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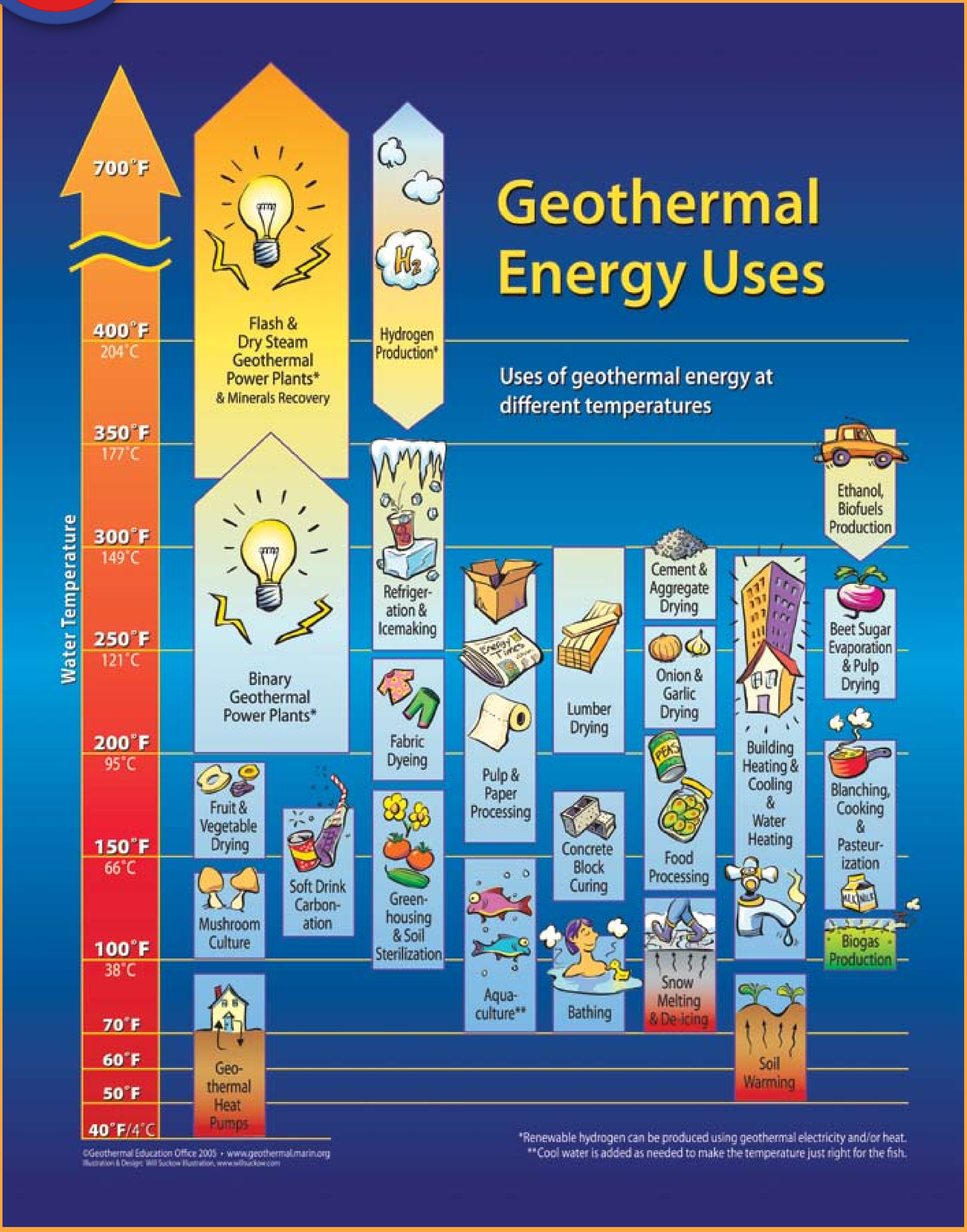

