

DIRECT USE OF GEOTHERMAL RESOURCES

John W. Lund

Geo-Heat Center
Oregon Institute of Technology
Klamath Falls, OR 97601

ABSTRACT

Geothermal energy was used by early man primarily for direct heat applications such as cooking, bathing and balneology. Today it is used for space conditioning, industrial processing and agribusiness applications. District heat has received recent interest especially in the US. At present, over 2,000 Mwt are utilized in the world for direct use applications. Generally, conventional equipment is used to extract the heat from geothermal fluids, with material selection being dictated by the water and gas chemistry. Heat exchangers and piping have been adapted to geothermal use, along with water-to-water heat pumps. Cascading of the water can increase the utilization efficiency as illustrated in Japan and the USSR.

INTRODUCTION

Early man probably used geothermal water that occurred in natural pools and hot springs for cooking, bathing and to keep warm. We are also aware that the Indians of the Americas used these pools and springs to rest and recuperate from the wounds of battle. Recorded history shows uses by Romans, Japanese, Turks, Icelanders, Central Europeans and the Maori of New Zealand for bathing, cooking and space heating. Baths in the Roman Empire, the middle kingdom of the Chinese, and the Turkish baths of the Ottomans were some of the early uses of balneology--where body health, hygiene and discussions were the social custom of the day. This custom has been extended to geothermal spas in Japan, Czechoslovakia and New Zealand, which are world famous.

One of the older therapeutic uses of geothermal water is at the Ziaotangshan (Shaotangshan) Sanatorium northwest of Beijing (Peking), China. Here the water has been used for over 500 years (since the Ming dynasty) for medical purposes and for space heating 29,000 m² (312,000 ft²). Two hot springs, 48°C and 53°C (118°F and 127°F), and 3 wells provide water for bathing, showering, spraying and space heating, saving 800 tons of coal annually. Specific medical problems treated are high blood pressure, rheumatism, skin diseases, diseases of the nervous system, ulcers and recuperation after surgery (Lund, 1980 and Cai, 1981). These uses throughout the world have continued to this day; for example, over 2,200 hot spring resorts exist in Japan, visited by 100 million guests every year; residents and visitors to Rotorua, New Zealand, visit the hot tubs and pools every evening

to relax before a good night's rest; about 30 swimming pools in Iceland use natural hot water, with a total capacity of about 20,300 m³ (5.4 million gallons); and the 200 bed Queen Elizabeth Hospital in Rotorua uses geothermal water for the treatment of rheumatic diseases.

District heating began in Iceland in 1930 when the Reykjavik district heating system was put into operation on a small scale. Over 80°C (176°F) hot water from wells within the city was piped into a hospital, swimming hall, two school buildings, and 70 homes in the vicinity of the swimming hall. In 1943 a major expansion of the Reykjavik district heating system was completed when the system was extended to the majority of the city, serving a population of approximately 30,000. The water was at that time piped in from the Reykir geothermal area, about 16 km (9.9 miles) to the northeast of the city. In 1959 a modern rotary drilling rig was purchased to help expand the system. Today this system supplies heat to over 115,000 people with a capacity of approximately 475 Mwt (Karlsson, 1981).

Early industrial applications include the use of the natural manifestation of steam, pools and mineral deposits in the Larderello region of Italy. Serious industrial activity began only after the discovery of boric acid in the hot pools in 1777. The first attempt at using these minerals was made in 1810. The first factory, built by Francesco Larderel in 1846, was near the ancient castle of Montecerboli. Between 1818 and 1835 eight additional factories were built in the region. Initially, the boric acid was extracted from the geothermal fluids by boiling and subsequent crystallization using wood from the neighboring forests as fuel. In 1828, drilling brought additional fluid to the surface and from 1827 onward, natural thermal energy was used for fuel instead of wood. At this time, steam-collection devices or covered pools (lagone coperto) increased the efficiency of the boric industry. A flourishing chemical industry was thus in operation by the early 1900's. This industry was curtailed during the Second World War, and today it depends upon imported raw material, but still uses geothermal energy for the process. The use of the local fluid for its boric content is no longer economical, as electric power generation is more profitable (ENEL, 1976).

