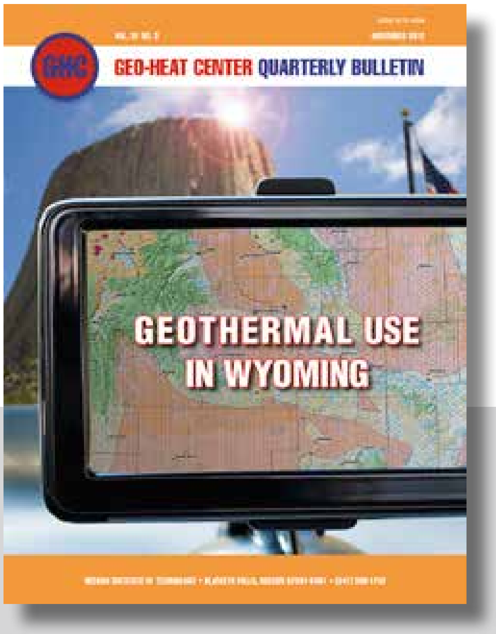

Cover: Photo mosaic of Devil's Tower, Wyoming & map of Geothermal Resources of Wyoming.

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THE ECONOMIC, ENVIRONMENTAL, AND SOCIAL BENEFITS OF GEOTHERMAL USE IN WYOMING

Andrew Chiasson, Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, Oregon

The marvels of geothermal energy have been made famous by Wyoming's Yellowstone National Park. The U.S. National Park Service states: "with half of the earth's geothermal features, Yellowstone holds the planet's most diverse and intact collection of geysers, hot springs, mudpots, and fumaroles. Its more than 300 geysers make up two thirds of all those found on earth. Combine this with more than 10,000 thermal features comprised of brilliantly colored hot springs, bubbling mudpots, and steaming fumaroles, and you have a place like no other". Outside the park boundaries, documented direct uses of geothermal waters in Wyoming are limited to recreational uses, spas, and resorts. There are a few other sporadic uses for aquaculture, greenhouse heating, and individual heating uses by ranchers. Previously-reported snow-melting operations in Laramie and Cheyenne using ammonia heat pipes are no longer operational (J. Nydahl, 2012; personal communication). In addition to direct uses, the Rocky Mountain Oilfield Testing Center (RMOTC) has been conducting research on the feasibility of electrical power generation from co-produced fluids (petroleum and hot water) from deep petroleum wells near Casper, WY.

ECONOMIC BENEFITS

According to U.S. National Park Statistics, Yellowstone National Park currently attracts about 3 million recreational visitors per year, providing an enormous contribution to Wyoming's economy. Since Yellowstone was designated as a National Park in 1872 (America's first national park), over 156 million people have visited the park as of the end of 2011. Aside from tourism and limited recreational swimming and soaking, no other uses of geothermal energy are permitted in Yellowstone National Park.

Figure 1. Heart Spring, one of the many colorful thermal spring features enjoyed by recreational visitors to in Yellowstone National Park.

Outside of Yellowstone National Park, Wyoming's thermal spring resource is enormous, and (excluding the Park) Heasler (1985) estimates that 3 trillion British Thermal Units (Btu) of energy are released each year from natural springs as they cool to ambient temperature – enough thermal energy to heat approximately 8,000 Wyoming homes. However, many of these thermal springs are currently undeveloped and/or primitive, and springs developed for commercial uses in Wyoming are essentially concentrated in four areas: Thermopolis, Jackson, Cody, and Saratoga.

Thermopolis, a Greek word for "Hot City", is located in north central Wyoming, approximately 100 miles from Yellowstone National Park. Some of the geothermal features of Thermopolis, WY are described by Lund (1993). The city derived its name from the hot water that comes from Big Spring, which issues 3.6 million gallons per day of turquoise and green mineral laden water at 127°F. The water from this spring contains at least 27 different minerals, some say, making it very healthful to drink. The hot springs have created large terraces along the river, and these terraces are composed chiefly of colorful lime and gypsum layers known as travertine (from bicarbonate and sulfate ions). The springs are claimed to be the largest mineral hot springs in the world.

Figure 2. Rainbow Terraces produced by Big Springs in Hot Springs State Park, Thermopolis. Source: Thinkstock photos.com.

Commercial facilities at Hot Springs State Park consist of Hot Springs Water Park (formerly Tepee Pools), the State Bath House, the Star Plunge, Best Western Hotel (formerly a Quality Inn), and a Days Inn Hotel (formerly a Holiday Inn). The State Bath House was constructed to fulfill a treaty that was signed in 1896 with the Shoshone and Arapaho Tribes, which allowed public use of Big Spring. The hot springs was known as having "healing water", and there is no fee for using the State Bath House.

The Days Inn and Best Western hotels have hot mineral water piped in from Big Spring. The Days Inn advertises a full-time certified licensed masseuse, hot mineral tubs, steam room, private jacuzzi room, and a year-round outdoor hot mineral pool. The Star Plunge was first built in the late 1800s and has been enjoyed by a number of celebrities such as Buffalo Bill Cody, Butch Cassidy (and "The Hole in the Wall

Gang"), Marlon Brando, and Robert Redford. Both the Star Plunge and Hot Springs Water Park have large indoor and outdoor pools maintained at temperatures of about 90˚F, and flow of spring water is kept continuous through the pools thereby requiring no chemical treatment of the water.

Figure 3. The State Bath House in Hot Springs State Park, Thermopolis. (source: http://thermopolis.com/todo/hot-springs-state-park)

Also in the Thermopolis area is the Fountain of Youth RV Park and Resort using natural mineral water from the historic Sacajawea Well flowing at the rate of 1.4 million gallons per day. This 900-ft.. deep well was originally drilled for oil in 1918, but hot mineral water was found instead at 128˚F under such pressure that it destroyed the oil derrick. Over the decades, the hot water has deposited a colorful travertine cone around the well, which can be seen at the southern edge of the swimming pool. The park boasts the third largest mineral pool in the world.

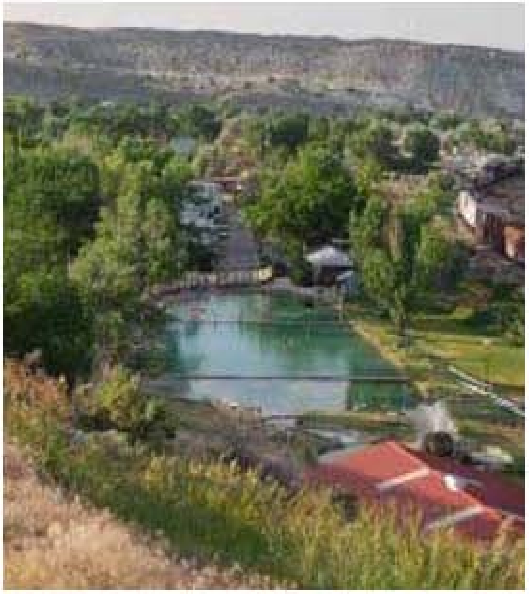

Figure 4. Fountain of Youth RV Park near Thermopolis. (source: www.fountainofyouthrvpark.com /hotspringspool.htm).

The Chief Washakie Plunge offers a warm outdoor pool with hotter indoor private baths, and is located on the Wind River Indian Reservation (on the Shoshone and Arapaho Recreation Complex) in west-central Wyoming. The 112˚F hot springs issues from a gravel-lined pool whose flow is controlled to maintain a 98˚F outdoor pool, an outdoor Jacuzzi, and a small wading pool. Inside the bathhouse are nine private plunge rooms kept at 102˚F for soaking.

Commercial geothermal spas of note in the Jackson area include Sulphur Hot Springs (near Auburn) and Granite Creek Hot Spring. Sulphur Hot Springs has a rich history, dating back to 1827 where trappers began to inhabit the area, trading furs with Indians. Prior to that, the Shoshone and Blackfoot Indians frequented the area for the healing effects of the waters. Today, Suplhur Hot Springs boasts at least 72 springs, with temperatures up to 168˚F, and cabins are available with soaking tubs. Granite Creek Hot Spring is a picturesque soaking pool located at an elevation of 7,000 feet in the Gros Ventre Mountains. According to Birkby (1999), this spring is increasingly popular with winter visitors and offers one of the most picturesque soaks in the Rocky Mountains. The spring temperature varies seasonally from the mid 80s˚F to 112˚F due to runoff from snowmelt.

The Saratoga Resort and Spa in Saratoga is a resort and spa with numerous amenities. Historically, the Indians of the Platte River Valley would seek this area which they called "the place of magic waters". Today, guests at the resort can soak either in a large outdoor pool or in private tepee-covered tubs with temperatures in the range of 105-112˚F. In the town of Saratoga, the historic Saratoga Hobo Pool is located on the banks of the Platte River, and is a natural hot springs once believed to possess healing properties. Now the mineral waters of the hot pool continue to serve as a draw for locals and visitors alike. The pool is open 24 hours a day, 7 days a week year round, with a temperature ranging from 108 to 119˚F.

In addition to the numerous recreational uses of geothermal waters in Wyoming, one documented significant aquaculture use exists at the Jackson National Fish Hatchery. This hatchery facility is physically located on the Fish & Wildlife Service's National Elk Refuge and rears trout for a distribution area that covers close to 18,000 square miles, and is also a part of the Fish & Wildlife Service's National Broodstock Program.

The Jackson National Fish Hatchery utilizes thermal water at 78˚F from a well for tempering trout-rearing ponds. Since trout prefer cold water, the main use of the geothermal source is in the winter months. The well is also used as an open-loop source for space heating of the building with a geothermal heat pump.

The numerous geothermal-related activities in Wyoming employ many people directly and indirectly. Geothermal uses significantly contribute to Wyoming's tourism economy, creating many direct and indirect jobs. Yellowstone National Park alone employs thousands of people every year, some seasonally and some permanently. Exclusive of Yellowstone, using a standard multiplier of 2.5, geothermal businesses create an estimated 100 direct, indirect, and induced jobs in Wyoming.

Figure 5. Tepee-covered soaking tubs at the Saratoga Resort and Spa, Saratoga, WY. (source: http://www.saratogaresortandspa.com/)

Figure 6. Jackson National Fish Hatchery.

ENVIRONMENTAL BENEFITS

In addition to energy savings, geothermal energy usage prevents the emissions of greenhouse gases (GHG) and air pollutants, helping to keep a healthy living environment. If these activities used fossil fuels to generate the heat that geothermal water provides, they would emit at least 154,841 tonnes of carbon dioxide equivalent each year (Table 1) — the equivalent of removing 30,200 passenger vehicles from the road, saving 360,000 barrels of oil, and saving 32,900 acres of pine forest.

SOCIAL BENEFITS

Social benefits are difficult to measure quantitatively. One key social benefit from geothermal energy use in Wyoming, however, is improved quality of life through recreation and spa therapy. Geothermal sources provide many unique recreational opportunities enjoyed by tens of thousands of people each year, attracting tourists to the state. Given the history of the geothermal spa industry, social benefits have been evident for many past generations. Yellowstone National Park has provided unique educational opportunities of geothermal features to people worldwide.

THE FUTURE

Wyoming has significant geothermal potential for future uses, from new applications of direct use heating, to resurgence in mineral spa therapy, to development of low-to-moderate temperature resources for electrical power generation.

Much of Wyoming's geothermal resources have yet to be developed for direct uses, perhaps because of the State's low population of less than 600,000 people (the lowest state population in the entire U.S.). However, the Geo-Heat Center lists 5 communities in the State that are within 5 miles of a geothermal resource with a temperature of 122°F or greater, making them possible candidates for district heating or other geothermal use. Also, Wyoming has a rich history related to the balneological use of geothermal waters, a practice which appears to be making a comeback. The western and northwestern portion of the State, particularly the Cody area, have semi-developed springs and/or previously-developed springs that are not currently commercially operational (e.g., Astoria Hot Springs, DeMaris Hot Springs, Granite Hot Springs, Kelly Warm Springs, Kendall Warm Springs, and Steele Hot Springs). Examples of previously developed thermal springs in the eastern portion of the state include Jackalope Plunge near Douglas. These semi-developed and previously-developed springs could be readily turned into viable businesses when the right buyers and market emerge.

The potential of electricity generation from co-produced geothermal fluids from Wyoming oil fields is significant. Hinckley (1983) calculated that 24 trillion Btu is available from water as a by-product of oil production, and continued interest in co-produced fluids remains at RMOTC.

Table 1. Energy Production and Carbon Emissions Offsets by Geothermal Energy Utilization in Wyoming.

Site	Location	Application	Temp. (F)	Annual Energy Use		Annual Emission Offsets (metric tonnes)		
				(10^9 Btu/yr)	(10^6 kWh)	NO_X	SO_X	CO_2
Jackson National Fish Hatchery	Jackson	Aquaculture	78	2.8	0.8	1.3	1.3	753
Hot Springs State Park	Thermopolis	Resort/Pool	135	383	112	174	184	103,811
Fountain of Youth RV Park	Thermopolis	Resort/Pool	125	107	31	48	51	28,897
Chief Washakie Plunge	Fort Washakie	Resort/Pool	112	14	4.0	6.2	6.5	3,690
Granite Creek Hot Spring	Teton County	Resort/Pool	112	7	2.1	3.2	3.4	1,899
Sulphur Hot Spring	Near Auburn	Resort/Pool	144	5.7	1.7	2.6	2.7	1,547
Saratoga Resort and Spa	Saratoga	Resort/Pool	114	32	9.2	14	15	8,547
Hobo Pool	Saratoga	Resort/Pool	118	21	6.2	9.5	10	5,698
TOTALS				**571**	**167**	**259**	**274**	**154,841**

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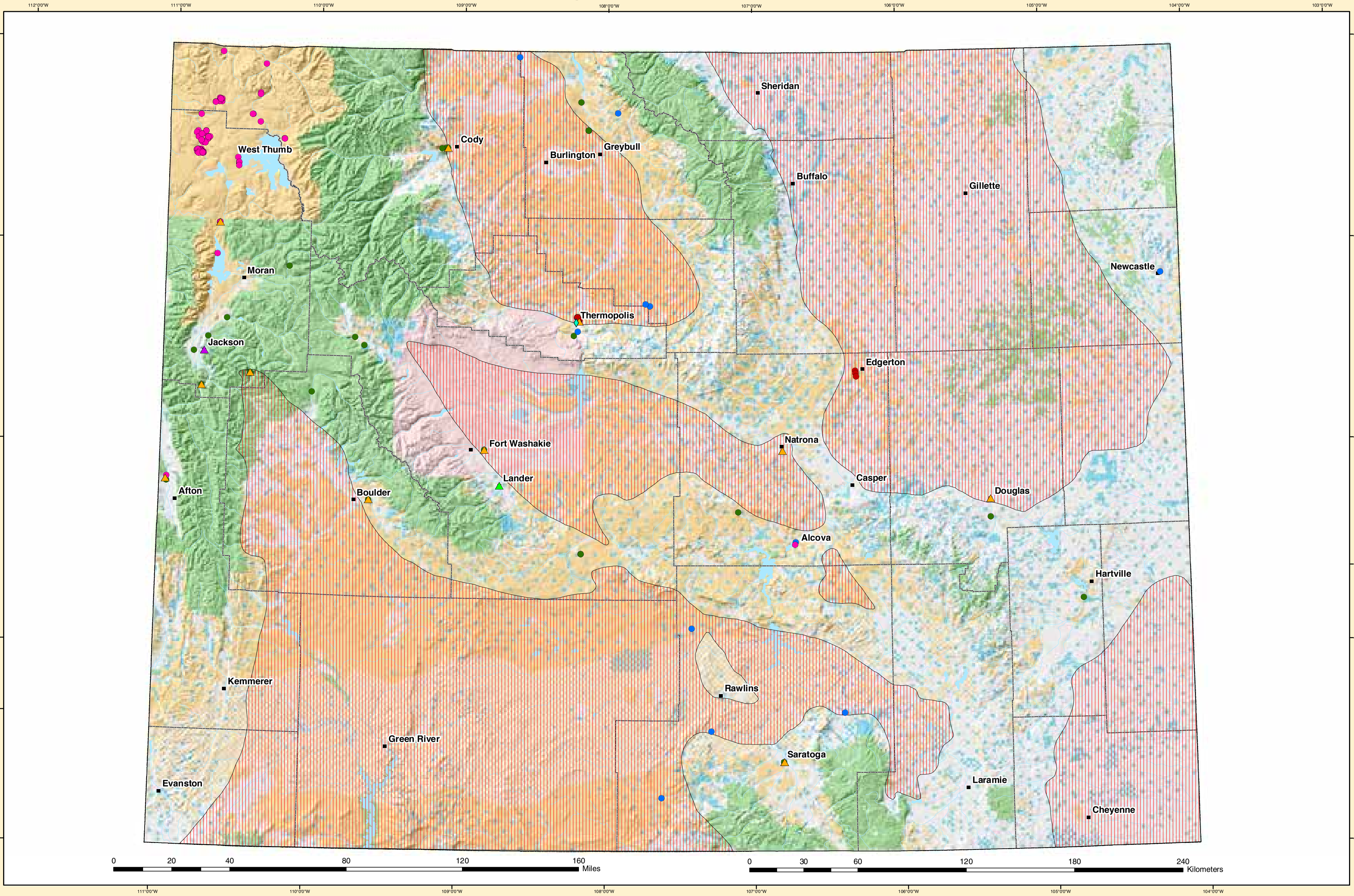
Wyoming Geothermal Resources



Legend

- ■ Cities/Towns
- County Boundaries
- Rivers/Streams
- Lakes/Reservoirs

Geothermal Categories

- ▲ Greenhouse
- ◆ Space Heating
- ▲ Aquaculture
- ▲ Spas/Resorts/Recreation Sites
- ▨ Regions of Known or Potential Geothermal Resources
- ● Wells > 50 Degrees C
- ● Springs > 50 Degrees C
- ● Wells ≥ 20 and ≤ 50 Degrees C
- ● Springs ≥ 20 and ≤ 50 Degrees C

Note: Not all of the known springs in Yellowstone National Park are plotted on this map.