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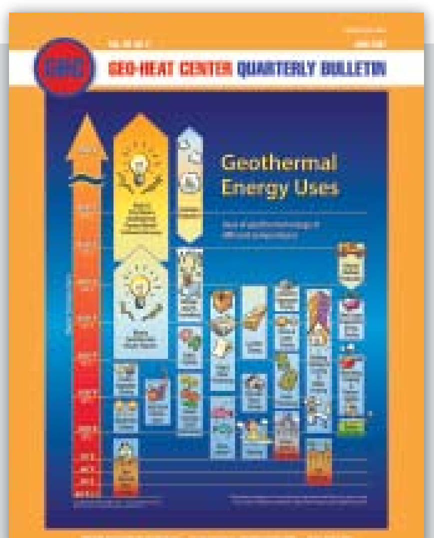
A Quarterly Progress and Development Report on the Direct Utilization of Geothermal Resources

CONTENTS



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Oregon Institute of Technology
3201 Campus Drive
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Phone: (541) 885-1750
Email: geoheat@oit.edu

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EDITOR

John W. Lund

Assistant Editor – Tonya "Toni" Boyd
Typesetting/Layout – Debi Carr
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CHARACTERISTICS, DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES

John W. Lund, Geo-Heat Center, Oregon Institute of Technology

INTRODUCTION

Early humans probably used geothermal water that occurred in natural pools and hot springs for cooking, bathing and to keep warm. We have archeological evidence that the Indians of the Americas occupied sites around these geothermal resources for over 10,000 years to recuperate from battle and take refuge. Many of their oral legends describe these places and other volcanic phenomena. 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, Germany, Iceland, and countries of the former Austro-Hungarian Empire, the Americas and New Zealand. Early industrial applications include chemical extraction from the natural manifestations of steam, pools and mineral deposits in the Larderello region of Italy, with boric acid being extracted commercially starting in the early 1800s. At Chaudes-Aigues in the heart of France, the world's first geothermal district heating system was started in the 14th century and is still going strong. The oldest geothermal district heating project in the United States is on Warm Springs Avenue in Boise, Idaho, going on line in 1892 and continues to provide space heating for up to 450 homes.

The first use of geothermal energy for electric power production was in Italy with experimental work by Prince Gionori Conti between 1904 and 1905. The first commercial power plant (250 kWe) was commissioned in 1913 at Larderello, Italy. An experimental 35 kWe plant was installed in The Geyers in 1932, and provided power to the local resort. These developments were followed in New Zealand at Wairakei in 1958; an experimental plant at Pathe, Mexico in 1959; and the first commercial plant at The Geysers in the United States in 1960. Japan followed with 23 MWe at Matsukawa in 1966. All of these early plants used steam directly from the earth (dry steam fields), except for New Zealand, which was the first to use flashed or separated steam for running the turbines. The former USSR produced power from the first true binary power plant, 680 kWe using 81˚C water at Paratunka on the Kamchatka peninsula – the lowest temperature, at that time. Iceland first produced power at Namafjall in northern Iceland, from a 3 MWe non-condensing turbine. These were followed by plants in El Salvador, China, Indonesia, Kenya, Turkey, Philippines, Portugal (Azores), Greece and Nicaragua in the 1970s and 80s. Later plants were installed in Thailand, Argentina, Taiwan, Australia, Costa Rica, Austria, Guatemala, Ethiopia, with the latest installations in Germany and Papua New Guinea. (See Cataldi, et al., 1999 for more background).

TYPES OF GEOTHERMAL RESOURCES

Geothermal energy comes from the natural generation of heat primarily due to the decay of the naturally occurring radioactive isotopes of uranium, thorium and potassium in the earth. Because of the internal heat generation, the Earth's surface heat flow averages 82 mW/m^2 which amounts to a total heat loss of about 42 million megawatts. The estimated total thermal energy above mean surface temperature to a depth of 10 km is 1.3×10^{27} J, equivalent to burning 3.0×10^{17} barrels of oil. Since the global energy consumptions for all types of energy, is equivalent to use of about 100 million barrels of oil per day, the Earth's energy to a depth of 10 kilometers could theoretically supply all of mankind's energy needs for six million years (Wright, 1998).

