INTRODUCTION

Geothermal energy is one of the natural resources in the town of Rico, Colorado. Electric power generation and direct-use utilization are two applications of geothermal energy in the United States. The direct-use application of geothermal energy is primarily for direct heating and cooling and normally uses geothermal resources with temperature below 150˚C .[1] The main categories for direct use applications are : (1) swimming, bathing and balneology; (2) space heating and cooling including district energy systems; (3) agricultural applications; (4) aquaculture applications ; (5) industrial applications; and, (6) geothermal (ground-source) heat pumps (GHP). The growth rate for direct-use was 8.3% annually from year 1990 with the largest annual energy growth has been in the GHP.[2] Figure 1 shows direct use applications of heat energy in the United States at year 1990, 1995, and 2000.

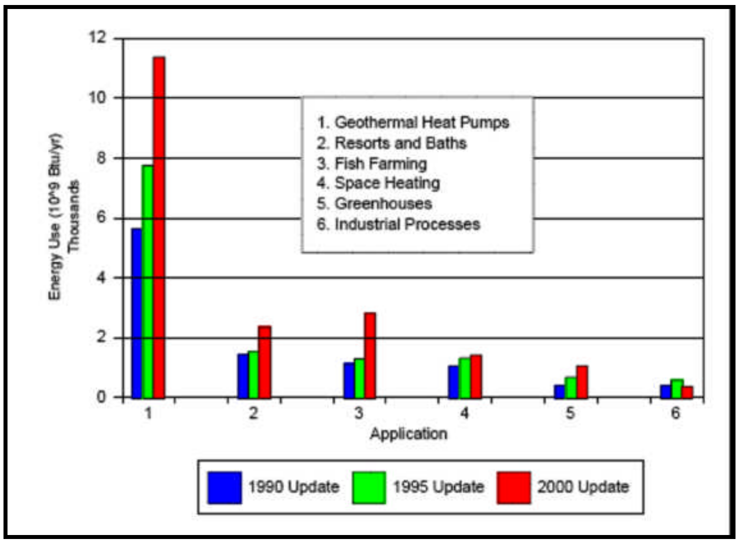

Figure 1. – Direct Heat Utilization in the United States (from Lund and Boyd, 2000)

This report will discuss the different direct-use applications of geothermal energy that may be applicable for the town of Rico, Colorado. The first part of the report will look at the fundamentals of different direct-use applications with some examples. The second part of the report will provide analysis on which direct-use applications that may be beneficial and feasible for the town of Rico. The main types of geothermal direct-use applications that this report will focus on are district heating, greenhouses, produce and lumber drying, metal and mineral leaching, and aquaculture.

[1] Lund J. W., 2007, **Characteristics, Development and Utilization of Geothermal Resources**, Geo-Heat Center Bulletin, June, Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR.
[2] Lund J. W., and Boyd, T. L., 2000, **Geothermal Direct-Use in the United States in 2000**, Geo-Heat Center Bulletin, March, Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR.

DIRECT-USE APPLICATIONS OF GEOTHERMAL ENERGY

1. District Heating

District heating systems distributes hydrothermal water through piping system to blocks of buildings. Like common direct-use systems, there are three typical components of a district heating system: a production facility, a mechanical system, and a disposal system.[3] A production system is usually a well to bring the hydrothermal water/heat energy from the geothermal reservoir. A mechanical system is a system that delivers the hydrothermal water/heat energy to the process. A disposal system is a medium/area that receives the cooled geothermal fluid. It can be a pond, river, or an injection fluid. Figure 2 illustrates a district heating system with geothermal energy.