Ownership

- ▨ Private Lands
- ▨ Bureau of Land Management and Other Federal Lands
- ▨ State Lands
- ▨ Native American Lands
- ▨ U.S. Forest Service Lands

Map Prepared by Patrick Laney and Julie Brizzee at the Idaho National Engineering and Environmental Laboratory
For
The U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Geothermal Technologies Program

Geothermal Data Provided by:

1. Geo-Heat Center State Geothermal Database, [Compact Disk], February 2002
2. National Geophysical Data Center, National Oceanic and Atmospheric Administration, 1983, Geothermal Resources of Wyoming: Prepared for the Geothermal and Hydropower Technologies Division United States Department of Energy, Map 1:500,000

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Map Projection Information:
Projection: Lambert Conformal Conic
Units: Meters
Central Meridian: -107.50
Standard Parallel 1: 33.00
Standard Parallel 2: 45.00
Latitude Of Origin: 41.00
Datum: North American 1927

USE OF GEOTHERMAL ENERGY IN DAIRY PROCESSING

Jack Kiruja, Geothermal Development Company, Nairobi, Kenya

ABSTRACT

The growth of industries is dependent on the availability and affordability of energy. However, conventional energy sources such as fossil fuels are getting depleted and their price is increasing rapidly due to market forces and world politics. It is therefore necessary to consider alternative sources of energy and geothermal energy is a potential option. Geothermal energy can be utilized for both electricity generation and direct uses such as heating and cooling. The dairy industry in Kenya can benefit immensely from the vast geothermal energy in the country since both dairy farming and the geothermal resources are located in the same region i.e. the Rift Valley region. Furthermore, dairy processing involves both heating and cooling operations, whose energy requirements are within a range for the geothermal resource in Kenya to cater. This paper discusses some of the dairy processing operations which can utilize geothermal energy and the appropriate technology which can be applied for each operation. The energy demand and the cost of each operation are also discussed.

INTRODUCTION

Kenya is largely an agricultural country in which crop cultivation, livestock keeping, fisheries and beekeeping are the main activities especially in the rural areas where most of the population live. These activities are practiced in different parts of the country depending on the prevailing climatic conditions of the region and the customs of the people living in that region.

Livestock keeping has been practiced for centuries in Kenya, mainly in the semiarid North and North-eastern parts of the country where the drought resistant Zebu cattle are the main breed. Traditionally the cattle were kept to provide milk and blood which were the main diet at the time and as a measure of wealth. However, with the coming of the European settlers, new breeds of cattle were introduced into the country mainly for milk production. These included Friesian, Ayrshire and Guernsey among others (EPZA, 2005).

Dairy farming is practiced extensively in the Central highlands and in the Rift Valley region of Kenya. The output from these regions account for about 80% of the milk produced in the country (KDB, 2010). Table 1 below shows the areas of the country in which dairy farming is most active. It is important to note that Nakuru and Naivasha are in the Rift Valley while Nairobi gets most of the milk from Kiambu which is in the Central region.

Since the liberalization of the dairy industry in 1992, there has been an increased entry of milk processors in the market. Among the products they process are liquid pasteurized milk, yoghurt, cheese, ice cream and ghee (EPZA, 2005). Liquid pasteurized milk is by far the largest output due to its huge demand in the country especially in the urban centres. There are wide discrepancies in milk consumption in rural and urban populations and across income groups. However, consumption at household level is higher in urban than in the rural regions. Statistics for 1999 indicate that the annual per capita consumption of milk in rural areas was 45 litres for milk-producing households and 19 litres for milk-purchasing households, while the urban per capita milk consumption was estimated at 125 litres (KDB, 2009).

Table 1. Dairies in Central Kenya and Rift Valley Region (EPZA, 2005).

Area	Producers	Processors	Milk Dairies
Nairobi	499	11	6
Mombasa	65	3	-
Nakuru	65	7	2
Naivasha	73	3	2

Initially, large scale dairy farming was the main driver of the dairy industry but at the moment small scale dairy farming accounts for about 70% of the produce (EPZA, 2005). The dairy industry in Kenya has been growing steadily over the years and at the moment; milk production from cows only is about 4 billion litres per year. This is illustrated in Figure 1.

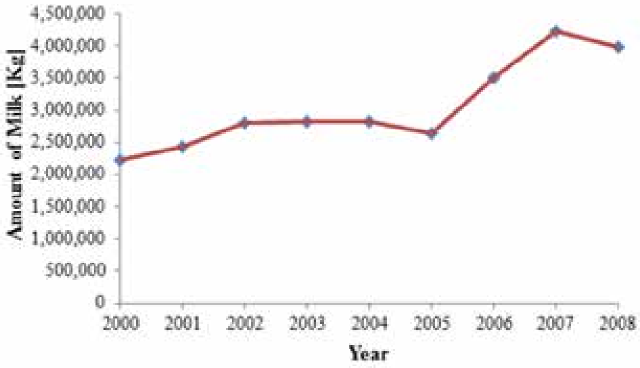

Figure 1. Milk production in Kenya (KDB, 2009).

Energy Source for Dairy Processing

The Kenyan Rift Valley is not only home to dairy farming but also the largest geothermal resource in Africa. The expansion of geothermal energy production in the country is expected to avail surplus thermal energy. Proper planning for the use of this energy is important prior to reinjecting the water back into the ground.

Kenya's geothermal resources are high temperature and liquid dominated. This means that large quantities of hot water are produced as by-products of power generation. It is also important to note that some of these geothermal resources are strategically situated in agriculturally rich areas such as Menengai geothermal prospect in Nakuru County. Nakuru town is one of the fastest growing towns in Kenya, where several industries are starting their operations. This provides vast opportunities for utilising the geothermal energy directly.

The heating and cooling processes of dairy processing can benefit from direct utilisation of the geothermal energy in Menengai. The technology that has been developed to utilise heat to provide cooling is known as absorption refrigeration while pasteurization is the technology for the thermal treatment of milk.

The dairy processing plants in Nakuru are situated close to the geothermal prospect and therefore transporting the geothermal fluid from the source to the target location will be relatively easy. Table 2 shows some of these dairies and their processing capacities. Geothermal wells have already been drilled close to some of these locations, and the use of geothermal fluid in the dairy industry can be considered as a by-product while electricity production is the primary product.

Table 2. Dairy Plants Close to the Geothermal Prospect of Menengai (EPZA, 2005).

Processor	Location	Installed Capacity (Lt/Day)	Actual Capacity (Lt/Day)
Spin Knit Dairy	Nakuru/Nairobi	150,000	100,000
Lelkina Dairy	Molo/Nakuru	30,000	20,000
Kenya Milk Products	Nakuru	15,000	6,000
Ilara	Rongai/Nakuru	40,000	5,000
Solai Mawa Factory	Solai/Nakuru	3,000	2,000
Supa Duka	Nakuru	1,500	1,000
Total		239,500	134,000

DAIRY PROCESSING

Milk starts to go bad within hours once it is out of the body of the cow. It is therefore important to begin to process it as soon as possible in order to preserve it for longer. Processed milk can be preserved for days or even months depending on the kind of treatment it has been subjected to. The major methods of treatment are chilling, heat treatment and evaporation (Bylund, 1995). It is clear that these are all thermal processes that entail the removal or addition of heat.

Chilling

Chilling is the initial treatment of milk prior to further processing. The temperature of milk is reduced to 2-4°C so as to slow down the action of microorganisms and enzymes which are responsible for spoilage. In addition, after processing the milk should be cooled again before packaging to secure a longer shelf life. Ice water is used to provide cooling in storage silos and in the cooling section of the pasteurizer.

Thermal Treatment

Thermal treatment involves heating of every particle of milk or milk product to a specific temperature for a specific period of time without allowing recontamination of that milk or milk product during the heat treatment process. This thermal treatment of milk is done for two major reasons. Firstly, it should achieve total destruction of all pathogenic microorganisms which could cause diseases in people. Secondly, a significant reduction in the quantity of spoilage enzymes and microorganisms in the milk should be achieved in order to improve the shelf life of the milk from a day or two up to about two weeks (DST, 1999).

In order to meet its objectives without destroying the natural chemical and physical properties of milk as well as the nutrients, a suitable time-temperature combination for heat treatment should be determined. The combination is determined by the concentration of microorganisms to be destroyed, the acceptable concentration of microorganisms that can remain behind after thermal treatment and the thermal resistance of the target microorganisms. This combination is based on the thermal death time of *Coxelliae burnettii*, which is the most heat resistant pathogen found in milk (Bylund, 1995).

Some of the most common thermal treatment techniques are shown in Table 3 below together with their required time-temperature combinations. Pasteurization is the most common of these techniques and can either be low temperature long time (LTLT) or high temperature short time (HTST).

Table 3. The Main Categories of Heat Treatment in Dairy Processing (Bylund, 1995).

Process	Temp. (°C)	Time (sec.)
Thermisation	63 – 65	15
LTLT pasteurisation of milk	63	1800
HTST pasteurisation of milk	72 – 75	15 – 20
HTST pasteurisation of cream.	>80	1 – 5
Ultra pasteurisation	125 – 138	2 – 4
UHT (flow sterilisation) normally	135 – 140	1-3
Sterilisation in container	115 – 120	1200-1800

The enzyme phosphatase which is always present in raw milk is normally used to determine the effectiveness of pasteurization. This is because it is destroyed by the time-temperature combination necessary for complete pasteurization and its absence in milk is an indicator of adequate heating as shown in Figure 2.

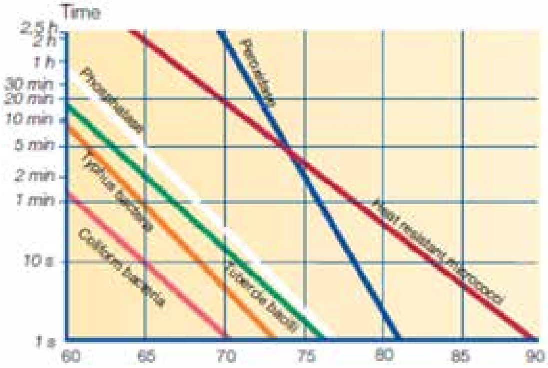

Figure 2. Time-temperature curves for the destruction of some enzymes and microorganisms (Bylund, 1995).

Energy Demands

The growth of industries the world over has relied heavily on the availability of energy to drive the mechanical, electrical and thermal processes. The energy demand varies from one industry to another with the smelting industries leading with the highest demand.

The energy demand in dairy processing is mainly for heating the water which is used in pasteurization and cleaning of the equipment. Other operations that require energy are running of the machinery, refrigeration of the milk before and after processing to control spoilage and evaporation in order to obtain milk powder. Table 4 below shows the energy consumption in a typical modern dairy.

Table 4. Data on Total Consumption of Energy in kWh/litre of Processed Milk from Some Nordic Dairies (Korsström and Lampi, 2002).

Product range*	Sweden	Denmark	Finland	Norway
Market milk + cultured products	0.11 – 0.34	0.07 – 0.09	0.16 – 0.28	0.45
Cheese, whey	0.15 – 0.34	0.12 – 0.18	0.27 – 0.82	0.21
Powder, cheese and/or liquid products	0.18 – 0.65	0.30 – 0.71	0.28 – 0.92	0.29 – 0.34

HEAT EXCHANGERS

A heat exchanger is a partition that keeps the hot water, hot pasteurized milk, unpasteurized milk and cooling water separated during dairy processing. The heat exchangers in dairy processing are made of stainless steel plates which have a good overall heat transfer coefficient and are corrosion resistant. These are the pasteurizer, the regenerator and the cooling section.

Pasteurizer

A pasteurizer is the heat exchanger in which the milk attains the desired temperature from the heating medium. The heating medium could be hot water or low pressure steam but water is preferred. The temperature difference between the milk and the hot water should be maintained at 2-3°C at every point in the pasteurizer to prevent coagulation of the proteins as this will result in fouling (Bylund, 1995). Fouling creates a layer of organic material on the surface of the heat exchanger resulting in a reduction in the heat transfer coefficient of the plates.

Regenerator

In processing, products such as milk are heated and then cooled. The heat of the pasteurized milk is in most cases used to heat the cold incoming milk. By so doing, the incoming milk is preheated while the outgoing milk is precooled. This saves energy for heating and refrigeration, and it is referred to as heat recovery or regenerative heat exchange. In dairy processing, 90-95% of the energy is recovered through regeneration.

$$R = \left(\frac{t_r - t_i}{t_p - t_i}\right) \quad (1)$$

Where

R = regenerative efficiency (%)

t_r = milk temperature after regeneration (°C)

t_i = temperature of raw incoming milk (°C)

t_p = pasteurisation temperature (°C)

Cooling Section

After pasteurization, a few spoilage microorganisms still remain in the milk. It is for this reason that milk should be cooled to ≤ 4°C after pasteurization to keep these microorganisms inactive in order to minimise spoilage. Cooling of the milk takes place at the last section of the heat exchanger using ice water at a temperature close to 0°C. In some cases glycol is added to the cooling water to lower its freezing point and attain lower temperatures (Bylund, 1995). Figure 3 below shows the three heat exchangers used in milk pasteurization and cooling in a dairy plant.

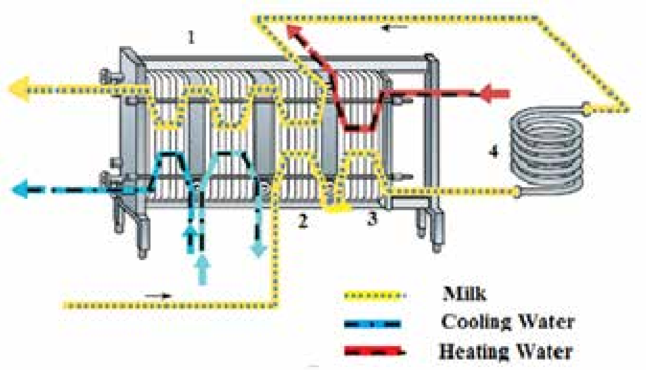

Figure 3. Cooling section (1), regenerator (2) and Pasteuriser (3) (Bylund, 1995)

The good overall heat transfer coefficient in the heat exchangers is made possible not only by the thinness and good thermal conductivity of stainless steel plates, but also by the design of the plates. The plates are corrugated to create turbulence in the flow of milk and hot water. Furthermore, the two fluids flow in opposite directions to enhance energy efficiency as shown in Figure 4.

Logarithmic Mean Temperature Difference

The driving force for heat transfer in a heat exchanger is the temperature difference between the heating medium and the product being heated. The bigger the temperature difference the bigger the quantity of heat transferred. However, the temperature difference when heating milk should be small to avoid fouling in the heat exchanger. Since this temperature difference varies within the heat exchanger, a logarithmic mean value is normally used and it is called Logarithmic mean temperature difference (LMTD).

In order to achieve efficient utilisation of energy during heat transfer, the two fluids should flow in opposite directions i.e. counter current flow, where the cold milk meets the cold heating medium at the inlet, and a progressively warmer medium as it passes through the heat exchanger. During the passage the milk is gradually heated so that the temperature is always only a few degrees below that of the heating medium at the corresponding point as shown in Figure 5.

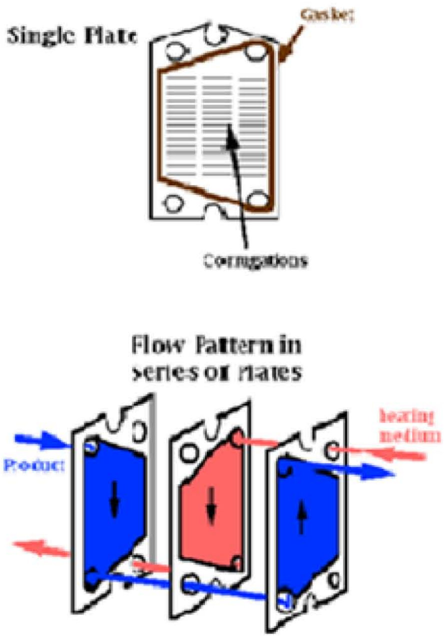

Figure 4. Plate heat exchanger (DST, 1999).