On average, the temperature of the Earth increases about 30˚C/km above the mean surface ambient temperature. Thus, assuming a conductive gradient, the temperature of the earth at 10 km would be over 300˚C. However, most geothermal exploration and use occurs where the gradient is higher, and thus where drilling is shallower and less costly. These shallow depth geothermal resources occur due to: (1) intrusion of molten rock (magma) from depth, bringing up great quantities of heat; (2) high surface heat flow, due to a thin crust and high temperature gradient; (3) ascent of groundwater that has circulated to depths of several kilometers and been heated due to the normal temperature gradient; (4) thermal blanketing or insulation of deep rocks by thick formation of such rocks as shale whose thermal conductivity is low; and. (5) anomalous heating of shallow rock by decay of radioactive elements, perhaps augmented by thermal blanketing (Wright, 1998).

Geothermal resources are usually classified as shown in Table 1, modeled after White and Williams (1975). These geothermal resources range from the mean annual ambient temperature of around 20˚C to over 300˚C. In general, resources above 150˚C are used for electric power generation, although power has recently been generated at Chena Hot Springs Resort in Alaska using a 74˚C geothermal resource (Lund, 2006). Resources below 150˚C are usually used in direct-use projects for heating and cooling. Ambient temperatures in the 5 to 30˚C range can be used with geothermal (ground-source) heat pumps to provide both heating and cooling.

Convective hydrothermal resources occur where the Earth's heat is carried upward by convective circulation of naturally occurring hot water or steam. Some high-temperature convective hydrothermal resources result from deep circulation of water along fractures.

Table 1. Geothermal Resource Types

Resource Type	Temperature Range (˚C)
Convective hydrothermal resources	
Vapor dominated	240˚
Hot-water dominated	20 to 350˚+
Other hydrothermal resources	
Sedimentary basin	20 to 150˚
Geopressured	90 to 200˚
Radiogenic	30 to 150˚
Hot rock resources	
Solidified (hot dry rock)	90 to 650˚
Part still molten (magma)	>600˚

Vapor dominated systems (Fig. 1) produce steam from boiling of deep, saline waters in low permeability rocks. These reservoirs are few in number, with The Geysers in northern California, Larderello in Italy and Matsukawa in Japan being ones where the steam is exploited to produce electric energy.

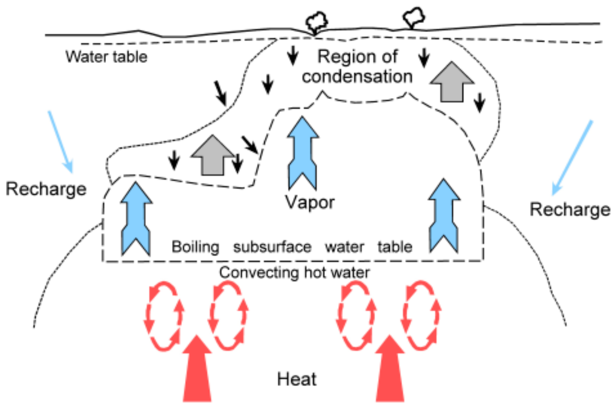

Figure 1. Vapor dominated geothermal system. (White, et al., 1971)

Water dominated systems (Fig.2) are produced by ground water circulating to depth and ascending from buoyancy in permeable reservoirs that are a uniform temperature over large volumes. There is typically an upflow zone at the center of each convection cell, an outflow zone or plume of heated water moving laterally away from the center of the system, and a downflow zone where recharge is taking place. Surface manifestations include hot springs, fumaroles, geysers, travertine deposits, chemically altered rocks, or sometimes, no surface manifestations (a blind resource).