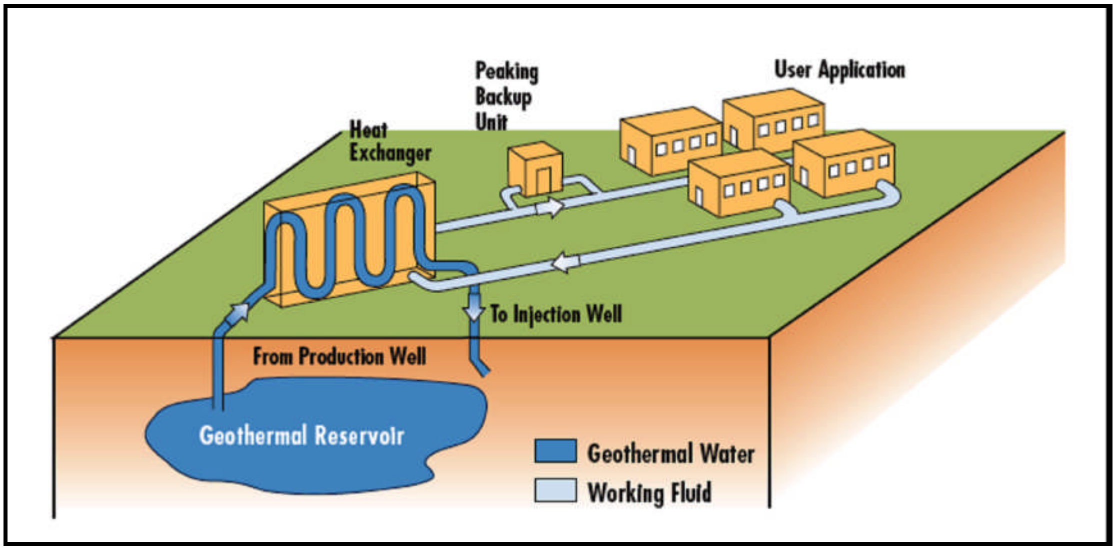

Figure 2. – District Heating System with Geothermal Energy (from The Office of Energy Efficiency and Renewable Energy of the U.S. Department of Energy, 2004)

In year 2000, 18 district heating applications of geothermal energy have been installed iin the United States.[2] District heating system in Boise, Idaho is the first modern district heating system and there are 271 communities with geothermal resources that can use this application.[4] Klamath Falls (Oregon), Midland School District and Phillip (South Dakota) are other success stories of district heating systems with geothermal energy.

The district heating system in Midland, South Dakota is an interesting project because the town has similar characteristics with the town of Rico. Midland is located in Haakon County, approximately sixty miles west of Pierre (the state capital). The town has a

[3] The Office of Energy Efficiency and Renewable Energy of the U.S. Department of Energy, 2004, **Geothermal Technologies Program: Direct Use**, National Energy Laboratory- The DOE National Laboratory.
http://www.nrel.gov/docs/fy04osti/36316.pdf.

[4] The Geothermal Education Office Website. http://geothermal.marin.org/pwrheat.html.

similar characteristic with Rico in terms of its small population. The summary of the district heating system in Midland in this report is based on Lund's paper (1997).[5]

The district heating system in Midland heats approximately 30,000 square feet (2,800 m^2) of floor space. The system heats buildings through a single pipe high and low-pressure line. The high pressure line supplies hot water for the heating of two school buildings, a church, campground buildings and pool, and a car wash. The high pressure line started from the well to the two school buildings. Each school buildings use one heat exchanger that can take maximum of 7^0F (4^0C) from the geothermal water before it goes back to main supply line. Then the line goes to the church, camp ground, and the car wash. The high pressure line then ended at the cooling pond in the water treatment plant that is supplied with approximately 80 gpm (5.0 L/s) of water in the winter and 110 gpm (6.9 L/s) in the summer.

The low pressure line supplies hot water for the heating of four downtown buildings. The geothermal water is sent directly to Modine heaters in the Legion Hall , Library, and Fire Hall. Then the line provides geothermal water for the Tim-Buck-2 Bar and Restaurant and dispose the waste water into the Bad River. This low pressure line can take maximum of 25^0F (14^0C) from the geothermal water. Figure 3 provides the piping system scheme of district heating system in Midland. The district heating system in this town provides an estimated $15,000 annual savings from the propane cost to the community.