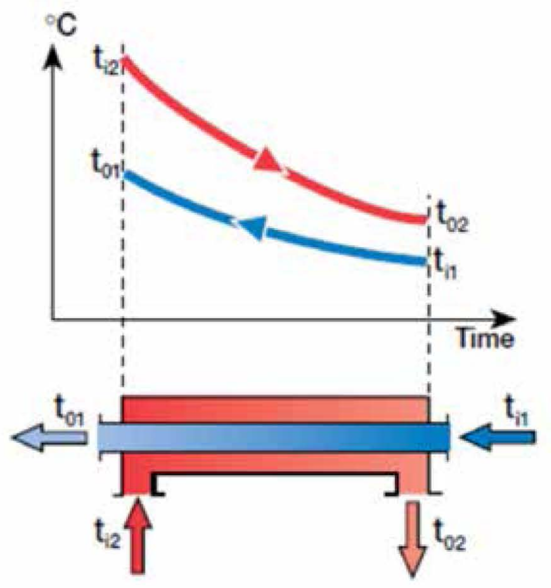

Figure 5. Counter current flow of fluids in a heat exchanger (Bylund, 1995).

$$\mathrm{LMTD} = \Delta T_m = \frac{(t_{i2} - t_{o1}) - (t_{o2} - t_{i1})}{ln\frac{(t_{i2} - t_{o1})}{(t_{o2} - t_{i1})}} \qquad (2)$$

The amount of energy transferred across a heat exchanger depends to a large extent on the area of the exchange surface. Area of the heat exchanger is determined as follows:

$$Q = UA\Delta Tm \qquad (3)$$

Where

A = Required heat transfer area [m^2]
ΔT_m = logarithmic mean temperature difference [°C]
U = overall heat transfer coefficient [W/m^2K]
Q = Heat transfer rate in the heat exchanger [W]

MILK POWDER

The processing of milk powder entails the reduction of moisture down to 2.5-5% through evaporation and drying. At this moisture content, bacteria cannot grow and therefore, the milk can be stored for up to six months in the case of whole milk and three years for skimmed milk (Bylund, 1995). Not only does drying increase the shelf life of milk but also reduce its volume and weight, and hence saves on transport and storage cost.

The first step in the production of milk powder is the evaporation of the free water between the solid particles. This is done in order to concentrate the milk and grow the size of the solid particles. Falling-film evaporators are generally used for milk concentration, which is carried out in two or more stages to a dry matter content of 45 – 55%. Since evaporation is carried out in a partial vacuum, the water in the milk boils at low temperatures. Hot water at 65-70°C is used as the heating medium and this can easily be obtained from geothermal sources. The second stage is the evaporation of water in the pores and capillaries of the solid particles. This stage is normally carried out in a spray tower as the one shown in Figure 6 (Bylund, 1995). It involves

- Dispersion of the concentrate into very fine droplets.
- Mixing of the finely dispersed concentrate into a stream of hot air which quickly evaporates the water.
- Separation of the dry milk particles from the drying air.

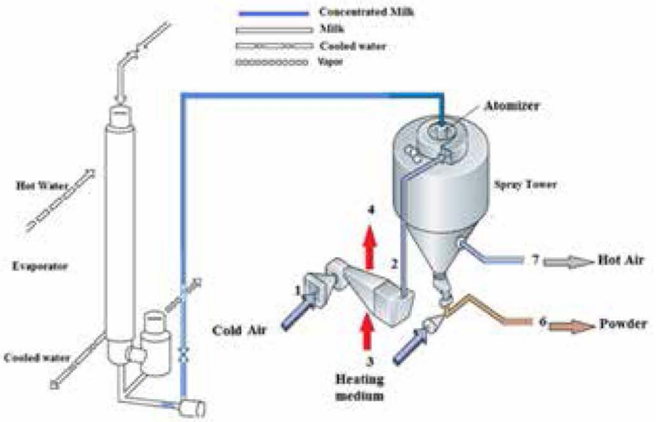

Figure 6. Falling film evaporator and spray tower for milk powder production (Bylund, 1995)

In the falling film evaporator, the following equations apply for mass flow determination (GEA, 2011).

$$m_{milk} = m_{concentrated\ milk} + m_{vapour} \qquad (4)$$

$$Ratio_{evaporation} = e = \frac{dry\ matter_{concentrated\ milk}}{dry\ matter_{milk}} \qquad (5)$$

$$m_{concentrated\ milk} = m_{milk} * \frac{1}{e} \qquad (6)$$

Where

m_{milk} = flow rate of unprocessed milk (kg/s)

$m_{concentrated\ milk}$ = flow rate of concentrated milk (kg/s)

m_{vapor} = evaporation rate (kg/s)

dry $matter_{concentrated\ milk}$ = dry matter in concentrated milk

dry matter $_{milk}$ = dry matter in unprocessed milk

CLEANING

Cleaning in dairy processing is very important for hygienic reasons and for maintaining good energy efficiency in the heat exchangers. This is because during pasteurisation and storage, milk particles stick on the surfaces of the equipment and could harbour bacteria and other harmful microorganisms. These particles usually have insulating properties and reduce the transfer of heat across the surfaces thereby leading to poor energy efficiency.

Cleaning achieves the removal of physical dirt from the surfaces, chemical dirt such as fats and vitamins and finally disinfection. In modern dairies, cleaning in place (CIP) without dismantling the equipment is the common practice and is of two types.

- CIP programs for circuits with pasteurisers and other equipment with heated surfaces.
- CIP programs for circuits with pipe systems, tanks and other process equipment with no heated surfaces.

The main difference between the two types is that acid circulation must always be included in the first type to remove encrusted protein and salts from the surfaces of heat-treatment equipment. A CIP program for a pasteuriser, i.e. hot components, consists of the following stages:

a) Rinsing with warm water for about 10 minutes.
b) Circulation of an alkaline detergent solution (0.5 – 1.5%) for about 30 minutes at 75°C.
c) Rinsing out alkaline detergent with warm water for about 5 minutes.
d) Circulation of (nitric) acid solution (0.5 – 1.0 %) for about 20 minutes at 70°C.
e) Post-rinsing with cold water.
f) Gradual cooling with cold water for about 8 minutes.

The pasteuriser is usually disinfected before production starts. This is typically done by circulating hot water at 90 – 95°C for 10 – 15 minutes.

A CIP program for a circuit with pipes, tanks and other "cold components" can comprise the following stages:

a) Rinsing with warm water for 3 minutes.
b) Circulation of a 0.5 – 1.5% alkaline detergent at 75°C for about 10 minutes.
c) Rinsing with warm water for about 3 minutes.
d) Disinfection with hot water 90 – 95°C for 5 minutes.
f) Gradual cooling with cold tap water for about 10 minutes.

The Table 5 shows the consumption of water by some dairies in the Nordic countries.

TABLE 5. Data on the Consumption of Water in litres/litre of Processed Milk from some Nordic Dairies (Korsström and Lampi, 2002)

Product range	Sweden	Denmark	Finland	Norway
Market milk + cultured products	0.96 – 2.8	0.60 – 0.97	1.2 – 2.9	4.1
Cheese, whey	2.0 – 2.5	1.2 – 1.7	2.0– 3.1	2.5 – 3.8
Powder, cheese and/or liquid products	1.7 – 4.0	0.69 – 1.9	1.4 – 4.6	4.6 – 6.3

MILK COOLING AND COLD STORAGE

Milk has a very short shelf life because it is a medium with an excellent environment for micro-organisms to thrive. It is therefore important to consume it as soon as possible after production. However, this is not always possible due to the requirement to heat treat it and also because of the need to transport it to different location for consumption after processing. In order to ensure that the milk does not go bad while awaiting processing or during storage, cooling should be undertaken to lower the activity of the micro-organisms.

When the milk arrives at the dairy, it is pumped into silos where it could remain for up to 24 hours before being processed. The micro-organisms in the milk if not contained will destroy the quality of the milk and alter its flavour and taste. The milk is therefore cooled to ≤4°C using ice water to decrease the activity of the micro-organisms (Korsström and Lampi, 2002).

After pasteurisation, most of the micro-organisms are destroyed by the heat but a few remain in the milk and can make it go bad in a short duration of time. It is because of these that the milk must be cooled again rapidly and stored in cold rooms before, during and after distribution. The thermal energy of geothermal fluids together with absorption refrigeration systems are suitable to provide the necessary cooling for a dairy processing factory.

Vapour Absorption Refrigeration

Vapour absorption systems are of two types: Lithium Bromide/water cycle, where water is the refrigerant while lithium bromide is the absorbent. This configuration is used mainly for air conditioning where temperatures do not go below 0°C as this would result in freezing of the refrigerant. The second configuration is the water/ammonia cycle where ammonia is the refrigerant. This is mainly used for refrigeration since it achieves temperatures below 0°C. In dairy processing, it is common for milk to be cooled to less than 4°C. To attain this temperature, chilled water or ice water at 1-2°C is required (Korsström and Lampi, 2002). This implies that only machines running on the ammonia cycle would be suitable for this application since the common Lithium Bromide machines in the market today can provide chilled water only down to 7°C (YESI, 2002).

The production of chilled water at 1-2°C risks resulting into freezing. This problem can be overcome by mixing the water with glycerol which forms strong hydrogen bonds with water molecules, competing with water-water hydrogen bonds. This disrupts the crystal lattice formation of ice unless the temperature is significantly lowered.

An absorption cooling system is made up of an absorber, an evaporator, a desorber, a condenser, heat exchanger, expansion valves and a pump. Two fluids, an absorbent and a refrigerant circulate through the system to provide the required cooling. Hot water is supplied to the desorber section and its heat transferred to the absorbent/refrigerant rich mixture. This heat causes the refrigerant to be boiled out of the mixture in a distillation process. A weak absorbent/refrigerant mixture remains and flows to the absorber. The refrigerant vapour that is generated passes into the condenser section where a cooling medium is used to condense the vapour back to a liquid state. After that, the liquid refrigerant flows through an expansion valve and the pressure drops. Hereafter, the boiling temperature is lower than in the condenser. The refrigerant then flows down to the evaporator section where it is sprayed over tubes containing the fluid to be cooled. The refrigerant liquid boils at a very low temperature. This boiling causes the refrigerant to absorb heat from the medium to be cooled, thus, lowering its temperature. Evaporated refrigerant then passes into the absorber section where it is mixed with an absorbent/refrigerant solution that is very low in refrigerant content. This solution tends to absorb the refrigerant vapour from the evaporator section. This is the absorption process that gives the cycle its name. The solution is then pumped to the desorber section to repeat the cycle as shown in Figure 7 (Herold et al., 1996).

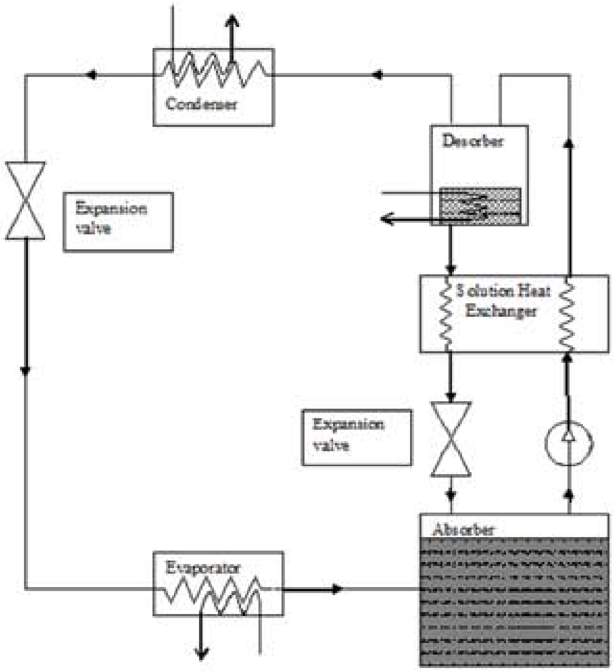

Figure 7. Vapour absorption cycle

An absorption system operates at two pressure levels. The desorber, solution heat exchanger and condenser are at a higher pressure than the evaporator and absorber.

Water/Ammonia System

The ammonia/water mixture boils over a range of temperature at a given pressure unlike pure liquids which boil at a constant temperature. The point at which the first bubble forms is called the bubble point and this bubble has considerably higher ammonia content than the liquid mixture. The point at which the last liquid droplet evaporates is the dew point and this drop has considerably lower ammonia than the vapour (Herold et al., 1996).

Since an absorption refrigeration system operates at two pressure levels, it means that there are two boiling curves for the mixture, each at a different pressure level as shown in Figure 8.

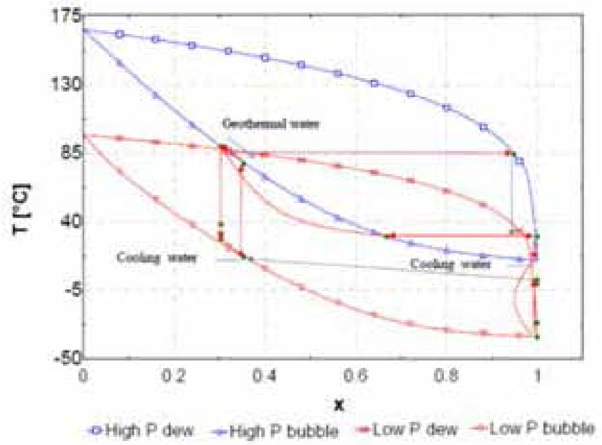

Figure 8. Thermo-dynamic properties of ammonia/water mixture

Desorber

It is in the desorber that the refrigerant vapour is generated from the rich mixture by distillation. The weak mixture that remains in the desorber is returned to the absorber through the solution heat exchanger. The heat for distillation is supplied by the hot geothermal water.

Energy balance

$$m_{rich} * h_{rich} + Qdesorber = m_{weak} * h_{weak} + m_{ref\text{-}vapour} * h_{ref\text{-}vapour} \quad (7)$$

Ammonia balance

$$m_{rich} * x_{rich} = m_{weak} * x_{weak} + mref\text{-}vapour * x_{ref\text{-}vapour} \quad (8)$$

Mass balance

$$m_{rich} = m_{weak} + m_{ref\text{-}vapour} \quad (9)$$

Where

m = Mass [kg/s];
h = Enthalpy [kJ/kg];
Q = Energy [kW]);
x = Vapour fraction.

Condenser

The refrigerant vapour is cooled in the condenser until it reached vapour saturation and then condensed to liquid phase at constant temperature. Condensation is necessary in order for the refrigerant to acquire the potential to extract heat from the evaporator. Cooling water is the medium that extracts heat from the refrigerant vapour.

Energy balance

$$Q_{cond} = m_{ref} * (h_{ref\text{-}vapour} - h_{ref\text{-}liq}) = m_{cooling\ water}\ (h_{cooling\ water\text{-}out} - h_{cooling\ water\text{-}in}) \qquad (10)$$

Expansion Valve

The high pressure refrigerant liquid from the condenser is throttled to the evaporator pressure by the expansion valve. The liquid neither does work nor is there work done on it, therefore, this process is assumed to be isenthalpic.

$$h_{ref\text{-}in} = h_{ref\text{-}out} \qquad (11)$$

Evaporator

The medium being chilled extracts heat from the refrigerated space and carries this heat to the evaporator. The liquid refrigerant extracts this heat and in the process it evaporates. The chilled medium is cooled and returned back to the refrigerated space.

Energy balance

$$Q_{evap} = m_{ref} * (h_{ref\text{-}vapour} - h_{ref\text{-}lig}) = m_{Ice\ water} * (h_{Icewater\text{-}in} - hI_{ce\ water\text{-}out}) \qquad (12)$$

Absorber

The refrigerant vapour is absorbed by the weak mixture to form a rich mixture. In this process, latent heat of vaporisation of the refrigerant is released and must be extracted using cold water in order to achieve a high concentration of ammonia in the rich mixture.

Energy balance

$$m_{weak} * h_{weak} + m_{ref\text{-}vapour} * h_{ref\text{-}vapour} = m_{rich} * h_{rich} + Q_{absorber} \qquad (13)$$

Ammonia balance

$$m_{weak} * x_{weak} + m_{ref\text{-}vapour} * x_{ref\text{-}vapour} = m_{rich} * x_{rich} \qquad (14)$$

Mass balance

$$m_{weak} + m_{ref\text{-}vapour} = m_{rich} \qquad (15)$$

Pump

The pump increases the pressure of the rich mixture from the evaporator pressure to the condenser pressure. In the process, it does work on the rich mixture and hence increases its enthalpy.

$$h_{after\ pump} = h_{before\ pump} + w_{pump} \qquad (16)$$

$$w_{pump} = v_{before\ pump} * (P_{high} - P_{low}) / \eta_{pump} \qquad (17)$$

Where

w = work
v = specific volume (m^3/kg)
p = pressure
η = efficiency (%)

Solution Heat Exchanger

In order to improve the coefficient of performance of the absorption system the solution heat exchanger recovers some of the heat from the weak mixture leaving the desorber and transfers it to the rich mixture entering the desorber.

Energy balance

$$m_{rich\text{-}in} * h_{rich\text{-}in} + m_{weak\text{-}in} * h_{weak\text{-}in} = m_{rich\text{-}out} * h_{rich\text{-}ou}t + m_{weak\text{-}out} * h_{weak\text{-}out} \qquad (18)$$

Coefficient of Performance (COP)

Thermal energy is supplied to the absorption refrigerator in order to produce the refrigeration effect. The measure of the ability of the absorption machine to transform supplied thermal energy to refrigeration effect is called COP and given by the following equation.

$$COP = \frac{Q_{out}}{Q_{in} + W_{in}} = \frac{Q_{evap}}{Q_{desorber} + W_{pump}} \qquad (19)$$

RESULTS AND DISCUSSION

The processing of milk is energy dependent and large quantity of heat is consumed during this exercise. At every stage of the processing, heat is either added or extracted from the milk in order to make milk safer for consumption or increase its shelf life.

The production of milk powder requires a large amount of energy to concentrate and dry the milk. Cleaning of the processing equipment with hot water for at least an hour daily requires considerable amount of energy. The other processes that require heat are pasteurization and cooling using absorption refrigeration machines. Thermal energy from geothermal fluids is sufficient to meet the energy needs of milk processing. Table 6 shows a summary of various parameters in a dairy processing plant calculated using EES with a milk flow of 1kg/s (F-chart software, 2007).

TABLE 6. Requirements for Dairy Plant Equipment.