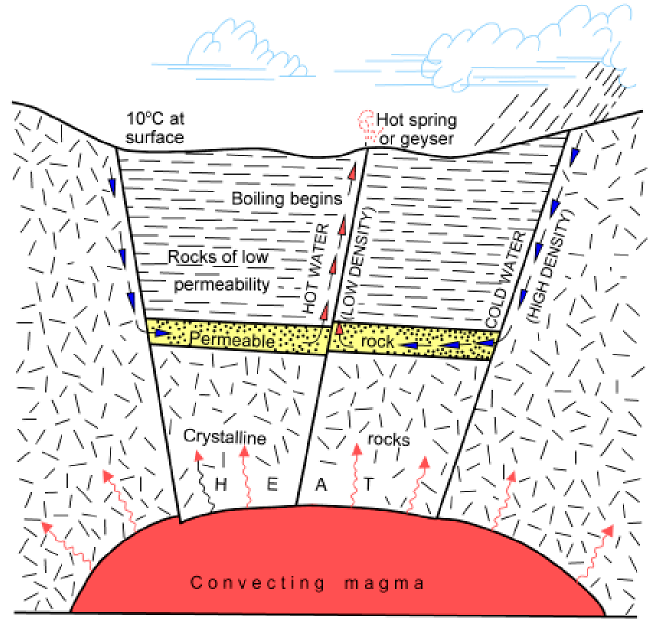

Figure 2. Hot water dominated geothermal system. (White, et al., 1971)

Sedimentary basins (Fig. 3) produce higher temperature resources than the surrounding formations due to their low thermal conductivity or high heat flow or both producing geothermal gradients >30˚C/km. These generally extend over large areas and are typical of the Madison Formation of North Dakota, South Dakota, Montana and Wyoming area of the northern United States and the Pannonian Basin of central Europe where it has been used extensively in Hungary.

Geopressured resources (Fig. 4) occur in basin environments where deeply buried fluids contained in permeable sedimentary rocks are warmed in a normal or enhanced geothermal gradient by their great burial depth. The fluids are tightly confined by surrounding impermeable rock and bear

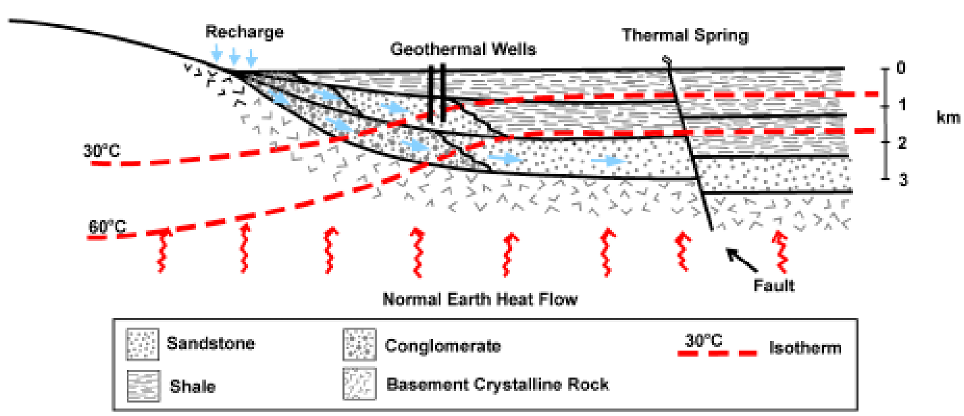

Figure 3. Sedimentary basin geothermal resource. (Anderson & Lund, 1979)