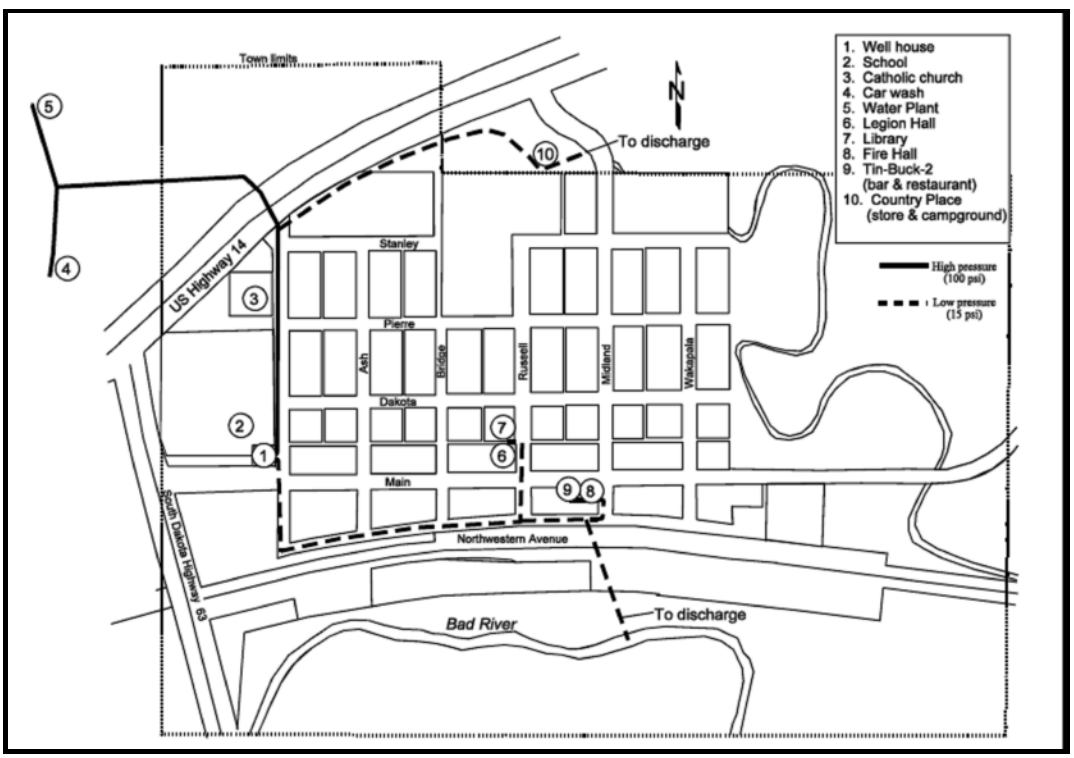

Figure 3 – District Heating Piping System in Midland, South Dakota (from Lund, 1997)

[5] Lund J. W., 1997,**Midland, South Dakota: Geothermal District Heating**, Geo-Heat Center Bulletin, December, Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR.

1.1. District Heating System for Rico

Based on current situation in Rico, most of the buildings are residential buildings. Some consider that district heating system for residential area is uneconomical due to the low heat load density. However, some characteristics residential areas can increase the economics of district heating.[6] These characteristics are: wide variety of heating fuels, availability of unpaved areas of the distribution system, fewer utilities in the pipeline corridor, less traffic control requirements during the construction, potential for the use of an uninsulated piping system, and an older, poorly insulated structures with high energy use. Furthermore, the largest potential area for a cost reduction is in the pipe and installation, trenching and backfilling, and the pavement related costs.

District heating system is proven can bring benefit through cost savings for the community and work for a town with a small population like the one in Midland, South Dakota. Based on the discussion with the representative of Rico on March 17th 2009, the town is trying to have a limited expansion. The town should then start to include the district heating system project plan in the regional master plan, especially in the planned residential and business areas. However, the project has to be compatible and possibly executed simultaneously with the plan to create the new water and sewer system for the town.

2. Greenhouse Applications

Greenhouse is one of the common direct-use applications of geothermal energy. Wide used of geothermal energy for greenhouse because geothermal energy provides savings from the energy consumption. Greenhouse is the largest energy consumer in agriculture due to its characteristics that usually has a poor insulating qualities and the need to maintain the climate inside the greenhouse despite the extreme difference with the outside climate.[7] Greenhouse operators estimate that geothermal energy use save 5 to 8% of the total operating costs.[8]

The summary of the greenhouse applications with geothermal energy in this report is based on the Geothermal Greenhouse Information package written by edited and updated by Boyd in 2008.[9] Before building a greenhouse business, there are several things to think about. These things are as follow: what crops to be grown? Is it going to be

[6] Rafferty, K., 1996, **Selected Cost Considerations for Geothermal District Heating in Existing Family Residential Areas**, Geo-Heat Center Bulletin, August, Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR.

[7] Popovski, K., 1997, **Greenhouse Climate Factors**, Geo-Heat Center Bulletin, January, Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR.

[8] Energy Efficiency and Renewable Energy U.S. Department of Energy, 2004, Geothermal Technologies Program:Direct Use, National Energy Laboratory- The DOE National Laboratory

[9] Boyd, T., 2008. ***Geothermal Greenhouse Information Package***, Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR.
http://geoheat.oit.edu/pdf/green.pdf.

operated year long or seasonal greenhouse? What growing media and system will be used for the greenhouse? How much is the annual production? What type of heating / cooling system that will be used? What marketing system will be used? What type of greenhouse will be used? Where is the market? and How to transport the product to the market?