PRESENT USE

Geothermal direct use has evolved from the simple bathing and therapeutic use to the more

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sophisticated space conditioning and industrial process applications. Today these applications represent a worldwide utilization of about 2,000 megawatts thermal (Mwt) which are summarized in Table 1 below (Lund, 1979; Peterson, et al, 1979; Gudmundsson, et al, 1981; and Lienau, 1982). District heating is receiving the greatest emphasis; with many new projects either in the planning stage or under construction. This is especially true in the US where approximately 40 projects are under consideration (Fornes, 1981). Space cooling is another popular application with several projects using lithium bromide absorption now in operation and one using ammonia - water under construction in India.

TABLE 1
Worldwide Direct Use of Geothermal Energy

Country	Space Heating/ Cooling (Mwt)	Agriculture/ Aquaculture (Mwt)	Industrial Processes (Mwt)
China	38.4	-	112.9
France	25.2	-	-
Hungary	34.6	316.9	14.5
Iceland	580.0	34.2	13.6
Italy	49.0	3.5	20.0
Japan	23.0	21.2	-
New Zealand	2.0	2.0	150.0
USA	40.4	55.9	17.6*
USSR	300.0	55.0	-
Others	44.0	10.0	5.0
	1,136.6	498.7	313.6

Heat exchangers are also becoming more efficient and better adapted to geothermal use, allowing the use of lower-temperature water and highly saline fluids. Heat pumps utilizing low temperature fluids, are extending geothermal development into traditionally non-geothermal areas such as France and Austria, as well as many areas in the US. A unique application of the heat pumps is the Ephrata Geothermal Energy Project in Washington that will use energy from the city's domestic water supply which is geothermally heated. The system will be the first US application of heat pumps to municipal water mains for space heating. In the first phase of the project, a large central heat exchanger will extract approximately 6°C (10°F) from 38 l/s (600 gpm) of 29°C (84°F) geothermal water in the city main. The energy will be used to heat the Grant County Courthouse during the winter and cool it during the summer.

Agriculture-related uses of geothermal energy generally require the lowest temperatures, with values from 25°C to 80°C (77°F to 176°F) being typical. The amount and types of chemicals and dissolved gases, such as boron and arsenic, are a major problem for plants and animals. Heat exchangers and proper venting of gases may be necessary in some cases to solve this problem. Extensive agribusiness-related energy utilization occurs in Hungary and the Soviet Union. Space heating requires temperatures in the range of 65°C to 100°C (149°F to 212°F), with 40°C (104°F) being used in

some marginal cases and heat pumps extending this range down to 4°C (40°F). The leading user of geothermal energy for space heating is Iceland where over 75% of the population enjoys geothermal heat in their homes. There are now about 50 geothermal district heating systems operating in towns, villages and smaller communities. Geothermal cooling examples are limited, with the International Hotel in Rotorua, New Zealand, and the Oregon Institute of Technology Campus being the prime examples. Industrial processing typically requires the highest temperature, using both steam and high temperature water. Temperatures above 150°C (302°F) are often desired; however, lower temperatures can be used in some cases, especially for drying of various agricultural products. Though there are relatively few examples of industrial processing use of geothermal energy, they represent a wide range of applications from drying of wool, fish, earth, timber and vegetables to pulp and paper processing, and chemical extraction. The two largest industrial users are the diatomaceous earth drying plant in Iceland and the paper and wood processing plant in New Zealand. Notable US examples are the onion dehydration plant at Brady Hot Springs, Nevada; the ethanol plants at Wabuska, Nevada and Hot Lake, Oregon; and milk pasteurization at Klamath Falls, Oregon.

UTILIZATION EQUIPMENT

Generally, conventional equipment directly off-the-shelf or slightly modified is used in direct-use projects to extract the heat from the geothermal water. In the case of geothermal water, proper allowances must be made for corrosion and scaling caused by the unique chemistry of the water. Since unmixed geothermal water has little or no dissolved oxygen, care must be taken to prevent the addition of oxygen to the system, especially in the presence of certain metals. Dissolved gases such as ammonia and hydrogen sulfide can also cause corrosion problems. The isolation of the geothermal water from the system by a heat exchanger may be all that is necessary to solve the problem. A clean secondary fluid is then circulated through the user side of the system.