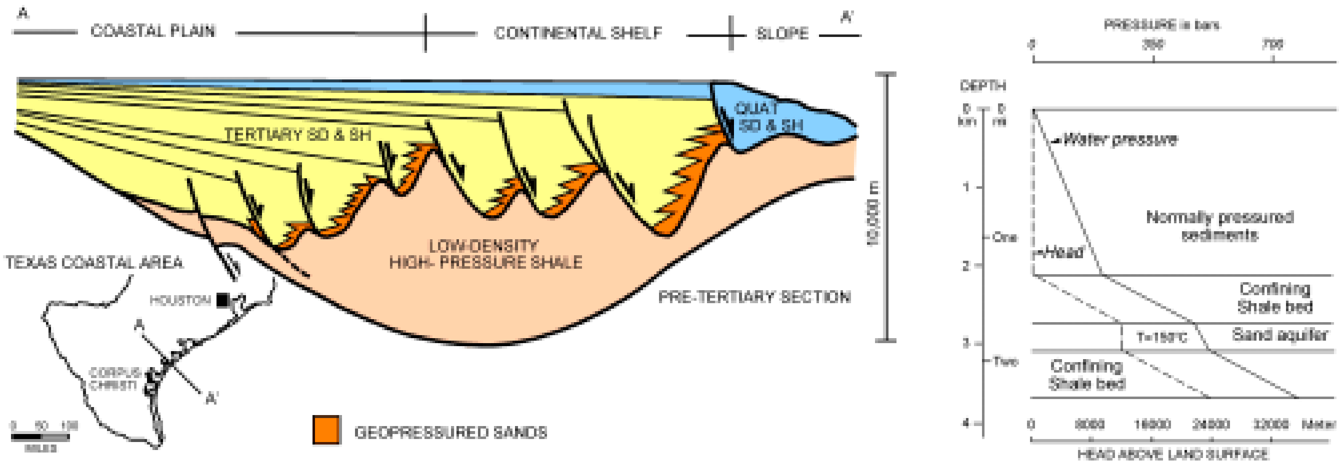

Figure 4. Geopressured geothermal system. (Bebout, et al., 1978)

pressure much greater than hydrostatic. Thermal waters under high pressure in sand aquifers are the target for drilling, mainly as they contain dissolved methane. The source of energy available from this type of resource consists of: (1) heat; (2) mechanical energy; and, (3) methane. The Texas and Louisiana Gulf Coast in the United States has been tested for the geothermal energy; however, due to the great depths of several kilometers, they have not proved economic.

Radiogenic resources (Fig. 5) are found where granitic intrusions are near surface heating up the local groundwater from the decay of radioactive thorium, potassium and uranium. This localized heating increases the normal geothermal gradient providing hot water at economical drilling depths. This type of resource occurs along the eastern United States, but has not been developed commercially.

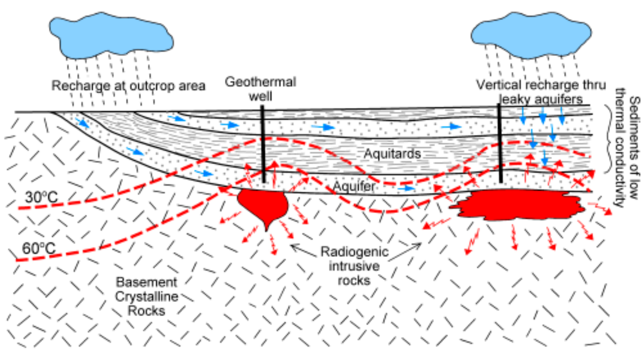

Figure 5. Radiogenic geothermal system. (Anderson & Lund, 1979)

Hot dry rock resources (Fig. 6a & b) are defined as heat stored in rocks within about 10 km of the surface from which energy cannot be economically extracted by natural hot water or steam. These hot rocks have few pore space, or fractures, and therefore, contain little water and little or no interconnected permeability. In order to extract the heat, experimental projects have artificially fractured the rock by hydraulic pressure, followed by circulating cold water down one well to extract the heat from the rocks and then producing from a second well in a closed system. Early experimental projects were undertaken at Fenton Hill (Valdes Caldera) in northern New Mexico and on Cornwall in southwest Eng-