Cities and towns close to Rico can be the market of greenhouse products. The town of Rico should consider the possibility to become the vegetable and/or flower suppliers to the region. The two largest greenhouses are in New Mexico and they serve out of state buyers. Commercial greenhouse industry can be attractive due to its low entry barriers (no dominant leaders in terms of net sales or size). Greenhouse that uses geothermal energy is definitely possible for the town of Rico.

The first step in evaluating the possibility of using geothermal energy for greenhouse is to analyze different heating requirements imposed by different construction methods. Generally, there are four construction categories for greenhouse: 1)glass, 2)plastic film, 3)fiberglass or similar rigid plastics, and 4)the combination of 2 and 3. Glass greenhouse is the most expensive construction due to the high material costs and the supporting framework costs. The greenhouse is usually 36 and 42 ft widths with 20 ft lengths increment. This type of greenhouse is preferable for greenhouse with plans that require high qualities of transmission light. However, glass greenhouses also have the poorest energy efficiency. Fiberglass greenhouses are similar with the glass greenhouses. The only difference is in the less requirement for structural support due to its light weight.

Plastic film construction with a double layer of film separated by air space reduces transmission losses (losses through the wall and roof) by 30 to 40% and infiltration (leakage of cold air). However, the high energy efficiency reduces the light transmission. Therefore, growing highly light sensitive crops in this type of greenhouses cannot be as successful as other type of greenhouses. Another important thing to consider about this construction is the high maintenance requirement that generally requires a replacement every 3 year or less. This type of greenhouse is usually constructed with 30 ft width, and 100 and 150 ft lengths.

It is important to analyze the heat loss in designing a greenhouse. Heat loss in a greenhouse comes from transmission loss through the walls and roof, and from the infiltration and ventilation losses caused by the heating of outside cold air. The first step in analyzing the heat loss is to calculate surface area with different materials. The transmission loss can then be calculated. The air change method can be used for the infiltration and ventilation losses. The method is based on the number of times per hour that the air (ACH) in the greenhouse is replaced by the cold air from leaking. Table 1 provides general values of air change data for different types of greenhouse construction.

Table 1. – Air Change Data for Different Greenhouse Constructions (from Rafferty in Boyd, 2008)[9]

Material	Air Changes/h
Single glass	2.5 to 3.5
Double glass	1.0 to 1.5
Fiberglass	2.0 to 3.0
Single poly	0.5 to 1.0
Double poly	0.0 to 0.5
Single poly w/low fiberglass sides	1.0 to 1.5
Double poly w/low fiberglass sides	0.5 to 1.0
Single poly w/high fiberglass sides	1.5 to 2.0
Double poly w/high fiberglass sides	1.0 to 1.5

a. Roberts, 1985, ASHRAE, 1978.

2.1. Geothermal Heating System for Greenhouses

The decision to choose geothermal heating system is not only influenced by the engineering and economic considerations, but also by the owner's preference. The owner's preference may related to the owner's past experiences and familiarity, types of crops potential diseases, etc. Basically, there are six different types of geothermal heating systems that can be used for greenhouses. These types are as follow:1)Finned pipe, 2)Standard unit heaters, 3)Low-temp. unit heaters, 4)Fan coil units, 5)Soil heating, and 6)Bare tube system.

The finned pipe is usually constructed of steel or copper pipe with steel or aluminum fins attached to the outside. The heating capacity is generally based upon 200^{o}F or higher average water temperature and 65^{o}F entering air temperature because most finned-pipe heating equipment was originally designed for standard hot water use.[10] The heating capacity of finned pipe is also a function of fin size, pipe size and flow velocity. The costs for finned pipe elements are a function of the type and size of piping, and the fin spacing (fins/ft).

Standard unit heaters consist of a finned coil and small propeller fan in a vertical or horizontal configuration The standard unit heaters is generally rated at 200^{o}F on entering water temperature and 60^{o}F entering air temperature. Some adjustment of units capacity is needed if the geothermal resources applied to the greenhouse is less than 200^{o}F. The low temperature unit heaters design is similar with the standard unit heaters. The design incorporates a more effective water coil and a higher capacity fan so it is optimized for

[10] Rafferty in Boyd (2008).

low-water temperature operation. The performance of this unit falls between the standard unit heaters and fan coil units.