Figures 1 and 2 illustrate the primary components of any direct-use geothermal system. In the first case, the geothermal water is benign enough to use directly in the heat recovery system, and in the second a heat exchanger is used. In both systems the common components are pipelines, circulation pumps, peaking or backup systems and user systems. Disposal is either surface or subsurface (reinjection). A peaking system may be necessary or economical (in the case of large systems) to meet peak demands by increasing the temperature or providing storage, resulting in a decrease in the number of wells required. In low-temperature systems where the geothermal fluid is below about 49°C (120°F), a heat pump would be considered.

*An additional 335 Mwt are used in Wyoming for enhanced oil recovery.

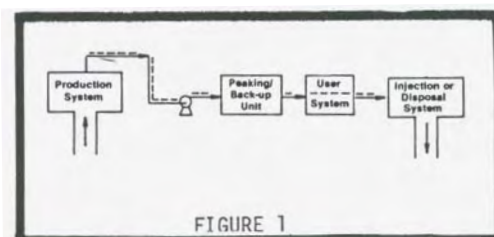


FIGURE 1

Direct Use System Without Heat Exchanger

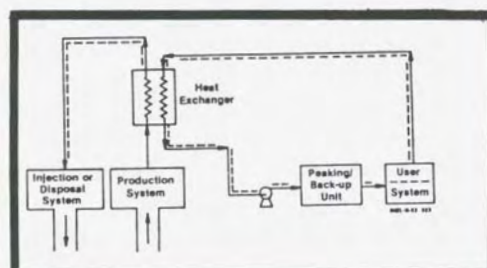


FIGURE 2

Direct Use System With Heat Exchanger

Heat Exchangers. Geothermal systems have used several types of heat exchangers successfully. The main types include shell-and-tube (water-to-water), plate and downhole. Other less common types are direct contact, fluidized-bed and plastic tube (Lienau, et al, in Anderson and Lund, 1979).

The shell-and-tube and plate heat exchangers are placed above ground either at the well head or at a central location. The shell-and-tube types consist of U-shaped tubes inside a cylindrical shell with primary fluid (geothermal) flowing inside the tubes. The plate heat exchanger consists of a series of steel plates (commonly stainless) with gaskets held in a rack by rods, allowing the primary and secondary fluid to counterflow across the plates. The gasket material will limit the maximum temperature that can be used. The plate heat exchanger has an advantage in that it is more efficient, requires smaller space, and is more accessible

and easier to expand to meet additional heating load. Temperature approaches (difference between incoming primary and outgoing secondary fluid) of 3°C (5°F) are easily obtained, as compared to about 11°C (20°F) for the conventional shell-and-tube. The plate heat exchanger is about 60% of the cost of the shell-and-tube when compared at the same surface area (Ryan, 1981). Both types of heat exchangers would require disposal of the geothermal fluid after it has passed through the primary side.

The downhole heat exchanger avoids the problem of disposal of the geothermal fluid since only heat is "pumped" from the well. It has the disadvantage of extracting less heat than the other types; however, initial costs are less. From 30 to 90 m (100-300 feet) of 5 cm (2 inch) diameter pipe below the water surface is needed to heat an average residence. A rough rule of thumb is to use 0.3 m (1 foot) of double pipe below the water surface for each 1,500 to 2,000 kJ/hr (1,500 - 2,000 Btu/hr) peak heating load. Installations have produced up

to 3 million kJ/hr (3 million Btu/hr) from a single well using three downhole heat exchangers (Ponderosa School in Klamath Falls, Oregon). They are generally not effective with well temperatures below 60°C (140°F). It should be noted that the use of downhole heat exchangers requires special well completion techniques to produce a vertical convection cell of heat in the well. In addition, it may be necessary to provide electrical isolation to the pipes at the surface to reduce downhole electrolysis problems. Downhole heat exchangers have been used successfully in Klamath Falls, Oregon and Reno, Nevada and are under testing in New Zealand (Culver, et al, 1978; Allis, 1981; Shannon, 1982; and Pan, et al, 1982 this volume).

Piping. Both metallic and nonmetallic piping are used in geothermal transmission lines. Carbon steel is the most widely used metallic pipe. Use of alloy pipe is limited due to cost, and copper and aluminum piping are affected by dissolved gases such as hydrogen sulfide and ammonia. The non-metallic pipes are inert to the normal chemical constituents in geothermal fluids; however, temperature may limit the use of these materials. The temperature limitations are shown in Figure 3 (Ryan, 1981).