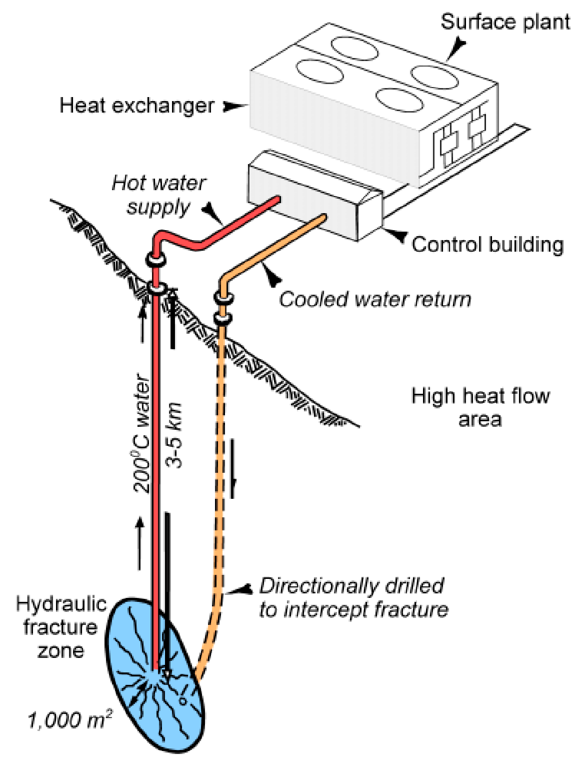

Figure 6a. Hot dry rock exploitation.

land; however both of these projects have been abandoned due to lack of funds and poor results. Projects are currently underway in Soultz-sous-Forêt in the Rhine Graben on the French-German border, in Switzerland at Basil and Zurich, in Germany at Bad Urach, several locations in Japan, and in the Cooper Basin of Australia (Tenzer, 2001).

Molten rock or magma resources have been drilled in Hawaii experimentally to extract heat energy directly from molten rock. It has been used successfully at Heimaey in Iceland (one of the Westmann Islands) after the 1973 eruption. A heat exchanger constructed on the surface of the lava flow recovered steam resulting from boiling of downward percolation water from the surface. The heat was used in a space heating system for over 10 years; but, is now shut down due to cooling of the surrounding rock.

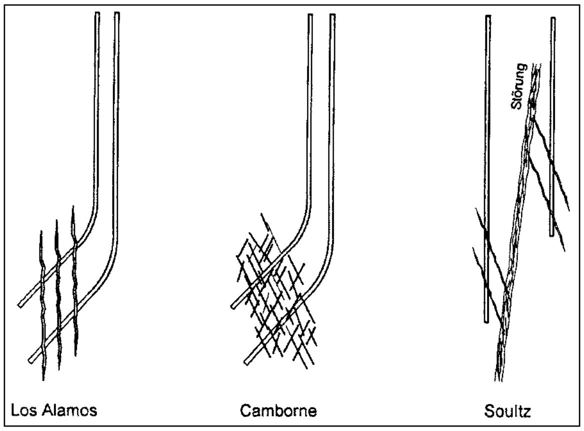

Figure 6b. Examples of hydraulic fracturing. (Tenzer, 2001)

UTILIZATION IN 2005

Based on 68 country update papers submitted to the World Geothermal Congress 2005 (WGC 2005) held in Turkey, the following figures on worldwide geothermal electric and direct-use capacity, are reported. A total of 72 countries have reported some utilization from WGC 2000 and WGC 2005, either electric, direct-use or both (Lund and Freeston, 2001; Lund, et al., 2005a; Bertani, 2005) (Table 2).

Table 2. Total Geothermal Use in 2005

Use	Installed Power MW	Annual Energy Use GWh/yr	Capacity Factor	Countries Reporting
Electric Power	8,933	56,786	0.73	24
Direct Use	28,268	75,943	0.31	72

The figures for electric power capacity (MWe) appear to be fairly accurate; however, several of the country's annual generation values (GWh) had to be estimated which amounted to only 0.5% of the total. The direct-use figures are less reliable and probably are understated by as much as 20%. The author is also aware of at least five countries, which utilize geothermal energy for direct-heat applications, but did not submit reports to WGC 2005. The details of the present installed electric power capacity and generation, and direct-use of geothermal energy can be found in Bertani (2005), and Lund, et al., 2005a. These data are summarized in Table 3.

A review of the above data shows that in electric power generation each major continent has approximately the same percentage share of the installed capacity and energy produced with North America and Asia having over 80% of the total. Whereas, with the direct-use figures, the percentages drop significantly from installed capacity to energy use for the Americas (32.3 to 16.7%) due to the high percentage of geothermal heat pumps with a low capacity factor for these units in the United States. On the other hand, the percentages increased for the remainder of the world due to a lesser reliance on geothermal heat pumps, and the greater number of operating hours per year for these units.