The fan coil units consist of a finned coil and a centrifugal blower in a single cabinet, similar to the standard unit heaters. The coil in this system is thicker with a closer fin spacing than the coil in a unit heater. This system can generate more heat, but larger and more bulky than the standard unit. Therefore, this system is more expensive than the standard unit heaters.

The soil heating system uses the floor of the greenhouse as a radiator for the heat. Warm water is circulated through a tube buried in the floor of the greenhouse. Then the heat is transferred from the warm water to the soil through the tube that eventually will heat the air in the greenhouse. This system is usually used complementary with other system because this system may give an excessive heat to the plants. The requirements for heat in peak period also increase the floor temperature that resulted in uncomfortable work place inside the greenhouse. This system provides the base heat load for the greenhouse while other systems provide for occasional purposes (peak load).Non metallic materials are preferable for the tube due to corrosion and expansion problems with the metallic materials. The most popular material for the tube is polybutylene.

The bare tube system use of bare tubing that usually made from polybutylene or similar material. The bare tube is usually installed on the floor or under the benches. The placement of tube should be considered carefully to make sure the placement does not lowering the heat capacity and reach the effective surface area. In the colder region, this system may generate the same problem as the soil system because this system will need large quantities of tubing.

3. Aquaculture

Aquaculture, also known as “fish farming”, is one of the primary uses of geothermal energy in the agribusiness industry. It is prevalent in both New Mexico and Idaho, and is responsible for producing both alligators and numerous types of fish.

In Animas, New Mexico a company called AmeriCulture Inc. is one of the largest domestic suppliers of tilapia fingerlings in the US. Tilapia fingerlings (Figure 4) are the early stage of the fish’s life cycle. AmeriCulture produces between four and seven million fingerlings annually, and then ships them all over the country. These fingerlings are sold to growers and researchers who then grow them to full size before use. Their utilization of geothermal energy provides a plethora of advantages. Their facilities are heated at a much lower cost, compared to the use of propane or electricity. Also, the tilapias have an accelerated growth rate due to the above average temperature of their environment. This further increases the energy savings of the company[11].

[11] The Office of Energy Efficiency and Renewable Energy of the U.S. Department of Energy, 2004, *Geothermal Technologies Program: Direct Use*, National Energy Laboratory- The DOE National Laboratory.

Figure 4 – A full grown tilapia fish (left), and tilapia fingerlings (right), (from US DOE, Office of Energy Efficiency and Renewable Energy).

Another grower of tilapia is located in the Snake River Valley in Southern Idaho. In 1973 Leo Ray began using geothermal water to raise catfish, tilapia, sturgeon, blue-channel catfish, and rainbow trout. Located in the Hagerman Valley near Buhl, Mr. Ray's site has hot artesian wells that produce geothermal water at a temperature of 95°F. Without the use of geothermal energy, this location would be too cold to grow these types of fish. But by mixing the hot water with cold spring water, Mr. Ray has turned this area into the optimum environment for fish farming. After they have reached full size, the fish are shipped to supermarkets and restaurants in the US and Canada.

In addition to raising fish, Mr. Ray also raises alligators! The warm geothermal waters help to create the perfect environment for the 2000 he is currently growing (Figure 5)[11].

Figure 5 – Application of geothermal waters to produce alligators (from US DOE, Office of Energy Efficiency and Renewable Energy).

3.1 Aquaculture in Rico

The temperature of Rico's water would easily support a fish farming industry. The food produced by this type of operation could either be used by the townspeople, or exported to surrounding cities.

Aquaculture does not require a high water temperature for implementation; however it does require land for construction. Based on the current size of Rico, its available area for expansion and its desire for limited expansion, aquaculture would not be a first choice for industry.

4. Geothermal Drying

Another application of geothermal water is the drying of timber. In a typical timber mill, after the tree has been cut and shaped into its desired form, it must go through a drying process to prevent warping later on and to set the sap. Often times drying kilns in smaller mills are heated by steam from conventional boilers. Substituting geothermal steam for that created by the boiler would provide substantial energy cost savings.

The sap in a piece of lumber sets at 135°F to 140°F, a temperature easily achieved using geothermal steam. Warping is prevented by creating uniform moisture content throughout the lumber. Wood left to dry at ambient conditions typically loses moisture faster on its exposed surfaces than in its interior. As a result, the evaporation rate within a kiln must be very carefully controlled. The allowed variation in drying rate decreases with thicker cut size, and changes depending on the species of wood. Figure 6 shows a typical lumber drying kiln[12].

[12] J. Lund, P. Lienau, B. Lunis, *Geothermal Direct Use Engineering and Design Guidebook*, 3rd Edition. United States of America, 1998.