Item	Area (m^2)	Energy requirement (kW)	Flow rate (kg/s)
Pasteurizer	8.4	22.6	0.77
Regenerator	29.2	237.5	-
Cooling Section	4.7	33.9	2.7
Absorber	22.2	115.6	2
Desorber	5.6	116.6	0.89
Solution Heat Exchanger	1.8	37.5	-
Evaporator	13.1	87.7	6.95
Condenser	6.2	88.9	1.5
Falling Film Evaporator	52.77	1354	32.4
Spray Tower Radiator	14.3	317.8	7.6
Vacuum Pump		51.55	
Ice Water Pump		87.71	6.95
Refrigerant Pump		0.1888	0.0707
Blowers (2 Units)		1.055*2	3.64*2

Fluid Milk Processing

Fluid milk refers to milk that has been processed for consumption as a fresh product. The processing of fluid milk entails heating it to 76°C and holding it at this temperature for about 15 seconds to obtain an adequately pasteurised product. The pasteurised product is then cooled to ≤ 4°C before packaging or storage. An absorption chiller is used to provide ice water which is used to cool the milk as shown in Figure 9.

In fluid milk processing, pasteurization and cooling are the main processes involved. Thermal energy from hot water provides the necessary energy to achieve the objectives of these two processes.

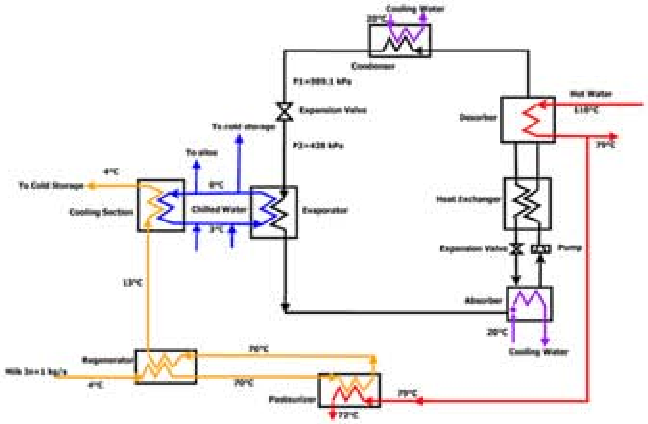

Figure 9. Pasteurisation and absorption cooling processes

The energy consumption in the dairy industry depends on the amount of milk that is being processed. Therefore, the more milk there is to process, the more the energy required. This energy is transferred across heat exchangers either from the heating medium to the milk during pasteurization or from the milk to ice water during cooling. The heat exchange area depends on the quantity of thermal energy being transferred and the flow rate of the fluids exchanging the heat as shown in Figure 10.

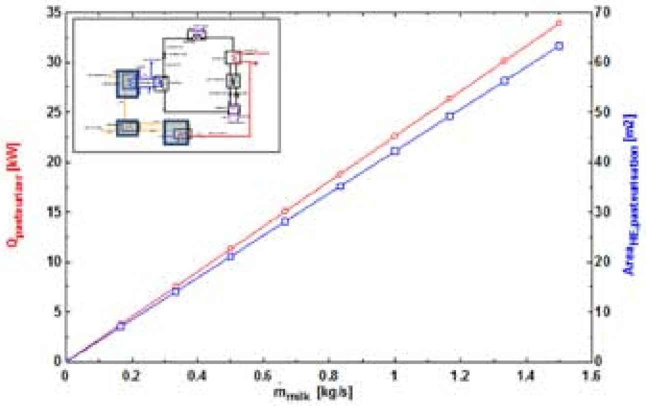

Figure 10. Heat exchange area and energy requirements for pasteurization

Pasteurization requires that each droplet of milk should attain the pasteurization temperature and maintain that temperature for a certain period of time. This means that the heating medium which is in most cases hot water should be sufficiently hot and have adequate flow rate to meet this requirement. The flow rate of the heating medium is therefore determined by the flow rate of the milk.

In the regenerator, no external heat is introduced into the system. The heat in the hot pasteurized milk is used to preheat the incoming cold milk. The amount of heat transferred in the regenerative section is very large and therefore, this is normally the biggest heat exchanger in dairy processing. 90-95% of the heat in the milk between the pasteurization and storage temperature is transferred at the regenerator.

Due to the pinch in the regenerator, the precooled milk is at a higher temperature than the storage temperature. It is necessary therefore to cool the milk to the storage temperature using ice water. Heat from the environment is conducted or gets infiltrated into the storage room and it must be removed so as to maintain the cold room at the storage temperature. Heat from other sources such as the storage containers, lighting, electrical appliances and people also finds its way into the storage room and should be removed or kept as low as possible.

The milk arriving at the processing plant from the farmers is usually not processed immediately because it should be de-aerated and the waiting period can be longer if there is backlog. To preserve this milk as it waits processing, it is cooled while in the storage silos.

The heat that should be removed from milk before processing, after processing and during storage constitutes the cooling load. Chilled water or ice water is the medium which is used to extract the cooling load from the milk and from the cold storage room. This means that the production of ice water is a continuous process even when there is no milk being processed in order to maintain the low temperature of the cold storage room as shown in Figure 11. In the processing of fluid milk, hot water is required both for pasteurization and to power the cooling process.

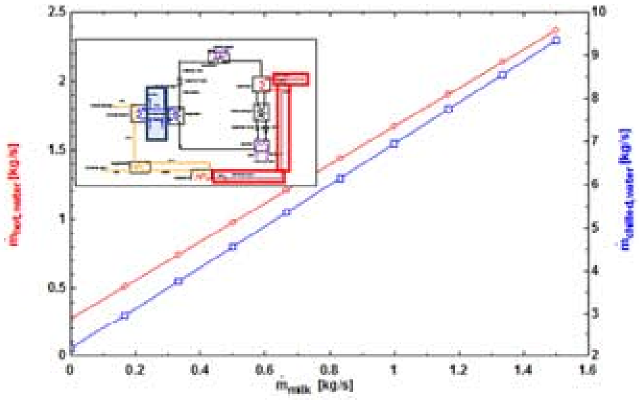

Figure 11. Hot water requirements and ice water production

The production of ice water or chilled water is a refrigeration process that involves extraction of heat from water at 3°C to about 0°C. The heat is removed by a refrigerant medium which extracts it from the water at the evaporator and rejects it at the condenser. In a vapour absorption system, an input of thermal energy at the desorber is required to drive the refrigerant through the system. The thermal energy required depends on the cooling demand that needs to be met. Figure 12 illustrates the amount of energy required by the desorber in order to provide adequate refrigeration at the evaporator.

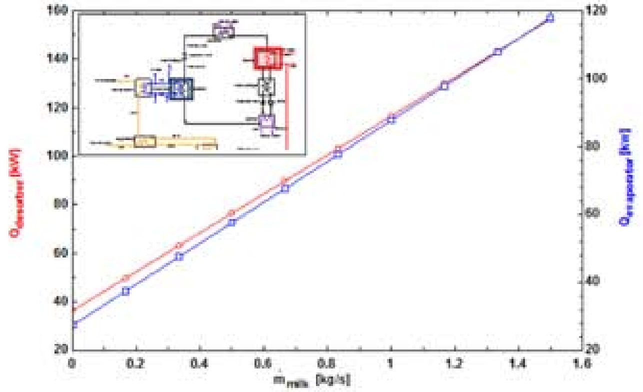

Figure 12. Energy requirements for adequate refrigeration

In order to meet the cooling demand of the dairy plant, the evaporator area should be large enough and the flow of the ice water adequate. The efficiency of the absorption refrigerator is determined by the ratio of cooling load to the energy input into the desorber and the refrigerant pump. In this design the COP of the absorption chiller was found to be 0.75.

The evaporator and the condenser are some of the heat exchangers in an absorption refrigeration machine. The other heat exchangers are the absorber, desorber or generator and the solution heat exchanger. To a large extent, the size of these devices depends on the refrigeration demand of the system which in turn depends on the milk being processed and the need to keep the cold room at a given temperature. On the other hand, milk processing has three heat exchangers namely the pasteurizer, regenerator and the cooling section. The size of these heat exchangers depends on the amount of milk being processed. The relationship between pasteurization heat exchange area and the chiller heat exchange area in relation to the milk being processed is shown in Figure 13.

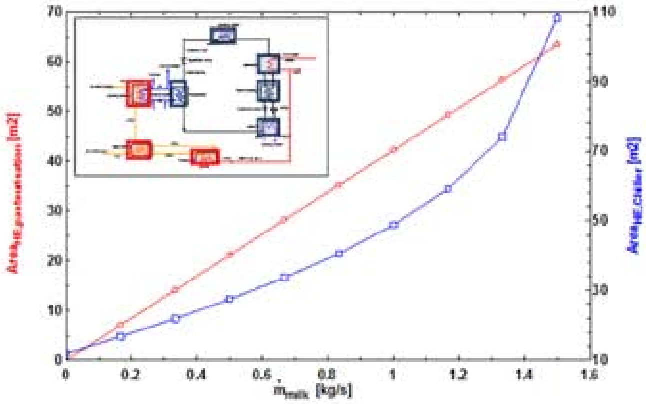

Figure 13. Area of the heat exchangers in a dairy processing plant

It is clear from this diagram that the area of the chiller heat exchangers is lowest relative to that of the pasteurization heat exchangers when the milk flow rate is between 0.8 kg/s and 1.3 kg/s. This can therefore be assumed to be the optimum operating range for the system at which the investment cost is lowest since the cost will depend on the size of the heat exchangers used.

Milk Powder

The production of milk powder is the most energy intensive dairy processing activity in terms of energy consumption per litre of milk processed. In the falling film evaporator, hot water at 70°C is used as the heat source and it is here that about 80% 0f the water that should be evaporated from the milk is removed. The resulting product is called concentrated milk and has a dry matter content of 45-55%. In the spray tower, atomized milk is dried by hot air. The air is heated in a coil by hot water or steam. The temperature of the drying air is 95°C while the temperature of the heating medium is 110°C as shown in Figure 14.

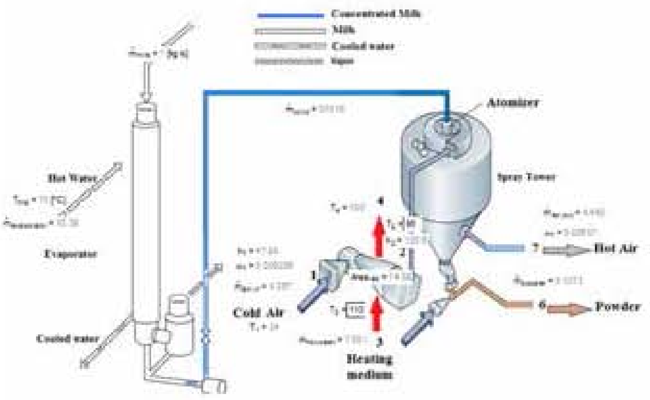

Figure 14. Falling film evaporator and spray tower

The quantity of milk to be dried depends entirely on the amount of energy available in the heating medium and the evaporation/drying area as shown in Figure 15. This energy is on the other hand determined by the temperature of the heating medium and its flow rate.

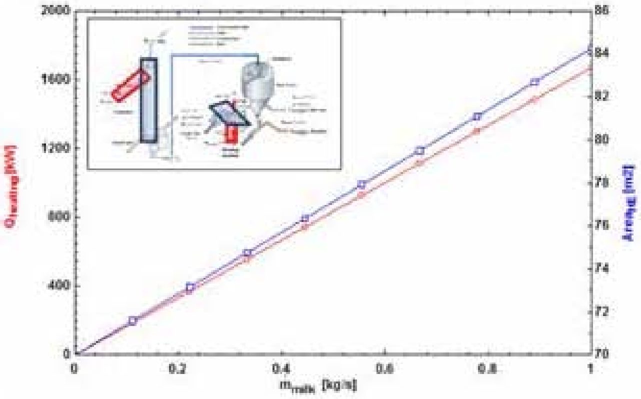

Figure 15. Milk powder energy and heat exchange area requirements

The air entering into the spray tower is at a constant temperature. Therefore, to ensure there is uniform drying of the milk while using a given quantity of heat, the air flow rate must be varied if the drying air temperature is to be varied as shown below in Figure 16.

The other factors that determine the flow rate of drying air are the temperature of the heating medium and its flow rate. An increase in any of these two factors results in an increase in the quantity of drying air required. This is because when either the temperature of the heating medium or its flow rate is increased, more milk can be processed and that requires more drying air.

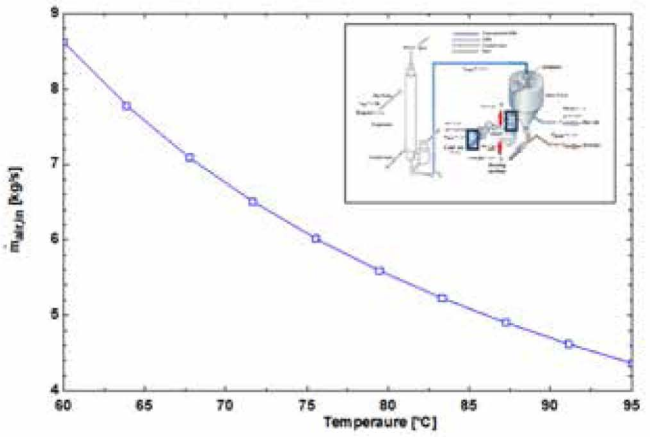

Figure 16. Drying air flow rate as a function of drying temperature

During the production of milk powder, the moisture content of the concentrated milk is reduced to between 2.5% and 5%. This reduction in the moisture content is accompanied by a reduction in volume, weight and size of the droplet from the atomizer. As can be seen from Figure 17, the weight of the milk powder is reduced to about 10% of the weight of milk.

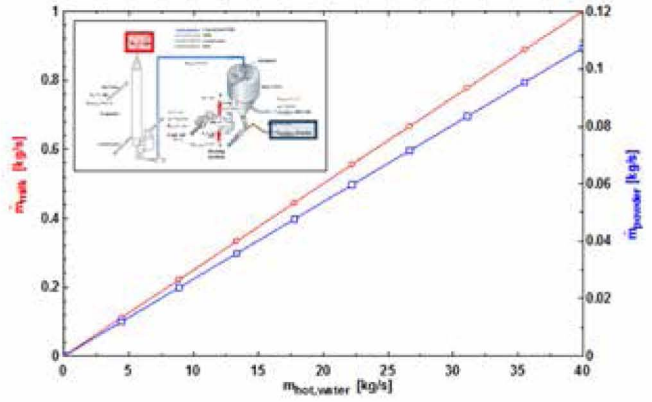

Figure 17. weight of liquid milk versus weight of milk powder

Cleaning of Equipment

Cleaning of dairy equipment is done in four stages namely rinsing with warm water to remove loose dirt and milk particles, cleaning with alkaline solution to remove fats, cleaning with acidic solution to remove encrusted proteins and salts and finally disinfection with hot water to kill germs. Cleaning is done after milk has been flowing through the equipment for hygienic reasons and also to remove fouling material which reduces overall heat transfer coefficient. It is assumed that the flow rate of the cleaning water at each stage is the same as that of the milk.

Each of the cleaning stages is carried out with water at a specific temperature and for a given period of time. This means that the water and energy demand for one stage is different from that of the other stages. However, the total water and energy demand for the cleaning process can be found by summing up the demands for each stage. In a typical cleaning exercise, water and energy demands are shown in the Figures 18 and 19. It is however important to note that most of the cleaning water is reused and the amount shown is only for the makeup water.

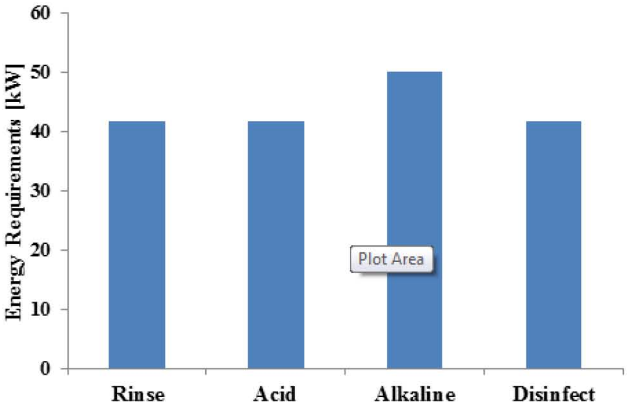

Figure 18. Cleaning water energy demand

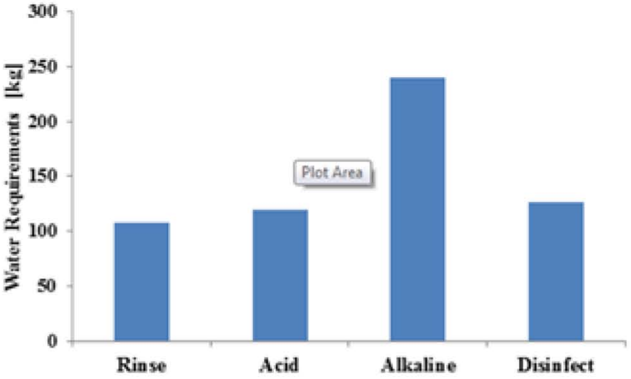

Figure 19. Cleaning water usage

COST ANALYSIS

The cost of equipment to be used in a dairy processing plant is mainly is determined to a great extent by the size of the heat exchangers installed while the major operating cost of the equipment depends on the consumption of hot and cold water. Other factors that determine the cost of a plant are the pump and blower costs and cost of power.