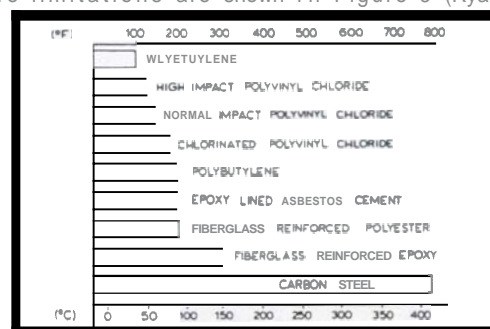


FIGURE 3 Maximum Temperatures-Piping Materials

In general, the higher the temperature limitation the more expensive the piping material. On the other hand, the nonmetallic pipes, having temperature restriction, are lighter and thus easier to handle and install. Joining the individual sections of the nonmetallic piping is also easier as they can be welded with solvents or heat fused. Metallic piping requires expansion provisions, either by a bellows arrangement or by loops. A typical metallic piping installation would have fixed points and expansion points about every 100 meters (300 feet). In addition, the piping would have to be placed on rollers or slip plates between points. Nonmetallic pipe generally has lower expansion coefficients and can handle the expansion within the fibers of the material, thus does not require expansion points. Finally, metallic piping, when buried, can be subjected to external corrosion from ground water and electrolysis and thus must be protected by coatings and wrappings. Concrete tunnels and trenches have been used to protect steel pipe such as in Iceland and Klamath Falls, Oregon; however, this may double the cost of the installation. The advantage of the tunnel is ease of future expansion and access for maintenance. Other utilities can also be located in the same tunnel. In Iceland and Klamath Falls, it is also

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used as a heated sidewalk in the winter.

For short piping distances, insulation will probably not be necessary as the temperature loss will be minimal. Depending upon the temperature of the fluid, the flow in the pipe and the tolerable **loss** in temperature, longer transmission distances may require insulation. In addition to minimizing the heat loss of the fluid, the insulation must be waterproof and water tight. Ground water can destroy the value of any insulation. Above ground and overhead pipeline installations can be considered in special cases; however, insulation will probably be necessary as they will be exposed to wind which can remove considerable heat. Considerable insulation is achieved by burying the pipe. Burying bare steel pipe results in a reduction in heat **loss** of about one third as compared to above ground in still air. If the soil around the buried pipe can be kept dry then the insulation value can be retained. The direct buried, uninsulated system has been used successfully in Iceland over a distance of 60 km (37 miles). Piping can be insulated with polyurethane foam and fiberglass. Below ground this should be protected with a PVC jacket and above ground aluminum can be used. Generally 2.5 to 7.5 cm (1 - 3 inches) of insulation is adequate.

At flowing full conditions the temperature loss is around 0.1 to 0.4°C/km (0.05 to 0.20°F/1000 feet) for insulated pipelines, and about 10 times that for uninsulated, buried pipe. Pipe material does not have a significant effect on heat loss; however, the flow rate does have a significant effect. At low flows (off peak), the temperature drop is large, which must be taken into account in the design of the system.

Heat Pumps. Heat pumps have been commercially available since the 1950's, but until recently were viewed merely as an air conditioning unit with the added ability to provide space heating where the heating requirements were small. With improved efficiency, the heat pump has become a definite alternative to other conventional heating systems.

The types of heat pumps that are adaptable to geothermal energy are the water-to-air and the water-to-water. Ground water is the source of the energy and has the advantage that the temperature varies little with the seasonal weather changes: it is warmer than the air in winter, and cooler than the air in summer. Therefore, the heat pump output is relatively constant year round. Ground water occurs at temperatures from 4° to 27°C (40° to 80°F) throughout most of the continental US and in many places in the world, making it possible to use a heat pump almost anywhere. Air source heat pumps do not have these advantages, and must use supplemental energy during extremely cold or hot weather.

Heat pumps are available with heating capacities of less than 10,000 kJ/hr (10,000 Btu/hr) to over 5 million kJ/hr (5 million Btu/hr), and are essentially "off-the-shelf" items. Dual service units, those that both heat and cool, can operate with a geothermal source of 15° to 35°C (60° to

95°F), whereas with a unit used solely for heating, the storage water temperature can vary from 4° to 49°C (40° to 120°F). Above 49°C (120°F) heating can be done directly without the use of a heat pump (Ryan, 1980).