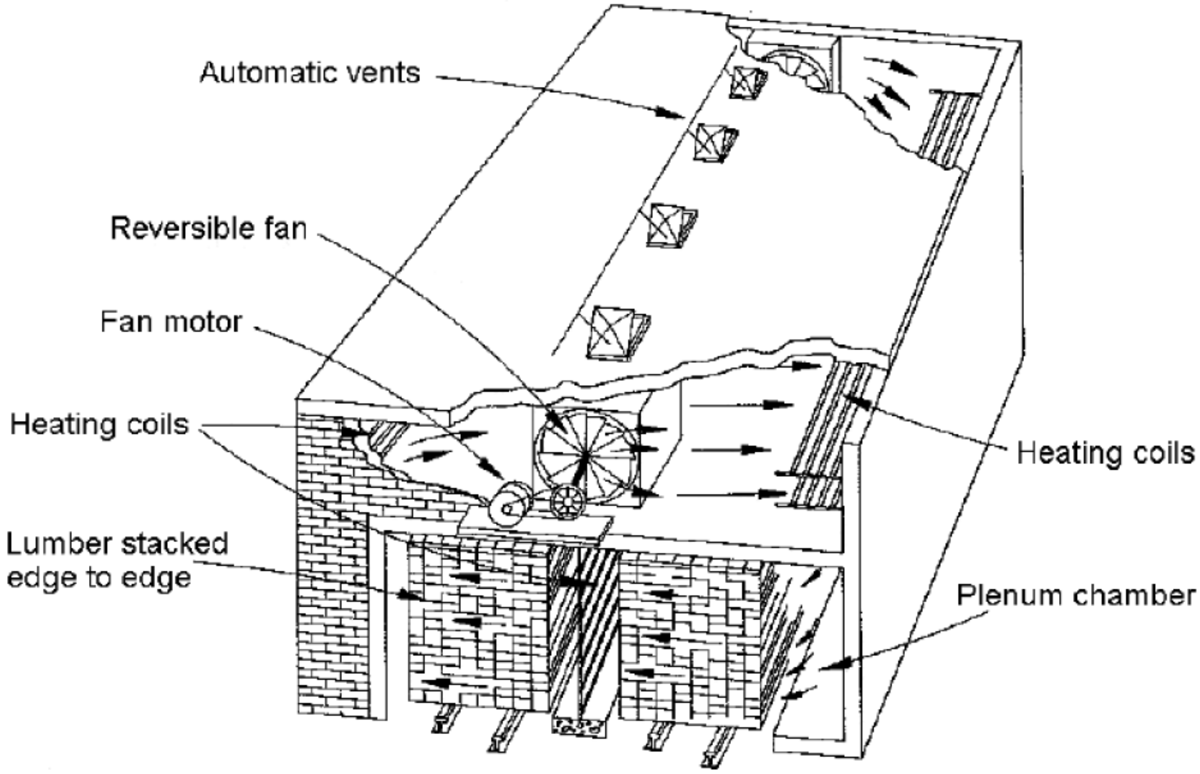

Figure 6 – Long shaft, double track, compartment kiln with alternately opposing internal fans (from Lienau, Lund, Lunis, Direct Use Design Guidebook).

During a drying cycle, a piece of lumber typically loses between 50% and 60% of its weight due to evaporation of water. As mentioned before, the intensity and duration of drying is closely regulated and varies depending on the species of tree the lumber from which the lumber is cut. Drying schedules can range from less than 24 hours to as much as several weeks per batch. The energy used during the drying process also varies considerably. Table 2 shows the energy consumed by the kiln during the drying process. It is organized by lumber type (column 1), energy consumed per pound of water (column 2), and the energy consumed for every foot of lumber that is dried (column 3).

Table 2 – Energy consumed by kiln drying wood (from Lienau, Lund, Lunis, Direct Use Design Guidebook).

Lumber	Energy Use ($Btu/lb\ H_2O$)	Btu/Dry (bd ft)
Douglas fir	2,000 to 3,000	1,560 to 2,340
Southern yellow pine	1,600 to 2,200	4,600 to 6,300
Red oak	3,000+	7,850+

Another drying process that incorporates geothermal energy is vegetable and drying or dehydration. Typical produce that can be dried using this technique is listed in Table 3.

Table 3 – Product drying using a conveyor dryer ((from Lienau, Lund, Lunis, Direct Use Design Guidebook).