The following equation can be used to estimate the cost of equipment where no direct quotation is available (Bejan et al., 1996).

$$C_{PE,y} = C_{PE,w} * (\frac{X_y}{X_w})^{\alpha} \tag{20}$$

Where

$C_{PE,\,y}$ = price of equipment of capacity or size X_y

C_{PE}, w = price of similar equipment of capacity or size X_w

α = scaling factor i.e. 0.4 for plate, 0.66 for shell and tube heat exchanger, etc.

It is important to note that as the size of the heat exchangers increase, the quantity of water consumed decreases. This is because more heat exchange area is availed to transfer the same amount of heat.

Table 7 below shows the sizes of some of the dairy plant equipment, their sizes and cost.

TABLE 7. Cost of Dairy Plant Equipment

Pasteurisation	Area (m^2)	Rating (kW)	Cost (USD)
Pasteurizer	8.34		2207
Regenerator	29.18		3643
Cooling section	4.71		1757
Total			**7607**
Absorption Chillers	5.59		2945
Desorber	6.14		3130
Condenser	13.07		5153
Evaporator	22.19		7309
Absorber	1.79		1193
Solution heat exchanger			100
Refrigerant pump		0.1888	900
Ice water pump		87.71	1914
Piping = 7% of heat exchangers			
Total			**22644**
Milk Powder	52.77		
Falling film evaporator		51.55	12948
Vacuum pump	14.28		665
Radiator		1.055*2	306
Blower (2 pieces)			245
Total			**14164**
Total investment cost			**44415**

The approximation method presented above in equation 20 uses a benchmark that does not originate from the dairy industry and hence care should be taken on absolute cost estimates. It is possible that the dairy industry requires specific stainless steel, surfacing methods or other finishing procedures that could have a significant effect on the estimates.

It is also important to note that this analysis does not include the cost of the wells, pipeline to the site of utilisation, wellheads and separators. The costs covered here are for those components which are in the circuit which is in direct contact with the heating and cooling medium or directly affected by these circuits. Therefore, circuits in which the milk only is flowing such as pipes and tanks are not included.

Before money is invested in any project, it is important to determine the total cost of the project over its entire life cycle. The costs included in the cost analysis of a dairy plant are the initial investment cost, the cost of electricity, the cost of hot water and the cost of cold water.

$$Price_{Hot\ Water} = 0.45 USD/m^3 \tag{21}$$

$$Price_{Cold\ water} = 0.28 USD/m^3 \tag{22}$$

$$Price_{elec} = 0.11 USD/kWh \tag{23}$$

Water consumption accounts for the largest annual operating cost. Hot water is used for pasteurization, concentrating and drying the milk, evaporating the refrigerant in the absorption chiller and cleaning while cold water is used mainly for cooling the refrigerant fluids and for cleaning. The cost of water depends on the price of water and the water consumption rate. In the case of hot water it is assumed that between 50% and 90% of the water is recycled at various stages of consumption because it still contains some useable energy, and therefore, the cost of hot water is mainly for makeup water. Dairy processing operations are also assumed to be carried out for 350 days in a year.

$$cost_{water} = m_{water} / \rho_{water} * Price_{water} * 3600 * hr/day * 350 \tag{24}$$

$$cost_{elec} = power_{equip} * hr * pric_{eelec} \tag{25}$$

Where

ρ = density of water

The present value of the plant after a given period of time is given by

$$P_o = F_a \frac{1}{r}\left(1 - \frac{1}{(1+r)^n}\right) \tag{26}$$

Where

P_O = present value

Fa = constant annual cost

ρ = rate of return

n = life cycle of the project.

hr = operation time per day in hours.

For this dairy plant, the operating cost for the first year is shown in Table 8.

TABLE 8. Annual Operating Cost of a Dairy Processing Plant

Item	Water consumption (m3)	Electricity consumption (USD/kWh)	Annual Running cost (USD)
Fluid milk			
Hot water	8499		3224
Cold water	23594		6606
Refrigerant pump		707	80
Water pump		328478	36133
Milk powder			
blower		738.4	82
Vacuum pump		36082	3969
Hot water	20152		9068
Cleaning			
Cleaning water	2097		936
TOTAL	**54342**	**366006**	**60098**

CONCLUSION

There are many energy sources available in the world today. The conventional sources such as fossil fuels are quickly getting depleted and release large quantity of pollutants into the atmosphere after combustion. Others such as hydropower have been exploited almost to the limit and cannot meet the growing energy demand. However, other renewable energy resources such as geothermal are relatively underdeveloped and underutilized. With the recent focus and growth in geothermal technology, a lot of emphasis is being put in the utilisation of geothermal energy both for electricity generation and direct uses. Direct use applications utilize the waste heat in the geothermal water before it is disposed.

Processing of dairy products such as fluid milk and milk powder requires heating and cooling in order to improve the shelf life of milk and make it safe for consumption. The thermal energy requirements for pasteurization, evaporation and drying and cleaning can be obtained from hot geothermal water at a much cheaper price than electricity and oil which are in most cases used to heat water for use in dairy processing. Cooling using vapour absorption machines also requires an input of thermal energy to drive the refrigerant.

Water from geothermal sources in most cases contains dissolved chemicals which could present challenges to its utilisation. To overcome these challenges in the transmission pipeline and milk processing equipment, fresh water is heated by the geothermal water across a heat exchanger and used to transport the heat to the dairy plant. Heat exchangers are the single most important components in a dairy plant since heat transfer between fluids is what dairy processing is all about. Plate heat exchangers and shell and tube heat exchangers are used in milk pasteurization, cooling and evaporation.

In order to obtain thoroughly processed milk, adequate thermal energy should be transferred from the geothermal water to other fluids such as fresh water, milk and the refrigeration fluids. This means that the heat exchangers should have sufficient area for heat transfer. Other factors that affect the quantity of heat transferred are the inlet and outlet temperatures of the fluid and its flow rate. Since heat exchangers are expensive equipment, a balance must be established among these parameters in order to minimize costs and maximize benefits.

RECOMMENDATIONS

In order to have a system which meets its objectives effectively and at the least cost, it is necessary to conduct further optimisation on the pasteurisation unit, the absorption chiller and milk powder processing unit. This optimisation should strike a balance between the amount of milk processed, the hot water required, cold water required, temperature of both hot and cold water and the area of the heat exchangers.

Before disposal of hot water in a dairy processing plant, it is important to use as much energy as possible from it in order to cut down on the cost of hot water. This can be achieved by cascading the use of water within the dairy processing plant for different operations, starting with the one requiring more energy. Reuse of the water should also be considered as a cost cutting measure.

To achieve a successful implementation of the use of geothermal energy in the dairy industry, it may be worth considering a stepwise approach. The easiest way is to start with heating for pasteurisation and production of milk powder while absorption refrigeration maybe applicable later. Production of hot water for cleaning and disinfection during packaging are the other applications that could use geothermal energy in the dairy industry.

ACKNOWLEDGEMENT

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NOMENCLATURE

CIP = Cleaning in Place
DST = Dairy Science and Technology
EPZA = Export Processing Zones Authority
HTST = High Temperature Short Time
KDB = Kenya Dairy Board
LMTD = Logarithmic Mean Temperature Difference
LTLT = Low Temperature Long Time
UHT = Ultra High Temperature
YESI = Yazaki Energy Systems Inc.
EES = Engineering Equation Solver

EDITOR'S NOTE

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GEOTHERMAL ENERGY POTENTIAL IN OKTIBBEHA COUNTY: IS MISSISSIPPI REALLY HOT?

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ABSTRACT

Geothermal energy is a clean, renewable energy source. Previous geothermal energy assessments of Mississippi have focused on areas in southern Mississippi and the Mississippi River flood plain. The focus of the current project is Oktibbeha County in eastern North Central Mississippi, an area currently home to active lignite coal mining and exploration. Lignite is one of the least efficient forms of coal and it is being mined in an area that potentially has thousands of megawatts of clean geothermal energy potential. Well logs were reviewed to gather bottom-hole temperatures, mathematically normalized and used to create a thermal gradient map of the county. The map shows clear indication of above-normal temperatures in western Oktibbeha County beginning at depths of around four thousand meters.

INTRODUCTION

The United States Energy Information Administration estimates that the average American household uses 12,000 kWh of electricity per year (USEIA, 2012). In 2011, Southern Methodist University researchers led by Dr. David Blackwell, in a project funded by Google, Inc., calculated that at 14% recovery, Mississippi had an estimated geothermal potential of over 60,000 megawatts (Google.org, 2012), which is enough to supply electricity to over sixty million homes. As a point of comparison, according to 2010 United States Census Bureau data, Mississippi currently has less than 1.3 million homes (US Census Bureau, 2012). Exploitation of this vast energy source could put Mississippi in the position of becoming an energy exporter.

It is likely actual temperatures found in some subsurface areas of Mississippi are higher than the estimates provide by Blackwell (2011). The numbers generated by Blackwell (2011) are based on data from only twenty-seven collection sites in Mississippi that were sampled in the 1970's geothermal investigation by the Department of Energy, none of which were located in Oktibbeha County (Richards, 2012). The resolution of geothermal data, for Mississippi is, therefore, low. A new assessment of the thermal gradient is needed to verify the true geothermal potential in the state of Mississippi. The particular area of interest in this study is Oktibbeha County, since the county is the location of continued subsurface hydrocarbon exploration the Black Warrior Basin.

LITERATURE REVIEW

In the 1970's several events led to increased interest in geothermal exploration in the United States, one of which was the formation of the Geothermal Energy Association. (USDOE, 2012). The Geothermal Energy Association is a trade association focused on expanding research and development in the geothermal field to increase the use of geothermal energy production for electricity and promoting public policies that encourage this expansion (GEA, 2012). In 1974 the government enacted the Geothermal Energy Research, Development and Demonstration (RD&D) Act and following the creation of the Department of Energy in 1977, a nationwide assessment of geothermal potential began As the Department of Energy campaign into geothermal assessment continued, a more cohesive network was formed and investments from both the public and private sectors increased (USDOE, 2012).

In recent years researchers at Southern Methodist University have worked to refine the temperature data used to assess geothermal potential. An initial correction was made to the recorded bottom-hole temperatures using the Harrison et al. correction (Harrison et al. 1983 in Blackwell and Richards, 2004). A second correction was then added to account for the crossover point of the Harrison et al. correction. This crossover occurs at about 3900 meters and at this point the correction begins to become negative. The second correction was based on standard geothermal gradient and more accurately matches equilibrium well data for depths over three thousand meters by increasing the temperature .01 degree C for every 500 additional meters (Blackwell and Richards, 2004). The most recent example of this refinement is the Google Earth interactive map created by the team at Southern Methodist University (Google.org, 2012).

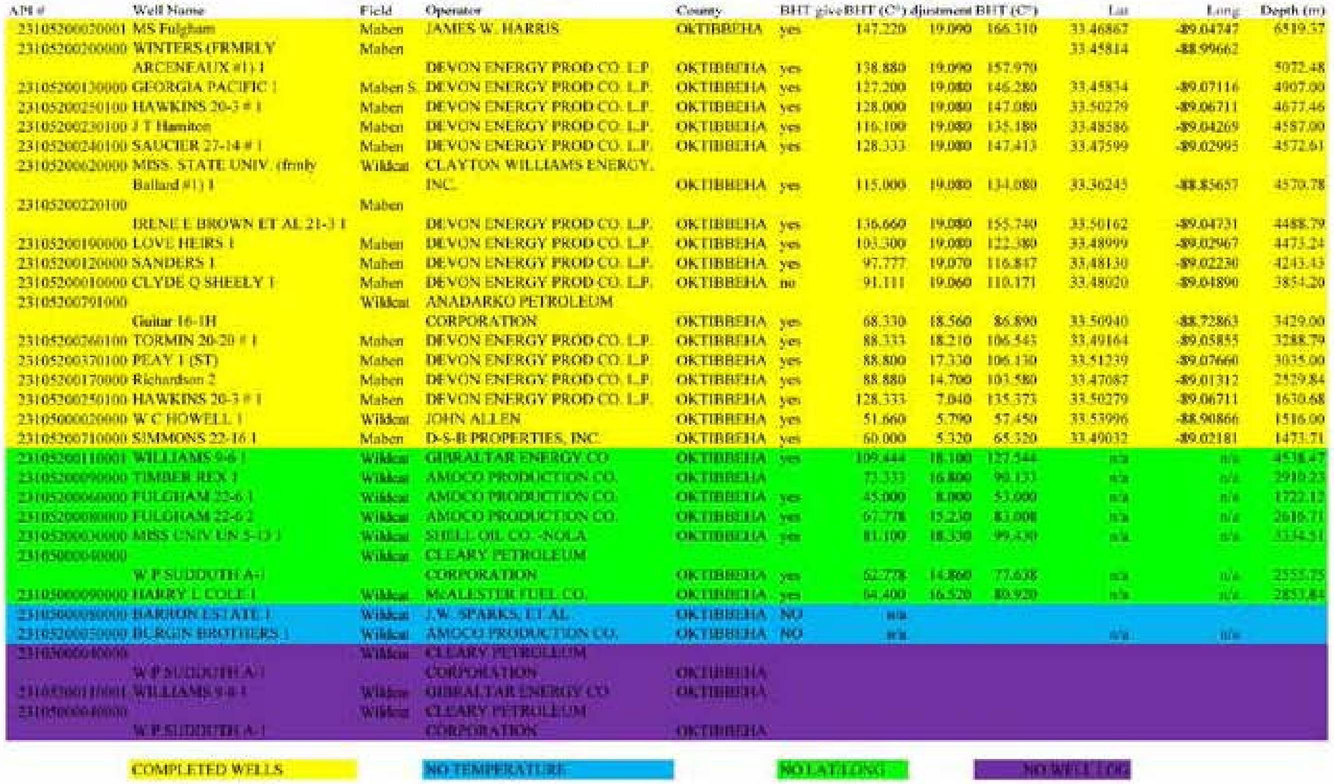
Mississippi currently has one geothermal project in development. The project is a hydrocarbon co-production system that utilizes geothermal fluids that are produced along with hydrocarbons to produce electricity. Gulf Coast Green Energy in collaboration with Denbury Resources will use the ElectraTherm mobile modular unit to produce as much as 50 kWh of electricity from hot water (Jennejohn, 2010).

Mississippi government resources are also valuable for the assessment of geothermal potential. The Mississippi Oil and Gas Board website allows access to digital copies of oil and gas well logs (MSOGB, 2012). Information such as well location and temperature data is available through this resource. The Mississippi Department of Environmental Quality (MDEQ) offers maps such as structural and geologic maps of areas being assessed (MDEQ, 2012).

METHODS

Data Collection

Data were obtained directly from the Mississippi Oil and Gas Board website (MSOGB, 2012). Well data for Oktibbeha County were exported from the website using the well information section of the data menu and selecting a filter to pull only Oktibbeha County. The complete report of all wells located within the county was exported to an excel file (Figure 1). Each well was then reviewed individually.