Water-to-water heat pumps can boost geothermal water temperatures efficiently approximately 33° to 44°C (60° to 80°F), giving a range of service water temperature of 38° to 82°C (100° to 180°F) for re-source temperatures from 4° to 49°C (40° to 120°F).

Larger temperature boosts will reduce the COP below 3 as seen in Figure 4 (Ryan, 1980). Large capacity custom design water-to-water heat pumps are also available to raise temperature as high as 110°C (230°F). These are multi-staged compressor units with special refrigerants. The COP will drop off to about 2 for these units.

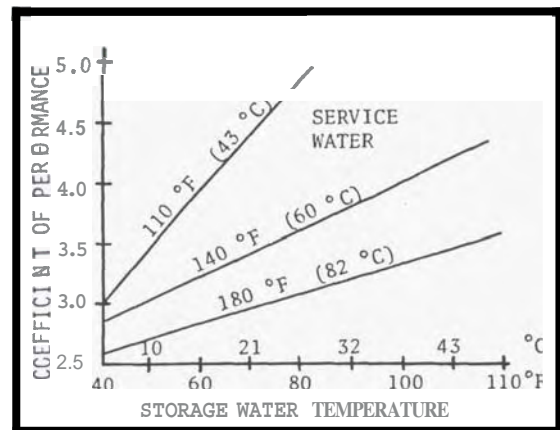


FIGURE 4
Heat Pump COP vs Water Temperature

An example of heat pump use for cooling and heating is the office building for the Church of Jesus Christ of Latter-day Saints in Salt Lake City, Utah. Four low-temperature wells, ranging from 13° to 24°C (56° to 75°F) supplying up to 250 L/s (4,000 gpm), provide energy to a heat pump system heating and cooling 63,400 m² (683,000 square feet) of office space. Three 9.5 MJ/hr (750 ton) liquid chilling systems (Freon 12 and water) powered by 600 kw (800 hp) motors are used. At times, in the fall and spring, the cooling and heat loads balance; however, in winter and summer the wells are used as heat sinks to absorb excess heat or provide heat to the system.

CASCADING

Geothermal resources can be used for many purposes such as power generation, space heating, greenhouses, industrial processing and bathing, to name a few. Considered individually, however, many of these uses may have difficulty in providing an attractive return on investment due to the high initial capital cost. Thus, we may have to consider using a geothermal fluid in several stages of utilization to maximize benefits. This multistaged

utilization, where lower and lower water temperatures are used in successive steps, is called cascading or waste heat utilization.

Geothermal cascading has been proposed and attempted successfully on a limited scale throughout the world. In Rotorua, New Zealand, for example, after geothermal water and steam is used for home heating, the homeowner will often use the waste heat for a backyard swimming pool and steam cooker (Lund, 1976). At the Otake geothermal power plant in Japan, about 165 tons/hr of hot water is furnished to downstream communities for space heating, greenhouses, baths and cooking. In Sapporo, Hokkaido, the waste water from the pavement snow melting system is retained at 65°C (150°F) and reused for bathing purposes. (Japan Geothermal Energy Assoc., 1974). Numerous other cascaded uses from power plants in Japan are either underway or being proposed at Ohnuma, Matsukawa, Kakkonda, Onikobe and Hatchobaru for space heating, greenhouses and bathing (Minohara and Sekioka, 1980).

In Japan, the Siramizu-gawa geothermal area exists near Sounkyo, Hokkaido. The estimate of geothermal potential for the area is 500 to 600 tons per hour with a steam temperature of 140°C (284°F) and a hot water temperature of 92°C (198°F). Three nearby communities of Asahikawa City, Kamikawa Town and Sounkyo Spa expect to use the energy. In addition to power generation, space heating, snow melting, greenhouse heating, fish breeding, poultry farming and bathing are the main uses. To optimize the use of geothermal energy a linear programming method was developed for cascading. The primary utilization was for power generation and to heat water. Secondary uses were for space heating, snow melting and greenhouses, with the final use for bathing. Fixed costs, maintenance expenses and the temperature and flow of steam and hot water were optimized by this method for the geothermal area (Yuhara and Sekioka, 1975).