Vegetables	Fruits	Nuts	Prepared Foods	Prepared Feeds
Beans	Apples	Almonds	Beef jerky	Aniamal feeds
Onion	Raisins	Coconut	Bouillon	Pet food
Garlic		Brazil	Cereals	Cattle feed
Peppers		Peanuts	Macaroni	Fish food
Soy beans		Pecans	Snacks Hay	
Beets		Walnuts	Soup mixes	
Carrots		Macadamia		
Potato (sliced, diced chips, frenchfries)				
Spinach				
Parsley				
Celery				
Okra				

This type of drying is accomplished using a tunnel dryer, or continuous conveyor dryer. This dryer uses fairly low temperature hot air, between 100°F and 220°F. Figure 7 shows an example of a tunnel dryer, highlighting the pathways the hot air follows[12].

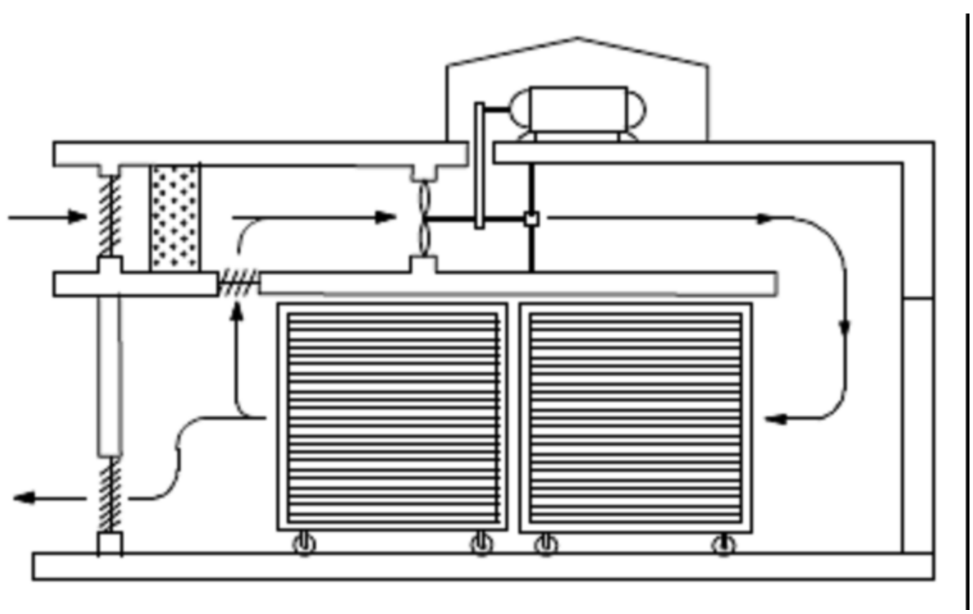

Figure 7 – Air flow patterns in a tunnel dryer system ((from Lienau, Lund, Lunis, Direct Use Design Guidebook).

4.1 Lumber and Produce Drying in Rico

As was the case with aquaculture, the town of Rico has water hot enough to more than provide for either lumber of produce drying or dehydration. The problem is (as before) where to put these structures. The town of Rico has mentioned that they do not wish to expand the size of their town. Also in short supply is flat, level ground that doesn't require expensive grading or earth removal/placement. Because of its location – mountains, wooded area – lumber drying would be more reasonable than produce drying, but neither option provides an ideal industry.

5. Metal and Mineral Leaching

The leaching of precious metals and minerals from mined ore is a fairly simple process. Geothermal heat can increase the efficiency of the extraction process, increasing the recovery rate with little or no increase in energy consumption. I will discuss gold and silver leaching, as well as zinc extraction.

Gold and silver recovery by means of ore leaching eliminates many of the complicated steps that are required in conventional milling. Heap leaching is the typical process, and it consists of placing crushed ore on an impervious pad. This ore is then sprinkled with a diluted solution of sodium cyanide. The solution makes its way through the ore, emerging as a "gold bearing" or "pregnant" solution on the other side. This solution contains gold or silver that would otherwise be unrecoverable. The solution is pumped through activated charcoal which absorbs the gold and silver. The barren cyanide is then treated with lime and reused in the same process. A diagram of the heap leaching process is shown in Figure 8 below.