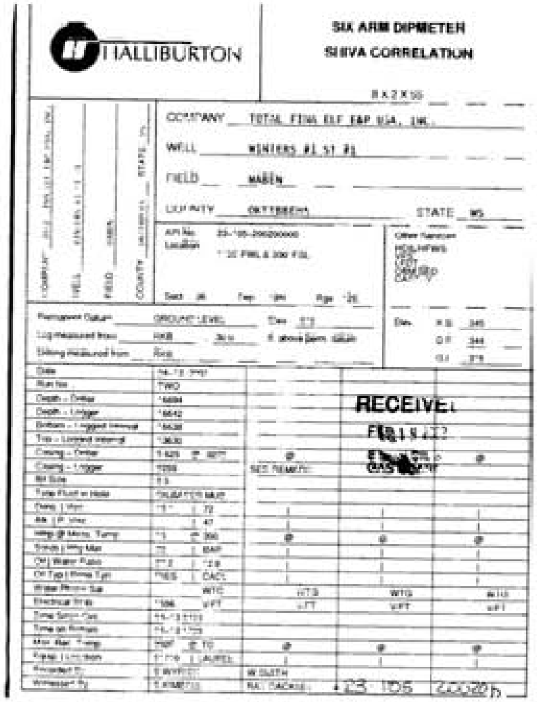


API #	Well Name	Field	Operator	County	BHT give	BHT (C°)	djustment	BHT (C°)	Lat	Long	Depth (m)
23105200020001	MS Fulgham	Maben	JAMES W. HARRIS	OKTIBBEHA	yes	147.220	19.090	166.310	33.46867	-89.04747	6519.57
23105200200000	WINTERS(FRMRLY ARCENEAUX #1) 1	Maben	DEVON ENERGY PROD CO. L.P.	OKTIBBEHA	yes	138.880	19.090	157.970	33.45814	-88.99662	5072.48
23105200130000	GEORGIA PACIFIC 1	Maben S.	DEVON ENERGY PROD CO. L.P.	OKTIBBEHA	yes	127.200	19.080	146.280	33.45834	-89.07116	4907.00
23105200250100	HAWKINS 20-3 # 1	Maben	DEVON ENERGY PROD CO. L.P.	OKTIBBEHA	yes	128.000	19.080	147.080	33.50279	-89.06711	4677.46
23105200230100	J T Hamilton	Maben	DEVON ENERGY PROD CO. L.P.	OKTIBBEHA	yes	116.100	19.080	135.180	33.48586	-89.04269	4587.00
23105200240100	SAUCIER 27-14 # 1	Maben	DEVON ENERGY PROD CO. L.P.	OKTIBBEHA	yes	128.333	19.080	147.413	33.47599	-89.02995	4572.61
23105200620000	MISS. STATE UNIV. (frmly Ballard #1) 1	Wildcat	CLAYTON WILLIAMS ENERGY, INC.	OKTIBBEHA	yes	115.000	19.080	134.080	33.36245	-88.85657	4570.78
23105200220100	IRENE E BROWN ET AL 21-3 1	Maben	DEVON ENERGY PROD CO. L.P.	OKTIBBEHA	yes	136.660	19.080	155.740	33.50162	-89.04731	4488.79
23105200190000	LOVE HEIRS 1	Maben	DEVON ENERGY PROD CO. L.P.	OKTIBBEHA	yes	103.300	19.080	122.380	33.48999	-89.02967	4473.24
23105200120000	SANDERS 1	Maben	DEVON ENERGY PROD CO. L.P.	OKTIBBEHA	yes	97.777	19.070	116.847	33.48130	-89.02230	4243.43
23105200010000	CLYDE Q SHEELY 1	Maben	DEVON ENERGY PROD CO. L.P.	OKTIBBEHA	no	91.111	19.060	110.171	33.48020	-89.04890	3854.20
23105200791000	Guitar 16-1H	Wildcat	ANADARKO PETROLEUM CORPORATION	OKTIBBEHA	yes	68.330	18.560	86.890	33.50940	-88.72863	3429.00
23105200260100	TORMIN 20-20 # 1	Maben	DEVON ENERGY PROD CO. L.P.	OKTIBBEHA	yes	88.333	18.210	106.543	33.49164	-89.05855	3288.79
23105200370100	PEAY 1 (ST)	Maben	DEVON ENERGY PROD CO. L.P.	OKTIBBEHA	yes	88.800	17.330	106.130	33.51239	-89.07660	3035.00
23105200170000	Richardson 2	Maben	DEVON ENERGY PROD CO. L.P.	OKTIBBEHA	yes	88.880	14.700	103.580	33.47087	-89.01312	2529.84
23105200250100	HAWKINS 20-3 # 1	Maben	DEVON ENERGY PROD CO. L.P.	OKTIBBEHA	yes	128.333	7.040	135.373	33.50279	-89.06711	1630.68
23105000020000	W C HOWELL 1	Wildcat	JOHN ALLEN	OKTIBBEHA	yes	51.660	5.790	57.450	33.53996	-88.90866	1516.00
23105200710000	SIMMONS 22-16 1	Maben	D-S-B PROPERTIES, INC.	OKTIBBEHA	yes	60.000	5.320	65.320	33.49032	-89.02181	1473.71
23105200110001	WILLIAMS 9-6 1	Wildcat	GIBRALTAR ENERGY CO	OKTIBBEHA	yes	109.444	18.100	127.544	n/a	n/a	4518.47
23105200090000	TIMBER REX 1	Wildcat	AMOCO PRODUCTION CO.	OKTIBBEHA		73.333	16.800	90.133	n/a	n/a	2910.23
23105200060000	FULGHAM 22-6 1	Wildcat	AMOCO PRODUCTION CO.	OKTIBBEHA	yes	45.000	8.000	53.000	n/a	n/a	1722.12
23105200080000	FULGHAM 22-6 2	Wildcat	AMOCO PRODUCTION CO.	OKTIBBEHA	yes	67.778	15.230	83.008	n/a	n/a	2616.71
23105200030000	MISS UNIV UN 5-13 1	Wildcat	SHELL OIL CO. -NOLA	OKTIBBEHA	yes	81.100	18.330	99.430	n/a	n/a	3334.51
23105000040000	W P SUDDUTH A-1	Wildcat	CLEARY PETROLEUM CORPORATION	OKTIBBEHA	yes	62.778	14.860	77.638	n/a	n/a	2555.75
23105000090000	HARRY L COLE 1	Wildcat	McALESTER FUEL CO.	OKTIBBEHA	yes	64.400	16.520	80.920	n/a	n/a	2853.84
23105000080000	HARION ESTATE 1	Wildcat	J.W. SPARKS, ET AL	OKTIBBEHA	NO	n/a					
23105200050000	BURGIN BROTHERS 1	Wildcat	AMOCO PRODUCTION CO.	OKTIBBEHA	NO	n/a			n/a	n/a	
23105000040000	W P SUDDUTH A-1	Wildcat	CLEARY PETROLEUM CORPORATION	OKTIBBEHA							
23105200110001	WILLIAMS 9-6 1	Wildcat	GIBRALTAR ENERGY CO	OKTIBBEHA							
23105000040000	W P SUDDUTH A-1	Wildcat	CLEARY PETROLEUM CORPORATION	OKTIBBEHA							

🟨 COMPLETED WELLS 🟦 NO TEMPERATURE 🟩 NO LAT/LONG 🟪 NO WELL LOG

Figure 1. Data Spreadsheet for Oktibbeha County

Latitude and longitude, if available were given in the Oil and Gas Board report. For most of the wells the depth and temperature were available on the well log header (Figure 2).



HALLIBURTON

SIX ARM DIPMETER

SHIVA CORRELATION

COMPANY TOTAL FINA ELF E&P USA, INC.

WELL WINTERS #1 ST #1

FIELD MABEN

COUNTY OKTIBBEHA STATE MS

RECEIVED

Figure 2. Sample Well Log Header

Data Reduction

Any well that did not include an image of the well log was not used. The criterion for a useful well was: bottom-hole temperature, latitude and longitude, and recorded depth. All well logs were entered on the data sheet but only those that met the needed criteria were used for creating the thermal gradient map of Oktibbeha County.

Data Processing

The bottom-hole temperature data available on the site would not necessarily represent an equilibrium temperature. The skewed reading could be due to temperatures being logged immediately following drilling. In this case the well temperature would not be at equilibrium. Due to this, each bottom-hole temperature was mathematically recalculated based on the formula used by the geothermal research team at Southern Methodist University. The initial correction formula is the Harrison et al. correction (Harrison et al. 1983 in Blackwell and Richards, 2004):

$$°C = -16.51213476 + 0.01826842109z - 0.0000023449369592z^2$$

where z = depth in meters.

Adjustments ranged from 5.32°C at just over 1400 meters to as much as 19.09°C at over 6500 meters. The recalculation formula was derived to adjust for climatic, geologic, or equipment interference with the actual temperature at depth. There is also a second correction that is applied for the deep wells, the SMU-Harrison correction, where the curve starts to overturn and decrease in correction values (at 3932 m the correction is about 19.07°C). Below this depth the highest correction value is taken and an additional .01°C is added for very additional 500 meter interval (Blackwell, et al., 2012). Units were changed from feet to meters and from Fahrenheit to Celsius, as needed, for calculations. The calculation formula was not calibrated to Oktibbeha County but is a general form of the equation. To calibrate the equation more information is needed such as mean surface temperature and identification of subsurface formations being drilled. Once a well has been identified that can be used to log temperature in the area, a more exact equation will be formulated specific to Oktibbeha County.

RESULTS

The Mississippi Oil and Gas Board website (MSOGB, 2012) hosts records of thirty wells for Oktibbeha County. Of the thirty wells, three had no well log scanned, seven had no available latitude and longitude and two had no temperature data. The remaining eighteen wells were used to gather information regarding the availability of adequate heat energy for geothermal production.

The highest temperature located was calculated at 166.34°C (331.41°F) at a depth of about six and a half kilometers. The MS Fulgham well, API #23105200020001, is located in the Maben field of Oktibbeha County (Figure 3) and is classified as a plugged and abandoned dry hole (MSOGB, 2012). The well was initially drilled for natural gas exploration. A total of nine other wells were identified as having temperatures exceeding 135°C, the minimum temperature required for the binary cycle geothermal energy facility. All nine wells with the minimum acceptable bottom-hole temperatures follow a general trend of increased temperature with increased depth (Figure 4).

Figure 3. MS Fulgham Well Location

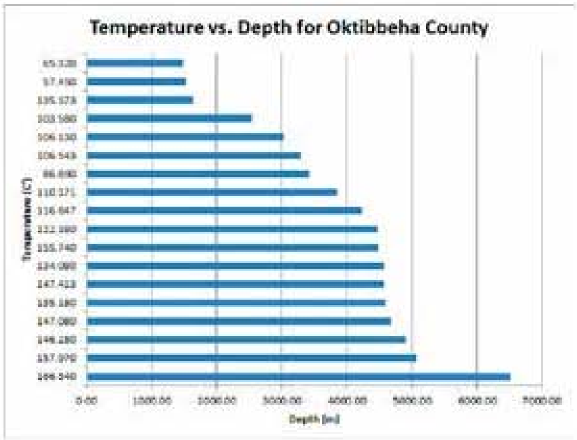


Figure 4. Temperature vs. Depth Trend

The data were also used to create a geothermal contour map of Oktibbeha County using R, a program used for statistical graphics (Figure 5). A formula was written for R using recorded latitudes, longitudes, and adjusted bottom-hole temperatures. The formula was used to interpolate a depth for each site needed to reach 135°C. It is clear from this contour map that depths needed in the northwestern quadrant of Oktibbeha County are in fact much shallower than the rest of the county.

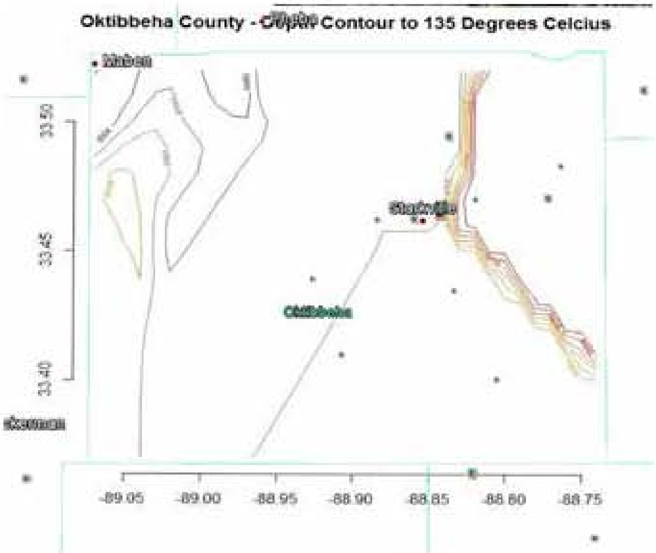


Figure 5. Geothermal Gradient Contour of Oktibbeha County

DISCUSSION

The temperatures found in Oktibbeha County exceed previous estimations on the most current geothermal maps of the United States. The latest, 2011 edition map created by the research team at Southern Methodist University, sponsored by Google Inc. (Google.org, 2012), shows an average temperate at six and a half kilometers depth to be around 100°C for Oktibbeha County. The presence of the higher temperatures found in this study is an indication that there is some geologic cause for this increased temperature reading that was not represented in previous assessments. Further evidence is needed to determine if this is, in fact, the case.

When compared to the 1969 geologic map of Mississippi (MDEQ, 2012) the higher gradients found in this study appear to be clustered in eastern Oktibbeha County near an area where the Porters Creek, Wilcox and the Naheola Formation boundaries exist. Well records submitted to the Mississippi Oil and Gas Board indicate the formation at the depths drilled in Oktibbeha County, or at least those exceeding the normal temperature gradient, is the Knox Formation. The stratigraphy of the surrounding formations is presented in Figure 6 (Ryder, Undated). The Knox formation is a Cambrian-Ordovician dolostone formation known to show evidence of karst porosity; and in some areas of Kentucky it shows evidence of porosity associated with dolomite crystal lined vugs, believed to have precipitated from hydrothermal fluids (Pittenger et al., 2009). The presence of either of these could be the cause for the increased temperature found in Oktibbeha County. Upon review of the structural map of Mississippi, also available on the MDEQ website, there is also evidence of two faults in this area. It is possible these faults allow for the upward movement of geothermal fluid in the crust, thus causing the increased temperatures (Blackwell, et al., 2012a). The horst area between these two faults could also have created traps for geothermal fluid. Further investigation is needed to determine if in fact these geologic occurrences are affecting the thermal gradient in Oktibbeha County.

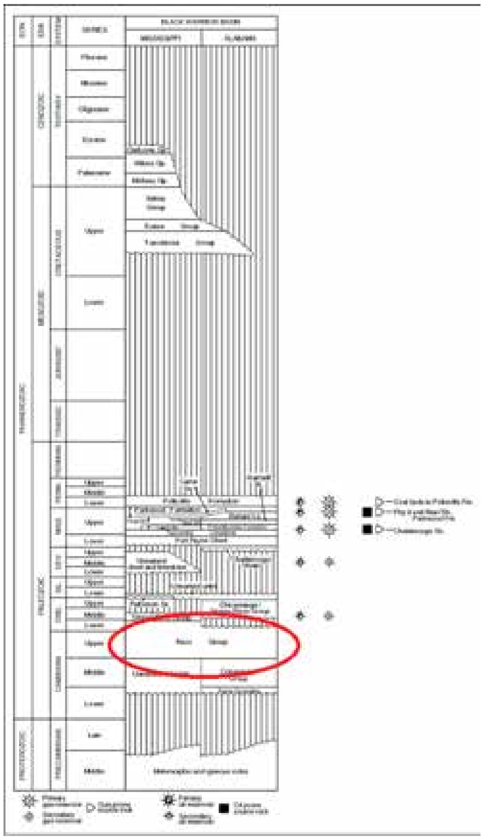


Figure 6. Stratigraphy of Black Warrior Basin

The greatest significance of this study for Oktibbeha County and Mississippi is the opportunity for Oktibbeha County to become home to a clean energy-producing facility. Such a facility could provide an alternative to another lignite coal operation in Mississippi, increase economic stability in the area, as well as encourage further exploration of geothermal potential statewide. As geothermal production increases, Mississippi could move from the top of the list of states that consume the most electricity per capita, to a state that actually exports electricity. Mississippi State University and the Department of Geosciences, in particular, also stand to gain from such an opportunity. Currently, the programs in the geosciences department are heavily geared towards petroleum exploration. Geothermal exploration would be an additional avenue of research for the department, adding Mississippi State to the small number of schools with geothermal programs (Holm, 2011). Research in geothermal could bring new funding, new staff, and an increased student body to the department.

CONCLUSIONS

Bottom-hole temperatures exceeding 135°C, a temperature sufficient for geothermal binary power production, were found to be present in Oktibbeha County. Mapping of the area suggests geologic causation, such as faulting or geothermal reservoirs to between stratigraphic layers, or increased temperature.

EDITOR'S NOTE

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MEASURING THE COSTS AND BENEFITS OF NATIONWIDE GEOTHERMAL HEAT PUMP DEPLOYMENT – A PROGRESS REPORT

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ABSTRACT

The use of geothermal heat pump systems (GHPs) in the United States is marginal, despite their high efficiency and minimal greenhouse gas emissions. To evaluate the consequences of broader deployment of GHPs we are conducting a national cost-benefit analysis for 30 metropolitan regions. The three-year effort is known as the GHPsRUS Project ("Geothermal Heat Pumps are U.S."). In previous papers, we reported on the project's basic approach and progress in acquiring geological data needed to quantitatively model GHP design specifications and cost. In this paper, we report on the progress of the GHPsRUS Project.

INTRODUCTION

Geothermal heat pumps (GHPs) deliver reliable, cost effective, and energy efficient heating and cooling. Among the most efficient heating and cooling technologies available, GHPs use the relatively constant temperature of the earth to heat and cool buildings. GHPs may also provide domestic hot water (DHW). GHPs are an important energy conservation technology; they use significantly less energy than conventional heating or cooling systems; about 70% of the total energy used in a GHP system is renewable from the ground (GeoExchange, Undated).

According to the U.S. Environmental Protection Agency (EPA), GHPs can reduce energy consumption—and corresponding greenhouse gas (GHG) emissions—by up to 44% compared to air-source heat pumps and by up to 72% compared to electric resistance heating with standard air-conditioning equipment (USDOE, Undated).

A 2008 Oak Ridge National Laboratory (ORNL) study (Hughes, 2008) which examined the barriers to increased GHP use in the United States found that, although the U.S. was once the world leader in GHP technology and market development, Europe now installs two to three times more GHPs than the U.S., and the GHP market is growing faster in Europe, China, South Korea, and Canada than in the United States. While the U.S. has the greatest number of GHP units installed on a per capita basis, it has fallen behind many European countries.

The total market for GHPs in the United States in 2008, including equipment and installation cost (not reduced by government or other incentives) is estimated at $3.7 billion. The GHP market is expected to triple in value by 2013 (Priority Metrics Group, 2009). In 2009, shipments of GHPs dropped nearly 5% to 115,442 units—the first decrease in GHP shipments since 2003 (USEIA, 2009). Shipments increased, however, in 2010.

Figures 1 and 2 show GHP shipments by number of units and rated capacity in tons (one ton = 12,000 Btu/hr) from 1994, when the Energy Information Administration (EIA) first began surveying the industry, through 2010. No survey was conducted in 2001. Funding for EIA's annual data collection and report on GHPs was terminated in the Fiscal Year 2011 budget. Data for 2010 came from the *GHPsRUS Project Manufacturer & OEM Survey.*

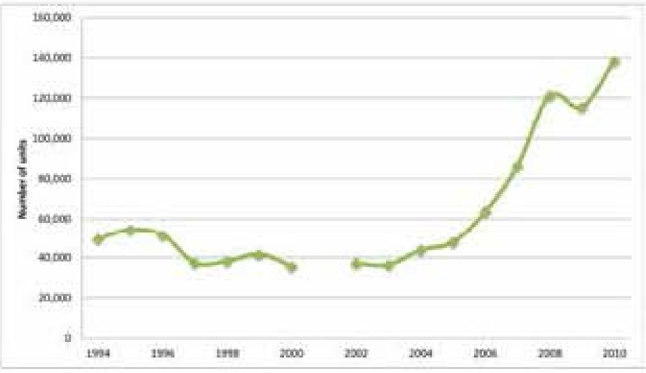

Figure 1. Geothermal heat pump shipments (number of units), 1994-2010.