Another example of cascading is in the Mostovski region of the Krasnodar province of the northern Caucasus in the USSR (Dvorov, 1982). Well drilling and limited greenhouse heating started in 1976. By 1980 12 ha (30 acres) of plastic film greenhouses and 6 ha (15 acres) of glass greenhouses producing 2,262 tons of vegetables were being heated geothermally with 75°C (167°F) water. The wastewater at 40° to 45°C (104°-113°F) is then used to heat cattle breeding units, two cow sheds, one calf shed, a pigsty and a poultry yard. In the fall and spring some wastewater is also used for space heating and domestic drinking water as well as for forage preparation. The wastewater at 20° to 30°C (77°-86°F) from this step is then used for a 30 ha (74 acre) fish farm operation producing 1,500 tons per year. In the spring and summer some of this water is also used to irrigate crops to increase agricultural growth. A second cascaded loop from the wells is used for space heating of residential and industrial buildings in Mostovski. This covers 200,000 m² (2,150,000 sq. feet) of floor space for 10,000 people. The wastewater at 40° to 45°C (104°-114°F) is then used to heat swimming pools, showers and laundries. The wastewater at 20° to 30°C (68°-86°F) also is used in furniture shops for drying wood and to heat co-

oper's shops at timber mills. Some wool washing (taking advantage of the alkaline nature of the water), animal space heating and food enrichment, and concrete block curing is also carried out. Work is also being undertaken to use the fluids for balneological purposes. The entire cascaded process is shown in Figure 5.

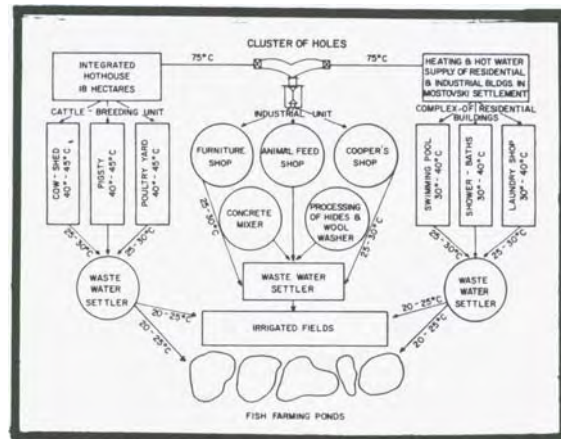


FIGURE 5 Geothermal Energy Use in the Mostovski Region of the Krasnodar Province

A final point should be made about cascading. Load balancing and the capability of end users must be considered to make the process efficient. Seasonal operations will restrict the use of the waste heat. For example, food processing or alfalfa pelletizing plant would normally operate only during the warmer months of the growing season. A greenhouse operation, using the waste heat from these plants, would only need heat during the colder months. In a similar manner, the waste heat from greenhouses might be considered for crop irrigation. However, when the greenhouses need heat, crops are not being grown and when crops are being grown, the greenhouses do not need heat. Year round operations are thus, obviously easier to match in a cascaded situation (Higbee, 1981).

SUMMARY

The entire project for a direct use application is made up of various components, many of which were discussed in this paper. The decision to develop and use a geothermal resource must be studied thoroughly from both a technical and economic viewpoint. The technical (geologic and engineering) issues and the economic issues are interrelated to the extent that a potential user or developer must continue analyzing the merits of the direct use project as additional data become available from the development activities. Fifteen major areas of consideration have been identified that should be reviewed (Schultz and Hanny, 1981). These are:

1. Site selection - it must be near the resource.
2. Geophysics - what can be afforded.

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3. Resource depth and cost.
4. Resource production.
5. Engineering - what must be altered to accommodate the geothermal fluid.
6. Utilization factor (load factor) - ratio of average to peak load.
7. Use temperature - including the minimum temperature that can be used and the temperature difference (AT).
8. Pumping costs.
9. Fluid transmission.
10. Water quality - corrosion and scaling potential.
11. Disposal.
12. Heat exchangers.
13. Institutional considerations.
14. Environmental.
15. Investment - financial and economical considerations.

Interactive planning and analysis throughout the complete sequence of geothermal project development, using the factors outlined above, will provide a developer or user a basis for making decisions.

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