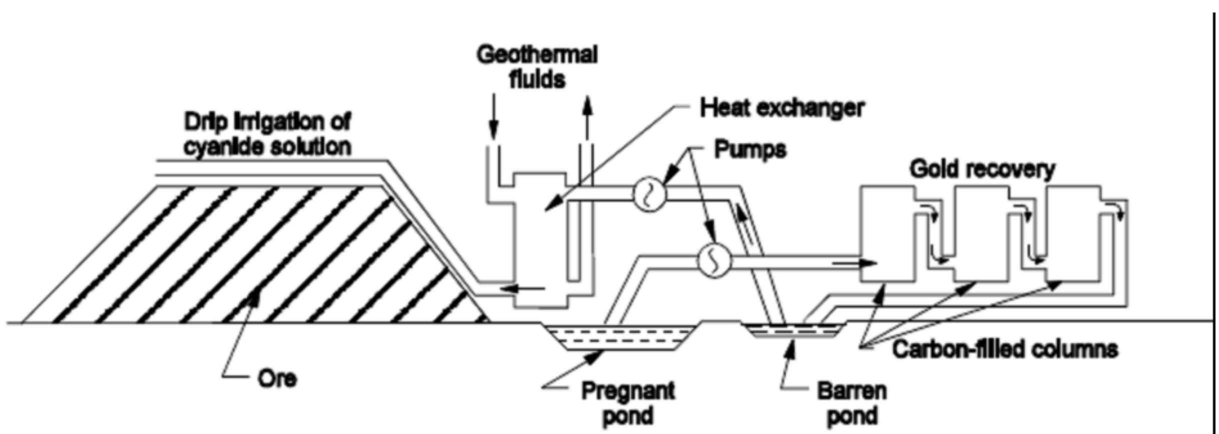

Figure 8 – Idealized thermally enhanced heap leaching process ((from Lienau, Lund, Lunis, Direct Use Design Guidebook).

The biggest drawback to heap leaching is the low recovery rate. Often only 70% of the gold and silver in the crushed ore is removed. This amount decreases further in winter when the temperature of the cyanide is lower. Geothermal heat can be used as a low cost means of increasing the cyanide solution temperature. This can boost the recovery rate to as much 95%, and the ability to keep the cyanide at a constant temperature lets the operation run year round. Locate the section marked “geothermal fluids” in the middle-left of Figure 8. This shows how geothermal water would be incorporated to increase the efficiency and output of this process.

The extraction of zinc from waste-brine can be explained by means of its most prevalent success story. In southern California’s Imperial Valley on the shores of the Salton Sea, a company called CalEnergy Operating Corporation has set up shop. The company currently operates ten geothermal power plants with a capacity of 347 Megawatts. Their most recent unit – a 49 Megawatt power plant called unit 5 – utilizes the hot waste brine from four of the existing power plants to produce electricity. This cools the brine from 182°C to 116°C (the ideal temperature for zinc extraction). The brine is then pumped to the minerals recovery plant, where the electricity produced by unit 5 is used to power the process that extracts the zinc! The zinc production facility, run by Cominco Ltd, is the lowest cost producer of zinc in the world, and the first and only operation designed to harvest minerals from high temperature waste brine in the US. Cominco Ltd produces 30,000 tons of 99.99% pure zinc every year[13].

5.1 Metal and Mineral Extraction in Rico

Both of these applications would be sustainable and beneficial to the town of Rico. Not only is their water hot enough to benefit any heap leaching operation, but it also contains enough dissolved minerals to make extraction economical (especially if extraction occurs after the water has already been utilized in another process, i.e. district heating, greenhouse, energy production, etc.). There is still the problem of where to put such a facility, but I believe the potential benefits outweigh the detrimental effects of such an operation[14].

Conclusion

The utilization of geothermal water and heat in direct-use applications can provide beneficial and economical dividends to any community willing to develop the resource. Numerous cities and towns across the United States posses the geothermal resource necessary to implement direct-use projects. It is our hope that this type of geothermal energy application will continue to grow and improve in years to come, eventually becoming a substantial part of the United States’ energy curriculum. Towns like Rico are lucky to have such resources. The earth is essentially providing free energy. Should the citizens of Rico decide to develop their geothermal resource, they will enjoy the fruit that geothermal energy is capable of bearing. And if they maintain and manage their investment, they will continue to reap the benefits for years to come.

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[13] Lund, J. W., 2003. *Examples of Industrial Uses of Geothermal Energy in the United States*, Geo-Heat Center Bulletin, September. Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, OR.
[14] Ronald DiPippo, *Geothermal Power Plants: Principles, Applications, Case Studies and Environmental Impact*, 2nd ed. Great Britain: Butterworth-Heinemann Publishing Company, 2008.