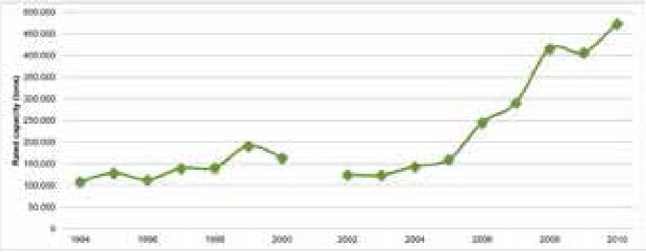

Figure 2. Geothermal heat pump shipments (rated capacity in tons), 1994-2010.

Figure 3 shows the value of shipments of GHPs in relation to all heating, ventilating, and air conditioning (HVAC) equipment from 2005 through 2010 (US Census Bureau, 2011). Figure 4 shows GHPs as a percentage of all air-conditioning and warm air heating equipment shipments from 2005 through 2010. The U.S. Census Bureau withheld the value of GHP shipments in 2009 and 2010 "to avoid disclosing data of individual companies." GHP data for 2009 came from the EIA; 2010 data came from the *GHPsRUS Project Manufacturer & OEM Survey.*

While the technology has been in use since the late 1940s, GHPs currently account for about 2% of the total U.S. heating and cooling market. In 2010, in terms of value of equipment shipments, GHPs made up $372 million or 2.3% of the $16-billion U.S. HVAC market. In comparison, $2.1 billion of air-source heat pumps, or 13.5% of all HVAC equipment, was shipped in 2010.

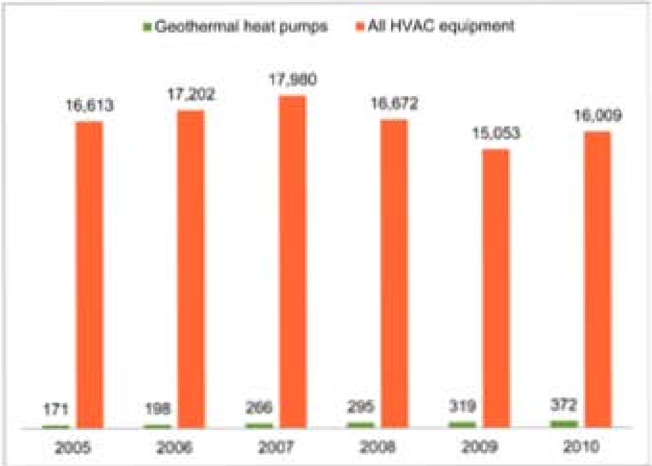

Figure 3. Value of shipments of air-conditioning and warm air heating equipment, 2005-2010 (millions of dollars).

But, what if the numbers were higher? How would a nationwide deployment of GHPs benefit the country economically, environmentally, and socially?

With support from the U.S. Department of Energy through the American Recovery and Reinvestment Act of 2009, Bob Lawrence & Associates, Inc. (BL&A) and the California Geothermal Energy Collaborative (CGEC) are in the final year of a three-year study to help determine the answers to these questions. The three-year effort is known as the GHPsRUS Project ("Geothermal Heat Pumps are U.S.") (http://ghpsrus.com). The GHPsRUS Project is composed of two main components: (1) Market Analysis and (2) Regional Modeling Analysis.

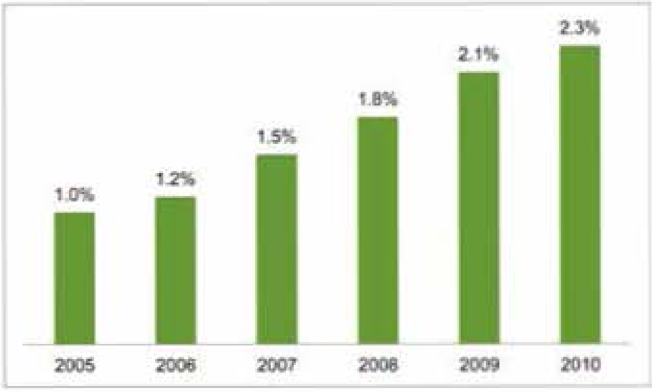

Figure 4. Geothermal heat pumps as a percentage of all air-conditioning and warm air heating equipment shipments, 2005-2010.

In previous papers, we reported on the project's basic approach (Battocletti and Glassley, 2010) and progress in acquiring geological data necessary to quantitatively model GHP design specifications and cost (Glassley and Battocletti, 2011). In this paper, we report on the progress of the GHPsRUS Project. This paper presents results collected and analyzed through April 2012.

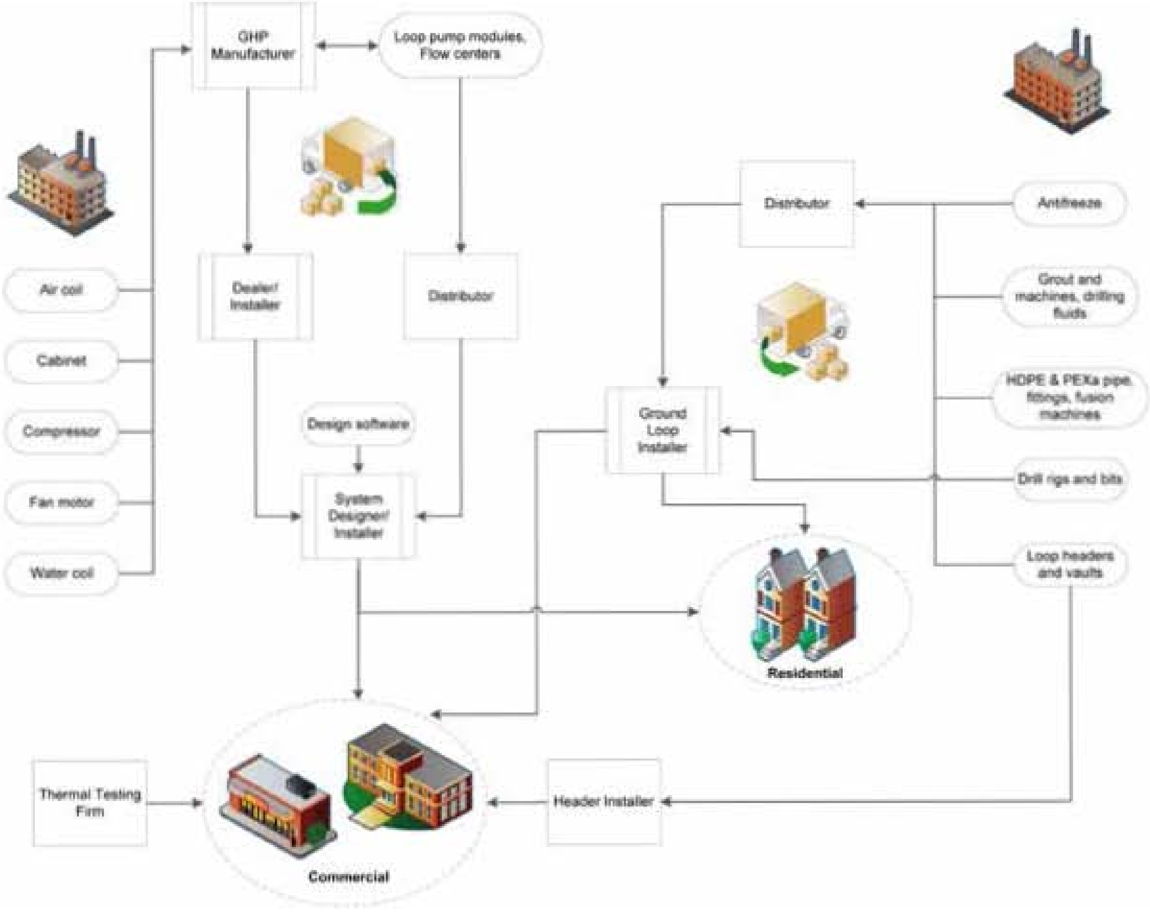

Figure 5. Major components of the U.S. geothermal heat pump industry

MARKET ANALYSIS

The purpose of the market analysis is to measure the current state of the GHP industry in order to establish a baseline for forecasting the benefits which would result from varying degrees of market penetration. Previous market analyses have generally focused on GHP manufacturers only. This analysis attempts to quantify the entire GHP industry—from manufacturing to design to installation (Figure 5).

We divided the GHP industry into four segments:

1. Manufacturers, Original Equipment Manufacturers (OEMs), and suppliers;
2. Geothermal loop installers;
3. Mechanical equipment installers; and
4. Other

The GHPsRUS Project created and widely disseminated four surveys to collect economic data from the four segments of the U.S. GHP industry. To maximize industry buy-in, increase credibility, and ensure that the data collected was as relevant as possible, each survey was carefully designed in close collaboration with GHP industry members. To encourage participation, respondents were assured that all information provided would be kept completely confidential and used only in the aggregate.

Survey Monkey (https://www.surveymonkey.com) was selected to create and publish the surveys and collect and analyze data. Survey Monkey was chosen for its ability to create and disseminate online and PDF surveys which are easy to complete, as well as for its data collection and analysis tools.

As of April 2012, 232 companies accounting for 6,458 direct full-time and 744 part-time jobs responded to one of the four economic surveys (Table 1). Indirect jobs are not included here but will be in the final analysis.

Table 1. Direct Jobs provided by Respondents to the GHPsRUS Project Economic Surveys (April 2012).

Company Type	Number of Companies	Full-Time Jobs	Part-Time Jobs
Builder/Developer	2	3	0
Dealer	1	15	0
Distributor	22	1,959	234
Driller	94	736	168
Engineer	7	82	30
Geothermal system designer	4	12	4
GHP manufacturer/OEM	24	2,594	127
Government official (local, state, federal)	3	37	0
HVAC company	2	503	0
Manufacturer, other	2	10	2
Mechanical equipment installer	52	274	50
Other	7	5	16
Professional, other	1	2	2
Supplier	4	165	12
Supplier, pump	1	50	50
Trade association	1	0	2
Utility	5	11	47
Totals	**232**	**6,458**	**744**

Responses were received from Canada and 40 states: Alabama, Arkansas, California, Colorado, Connecticut, Delaware, Florida, Georgia, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Jersey, New York, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, South Carolina, South Dakota, Tennessee, Texas, Utah, Virginia, Vermont, Washington State, and Wisconsin (Figure 6).

Figure 6. Locations of companies that responded to a GHPsRUS Project economic survey (in orange).

Geothermal heat pump industry jobs by state are shown in Table 2. The five states with the most GHP-related jobs are Indiana, Oklahoma, Georgia, Minnesota, and Florida. WaterFurnace International is based in Fort Wayne, Indiana; ClimateMaster, Inc. in Oklahoma City, Oklahoma; and FHP – Bosch Group in Fort Lauderdale, Florida.

Table 2. Geothermal Heat Pump Industry Jobs by State.

State	Full-time jobs	Part-time jobs	State	Full-time jobs	Part-time jobs
AL	2	8	MO	166	2
AR	37	1	MT	14	7
CA	11	6	NE	36	20
CO	123	13	NV	8	8
CT	35	3	NJ	22	14
DE	8	0	NY	300	39
CN	16	8	NC	29	4
FL	360	63	OH	102	72
GA	676	2	OK	822	9
ID	26	18	OR	2	3
IL	375	8	PA	106	39
IN	1,833	6	SC	12	100
IA	14	32	SD	23	0
KS	62	52	TN	8	29
KY	6	0	TX	50	22
ME	4	3	UT	4	3
MD	111	6	VT	10	19
MA	9	2	VA	242	5
MI	125	21	WA	43	4
MN	549	52	WI	74	41
MS	3	0			

All segments of the U.S. GHP industry are bullish about the future and expect that their GHP business will increase in the next few years (Figure 7).

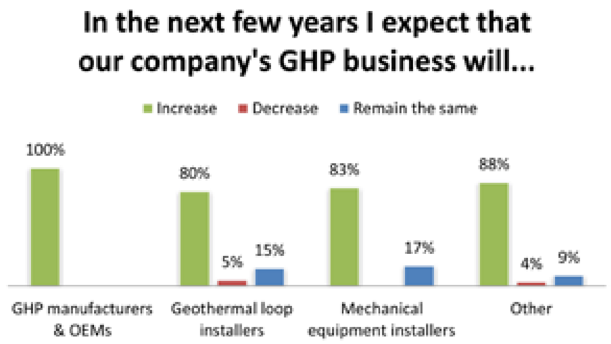

Figure 7. Outlook of U.S. geothermal heat pump industry segments.

Preliminary results of the four surveys as of April 2012 are described below.

Manufacturers, OEMS, and Suppliers

The *Manufacturer & OEM Survey* was launched on 23 June 2011. Its purpose is to collect economic data from manufacturers and Original Equipment Manufacturers (OEMs) including location of manufacturing facilities, number and location of full- and part-time jobs, plans for expansion, and data on up- and down-stream channels.

"Manufacturer" is defined as a company that manufactures geothermal heat pumps. "Original Equipment Manufacturer (OEM)" is defined as a company that buys geothermal heat pumps from a Manufacturer for sale under their own brand name(s). "Supplier" is defined as a company that manufactures the five most costly components of a GHP unit in terms of their cost as a percentage of the final unit (air coil, cabinet, compressor, fan motor, and water coil), and sells them to the Manufacturer.

As of April 2012, 24 responses were received to the *Manufacturer & OEM Survey*; 17 companies (70.8%) fully completed the survey. The 24 companies provided 2,594 direct full-time and 127 part-time jobs. They reported combined sales in 2010 of 118,347 units with a rated capacity of 373,731 tons (Table 3). Responses came from companies in 17 states: Arkansas, Connecticut, Florida, Georgia, Illinois, Indiana, Maryland, Michigan, Minnesota, New York, Ohio, Oklahoma, Oregon, Pennsylvania, South Dakota, Texas, and Washington State.

Table 3. Results of Manufacturer and OEM Survey (April 2012)

Began survey	24
Completed survey	17
Companies	24
States	17
Full-time jobs	2,594
Part-time jobs	127
Sales in 2010	Number of units: 118,347 Rated capacity (tons): 373,731
Dealers	19,803
Distributors	493
Commercial representatives	418
Other sales outlets	42

Half of the manufacturers produce water-to-air geothermal heat pumps (50%), followed by water-to-water (37%). Direct Geoexchange heat pumps _ account for 10% of GHP units produced (Figure 8).

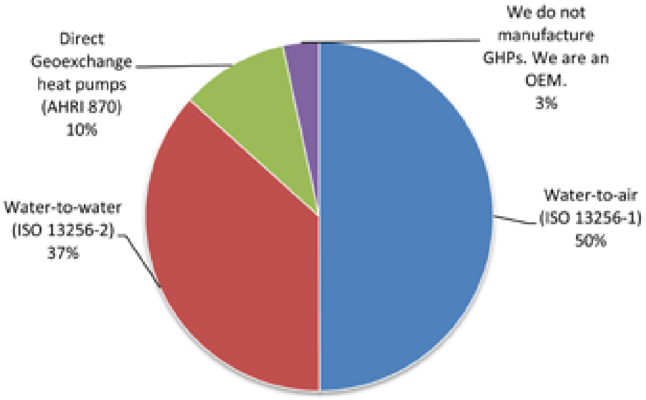

Figure 8. Types of geothermal heat pumps manufactured.

Fifteen (15) companies manufacture for the residential market, 13 for the commercial market, and 7 for the industrial market. The largest numbers of manufacturing facilities are located in New York and Oklahoma followed by Florida, Indiana, Maryland, New Mexico, Ohio, Oregon, Pennsylvania, South Dakota, and Texas. Two companies reported having manufacturing facilities in all 50 states.

Upstream Supply Chain

Since the GHPsRUS Project is trying to measure how the entire geothermal heat pump industry benefits the country, companies were asked about their upstream supply chain. Manufacturers and OEMs were requested to rank the most costly components of a GHP unit in terms of their cost as a percentage of the final unit. The five most costly components are the compressor, air coil, water coil, cabinet, and fan motor.

Companies were asked from what vendors they purchase the most costly components. The most commonly named suppliers were Bristol Compressors International, Inc., Emerson Climate Technologies (Copeland), Luvata (Heatcraft), Packless Industries, Regal Beloit (Genteq, Century), Tecumseh Products Company, and Turbotec (Table 4).

Table 4. Suppliers of Major Geothermal Heat Pump Components.

Supplier name	U.S. location	Component
Bristol Compressors, International, Inc.	Bristol, VA	Compressor
Emerson Climate Technologies (Copeland)	St. Louis, MI	Compressor
Luvata (Heatcraft)	Grenada, MS	Water coil
Packless Industries	Waco, TX	Water coil
Regal Beloit (Genteq, Century)	Fort Wayne, IN Tipp City, OH	Fan motor
Tecumseh Products Company	Arbor, MI	Compressor
Turbotec	Windsor, CT Hickory, NC	Air coil

Downstream Supply Chain

The 24 GHP manufacturers and OEMs sell GHPs through a nationwide distribution network of 19,803 dealers, 493 distributors, 418 commercial representatives, and 42 other sales outlets. The most common distribution channels are distributors (55.6%), commercial representatives (50%), dealer-direct (33.3%), and OEM to other brands (33.3%) (Figure 9).

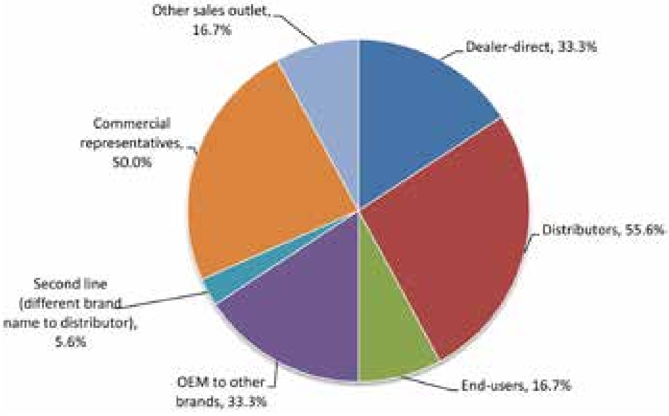

Figure 9. Distribution channels for geothermal heat pump manufacturers and OEMs

Loop Installers

The *Ground Loop Survey* was launched on 23 March 2011. It is directed towards geothermal loop installers to collect economic and geological data and determine drilling price per linear foot by zip code. "Geothermal loop installer" is defined as a company that installs the geothermal loop heat exchanger for a geothermal heating and cooling system.

As of April 2012, 105 responses were received to the *Ground Loop Survey* of which 71 people (67%) fully completed the survey. Ninety-four (94) companies in 32 states provided 736 full-time and 168 part-time jobs. The respondents installed a total of 6,722 geothermal loops in 2010. Respondents had an average of 12.75 years of experience installing geothermal loops; most companies entered the GHP industry 10 to 20 years ago (Table 5).

Table 5. Results of Ground Loop Survey (April 2012).

Began survey	105
Completed survey	71
Companies	94
States	32
Full-time jobs	736
Part-time jobs	168
Installations in 2010	6,722
Year in which company started installing GHPs	1979 (earliest) 2011 (latest) 1999 (average)
Average number of years installing GHPs	12.75

Responses were received from companies in 32 states: Alabama, California, Colorado, Connecticut, Delaware, Florida, Idaho, Illinois, Iowa, Indiana, Kansas, Maryland, Massachusetts, Michigan, Minnesota, Missouri, Montana, Nebraska, Nevada, New Jersey, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, South Carolina, Texas, Utah, Vermont, Virginia, Washington State, and Wisconsin. The greatest numbers of responses were received from companies in Michigan, Wisconsin, Ohio, Pennsylvania, and Virginia (Table 6).

Table 6. Location and Number of Responses to the Ground Loop Survey by State.

State	Number of responses	State	Number of responses
Alabama	1	North Carolina	5
California	3	Nebraska	2
Colorado	4	Nevada	1
Connecticut	2	New Jersey	2
Delaware	1	Ohio	7
Florida	3	Oklahoma	2
Iowa	2	Oregon	1
Idaho	3	Pennsylvania	7
Illinois	2	South Carolina	1
Indiana	3	Texas	3
Kansas	2	Utah	1
Maryland	3	Virginia	6
Massachusetts	1	Vermont	2
Michigan	12	Washington	4
Minnesota	3	Wisconsin	8
Montana	2		

Mud drilling was the most common drilling method reported followed by air drilling (Figure 10). Vertical boreholes accounted for 74% of all installations, horizontal trenches for 17%, horizontal (directional) drilling for 7%, and Direct Exchange for 1%. No pond or lake loops were reported (Figure 11).

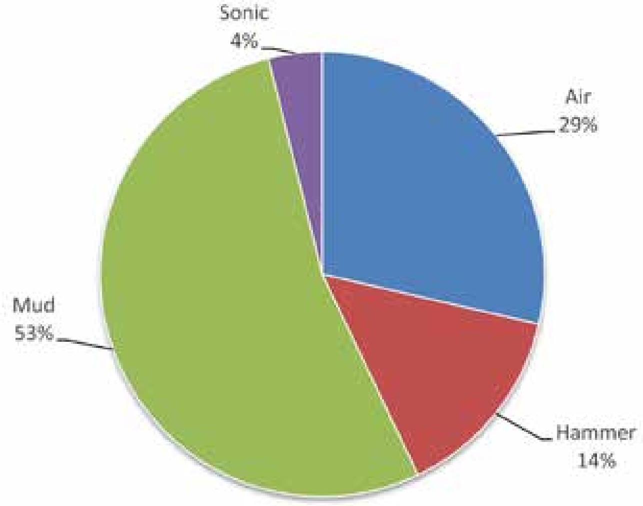

Figure 10. Drilling methods reported in Ground Loop Survey.

Respondents were given a choice of supplying geological and price data for either an average or an actual ground loop installation. Geology encountered with the approximate thickness of each (feet) was requested for vertical boreholes. Data on borehole depth was reported for a total of 62 vertical ground loops—49 average loops and 13 actual loops. The value (price) of all 62 vertical boreholes combined was $259,597 (Table 7).

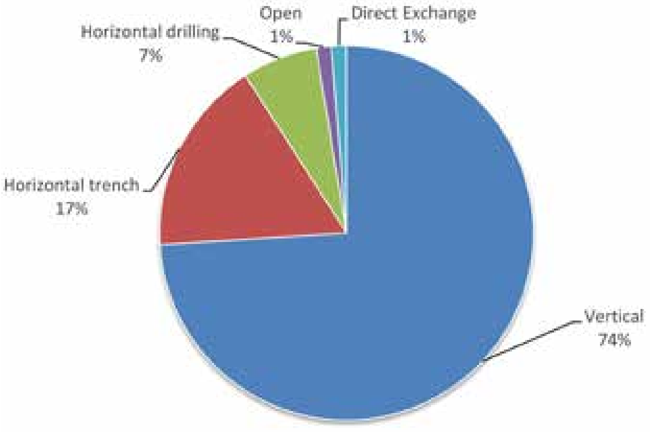

Figure 11. Loop types reported in Ground Loop Survey

Table 7. Average and Actual Vertical Boreholes.

Installation type	Number of vertical boreholes reported	Average borehole depth (feet)	Average price per foot	Average price per borehole	Total price
Average	49	272	$13.63	$3,707	$181,661
Actual	13	351	$17.08	$5,995	$77,936
				Total	**$259,597**

Mechanical Equipment Installers

The *Mechanical Equipment Installation Survey* was launched on 11 November 2011. Targeted towards companies that install the GHP equipment inside the building, the survey was created to collect basic economic data and equipment installation price by zip code. "Mechanical equipment installer" is defined as a company that installs the mechanical GHP equipment inside the building for a geothermal heating and cooling system.

As of April 2012, 54 responses were received to the *Mechanical Equipment Installation Survey* of which 44 people (81.5%) fully completed the survey (Table 8). The 52 companies provided 274 full-time and 50 part-time jobs, and have worked in the GHP industry an average of 13 years. The respondents installed a total of 1,773 GHP systems in 2010. The majority of companies had 1 to 5 or 10 to 20 years of experience installing GHP systems.

Table 8. Results of Mechanical Equipment Installation Survey (April 2012).

Began survey	54
Completed survey	44
Companies	52
States	29
Full-time jobs	274
Part-time jobs	50
Installations in 2010	1,773
Year in which company started installing GHPs	1978 (earliest) 2011 (latest) 1999 (average)
Average number of years installing GHPs	13

Responses were received from companies in 29 states: Alabama, Connecticut, Delaware, Florida, Georgia, Idaho, Indiana, Kansas, Kentucky, Maine, Maryland, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Jersey, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, Texas, Virginia, Vermont, Washington State, and Wisconsin.

Respondents were asked to provide information for up to five equipment installation jobs their company recently completed. Equipment installations were reported for residential (93.6%), educational (4.3%), and commercial (2.1%) buildings. Retrofit installations (57%) outnumbered new construction (43%).

Table 9 summarizes the data collected on mechanical equipment installations through April 2012. Companies provided information on installations into 86 buildings totaling 766,398 square feet of conditioned space. Installed tons were 1,851 using 414 geothermal heat pumps. The total installation price for all installations was $7.2 million.

Other

The *Geothermal Heat Pump Industry Survey* was posted on 21 November 2011. Its purpose is to collect economic data including location, jobs, plans for expansion, etc. from members of the U.S. GHP industry not addressed by one of the other three surveys.

Table 9. Mechanical Equipment Installations (April 2012).

Building type	Number of buildings	New/ Retrofit	Total conditioned space (ft2)	Installed tons	Number of GHPs	GHP type	Price
Commercial	1	New	25,000	60	10	Water-to-air	$225,000
Commercial	1	Retrofit	5,000	5	1	Direct Geoexchange	$15,000
Commercial	1	Retrofit	4,000	10	2	Water-to-air	$30,000
Educational	1	New	450,000	1,250	250	Water-to-air Water-to-water	$3,500,000
Medical	1	New	7,000	22	12	Water-to-air	$360,000
Residential	7	New	28,960	56	14	Water-to-air Water-to-water	$312,440
Residential	3	New	7,000	12	3	Water-to-water	$92,000
Residential	24	New	96,150	148	40	Water-to-air	$1,041,235
Residential	4	Retrofit	21,900	61	17	Water-to-air Water-to-water	$408,000
Residential	1	Retrofit	2,500	4	1	Other (i.e. hybrid, etc.)	$50,000
Residential	2	Retrofit	7,105	11	2	Water-to-water	$69,490
Residential	39	Retrofit	108,183	208	61	Water-to-air	$1,070,740
Residential	1	Retrofit	3,600	4	1	Water-to-air	$22,000
Totals	86		766,398	1,851	414		$7,195,905

"Other" is defined as all other companies involved in the U.S. GHP industry including distributors; pipe and fittings manufacturers; drill rig, bit, and fluid manufacturers; grout manufacturers; design software companies; header installers; antifreeze manufacturers; etc.

As of April 2012, 58 responses were received to the *Geothermal Heat Pump Industry Survey* of which 54 people (93.1%) fully completed the survey. The 57 companies provided 2,812 full-time and 391 part-time jobs, and have worked in the GHP industry an average of 15.3 years. About one-third of the companies are relative newcomers to the GHP industry: 32% entered the industry within the last five years. Almost half of the companies entered the GHP industry within the past 10 years (Table 10).

Responses were received from companies in Canada and 27 states: Colorado, Delaware, Florida, Georgia, Idaho, Illinois, Indiana, Iowa, Kansas, Massachusetts, Michigan,Minnesota, Missouri, Montana, Nebraska, New Jersey, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, South Carolina, Tennessee, Texas, Virginia, Washington State, and Wisconsin.

Table 10. Results of Geothermal Heat Pump Industry Survey (April 2012)

Began survey	58
Completed survey	54
Companies	57
States	27
Full-time jobs	2,812
Part-time jobs	391
Year in which company started in the GHP business	1935 (earliest) 2011 (latest) 1997 (average)
Average number of years in the GHP business	15.3

REGIONAL MODELING ANALYSIS

To accomplish an analysis of the regional and national benefits of GHP deployment, it is important to evaluate the effects on energy consumption and atmospheric pollutants, including greenhouse gases, if GHP systems displace conventional HVAC systems. To do this, we have

New York-Northern New Jersey-Long Island, NY-NJ-PA
Los Angeles-Long Beach-Santa Ana, CA
Chicago-Naperville-Joliet, IL-IN-WI
Dallas-Fort Worth-Arlington, TX
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD
Houston-Sugar Land-Baytown, TX
Miami-Fort Lauderdale-Pompano Beach, FL
Atlanta-Sandy Springs-Marietta, GA
Washington-Arlington-Alexandria, DC-VA-MD-WV
Boston-Cambridge-Quincy, MA-NH
Detroit-Warren-Livonia, MI
Phoenix-Mesa-Scottsdale, AZ
San Francisco-Oakland-Fremont, CA
Riverside-San Bernardino-Ontario, CA
Seattle-Tacoma-Bellevue, WA
Minneapolis-St. Paul-Bloomington, MN-WI
San Diego-Carlsbad-San Marcos, CA
St. Louis, MO-IL
Tampa-St. Petersburg-Clearwater, FL
Baltimore-Towson, MD
Denver-Aurora, CO
Pittsburgh, PA
Portland-Vancouver-Beaverton, OR-WA
Cincinnati-Middletown, OH-KY-IN
Sacramento--Arden-Arcade--Roseville, CA
Cleveland-Elyria-Mentor, OH
Orlando-Kissimmee, FL
San Antonio, TX
Kansas City, MO-KS
Las Vegas-Paradise, NV

Figure 12. Thirty (30) largest metropolitan areas in the United States (from largest to smallest)

undertaken a systematic modeling effort in which loop designs for standard residential and commercial buildings were developed using commercially available software. Load characteristics for the buildings were modeled for the 30 largest metropolitan areas in the United States (Figure 12), and used as input for the loop design software (Glassley and Battocletti, 2011).

As previously noted, GHP systems utilize the constant thermal properties of the subsurface as a reliable reservoir for storing and/or extracting heat. Performance of these systems depends, as a result, on a variety of properties important for heat transfer in geological materials, including soil thermal conductivity and diffusivity, degree of saturation, and temperature. We have assembled and made databases for these properties web-accessible (http://cgec.geology.ucdavis.edu/ghpstudy.php).

Although we have used this information in conducting the loop design calculations, the common absence of reliable thermal conductivity data made it necessary to calculate loop length over a range of thermal conductivity values for each metropolitan area. This allows us to characterize, over a range of conditions, likely loop properties. Although the data we collected showed that, contrary to common assumptions (Glassley and Battocletti, 2011), subsurface temperature varies considerably in many metropolitan areas, insufficient data coverage required that we utilize a standard table of assumed temperatures (McQuay International, 2002) in order to conduct the calculations. These constraints raise several caveats about the model results that must be borne in mind when discussing the outcomes. First, loop lengths as a function of thermal conductivity are approximate and strongly dependent on the assumptions noted above. Second, even using a range of thermal conductivities, in order to address uncertainties in soil properties, the use of a single subsurface temperature for a given metropolitan area will introduce some error in the calculated loop length for a given installation, since subsurface temperatures are variable, even within a single metropolitan area. These points are intended to emphasize that these model results should not be used as a substitute for rigorous design efforts for specific building applications. Rather, these results are intended to establish a means for comparative analysis across many regional sites, and should not be used as a construction guide.

In Figure 13 we present a comparison of the annual energy use (in kWh/yr) for residential heating and cooling using conventional HVAC equipment and GHP systems. Energy use by energy source (electricity, natural gas, coal, etc.) was accounted for based on EIA and Federal Energy Regulatory Commission (FERC) data. It was assumed that the thermal conductivity of the soil fell in the range of 0.8 to 1.2 (BTU/hr-ft-F). Because of this range, error bars of +/-10% are also drawn for each point

As Figure 13 shows, the greatest energy savings are obtained in regions where the building air conditioning is dominated by a heating load. This is consistent with the fact that current GHP designs run most efficiently in a heating mode. The overall national average energy savings would be close to 50%, if GHP deployment was evenly distributed throughout these cities and conventional HVAC systems replaced. Similar results are obtained for commercial deployment.

Because of the correlation between energy production and use, reductions in greenhouse gas emissions and atmospheric pollutants (e.g., CO, SO, and NOx) follow closely the same patterns shown for energy use in Figure 13.

CONCLUSION

The U.S. GHP industry has a well-distributed national presence. Although currently small, if encouraged to grow, the consequence would be national jobs and economic growth – this is not just a Midwest or rust belt industry. The impact would be broad, since the industry is distributed over many components of the economy – manufacturing, drilling, construction, engineering and design, distribution, etc. Energy use and greenhouse gas emissions could be reduced significantly in nearly all regions of the country. Results of the GHPsRUS Project to date are robust. Although specifics are not currently evident several months prior to the project's end, the overall impact is very heavily weighted to the positive side.

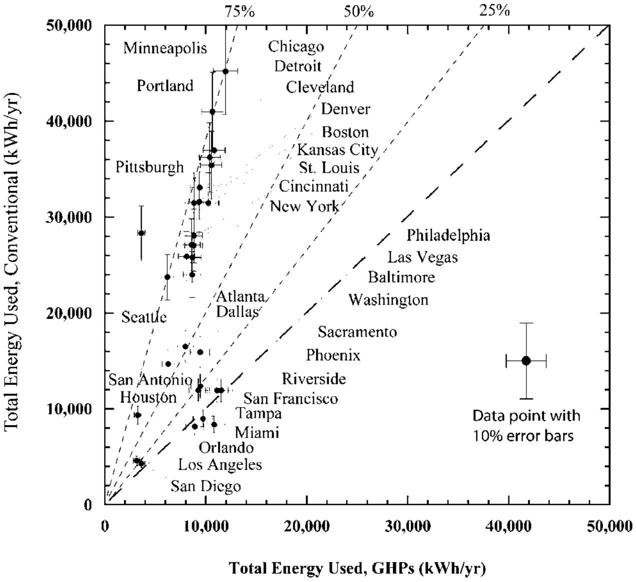

Figure 13. Comparison of energy use for residential buildings (in kWh/yr) for each of the indicated 30 metropolitan areas. Conventional HVAC system energy use is shown on the vertical axis, GHP energy use is on the horizontal axis. The light dashed lines show the reduction in energy use (in percent) for GHP use relative to conventional HVAC use.

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DISCLAIMER

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EDITOR’S NOTE

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