Table 3. Summary of Regional Geothermal Use in 2005

Region	Electric Power		Direct-Use	
	%MWe	%GWh/yr	%MWt	%GWh/yr
Africa	1.5	1.9	0.7	1.1
Americas	43.9	47.0	32.3	16.7
Asia	37.2	33.8	20.9	29.4
Europe	12.4	12.4	44.6	49.0
Oceania	5.0	4.9	1.5	3.8

ELECTRIC POWER GENERATION

Geothermal power is generated by using steam or a secondary hydrocarbon vapor to turn a turbine-generator set to produce electrons. A vapor dominated (dry steam) resource (see Fig. 1 and 7) can be used directly, whereas a hot water resource (see Fig. 2 and 8) needs to be flashed by reducing the pressure to produce steam. In the case of low temperature resource, generally below 150˚C, the use of a secondary low boiling point fluid (hydrocarbon) is required to generate the vapor, in a binary or organic Rankine cycle plant (see Fig. 9). Usually a wet or dry cooling tower is used to condense the vapor after it leaves the turbine to maximize the temperature drop between the incoming and outgoing vapor and thus increase the efficiency of the operation. The worldwide installed capacity has the following distribution: 29% dry steam, 37% single flash, 25% double flash, 8% binary/combined cycle/hybrid, and 1% backpressure (Bertani, 2005) (Figures 8 & 9 courtesy EGI).

Electric power has been produced from geothermal energy in 27 countries; however, Greece, Taiwan and Argentina have shut down their plants, due to environmental and economic reasons. Since 2000, the installed capacity in the world has increased almost 1,000 MWe. Since 2000, additional plants have been installed in Costa Rica, France on Guadeloupe in the Caribbean, Iceland, Indonesia, Kenya, Mexico, and the Phillipines. In 2004, Germany installed a 210-kWe binary plant at Neustadt Glewe and a 6-MWe plant has been installed on Papua New Guinea to generate electricity for a remote mine. Russia has completed a new 50-

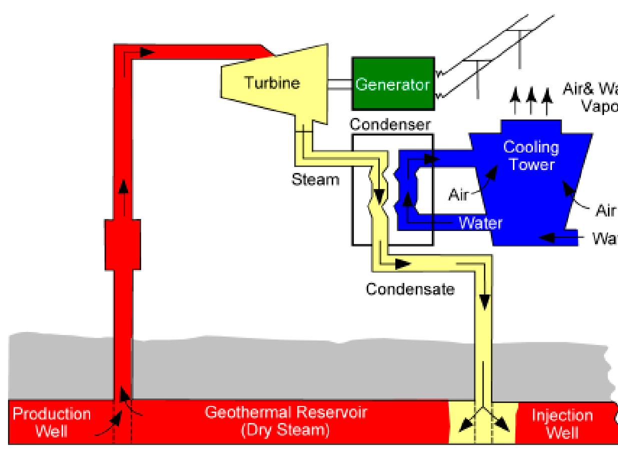

Figure 7. Steam plant using a vapor or dry steam dominated geothermal resource.

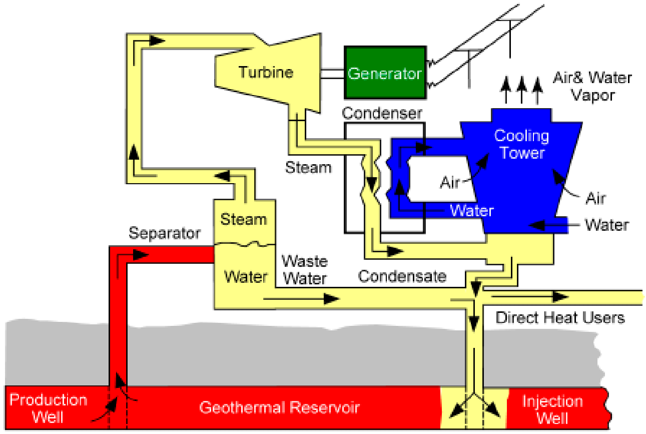

Figure 8. Flash steam plant using a water-dominated geothermal resource with a separator to produce steam.

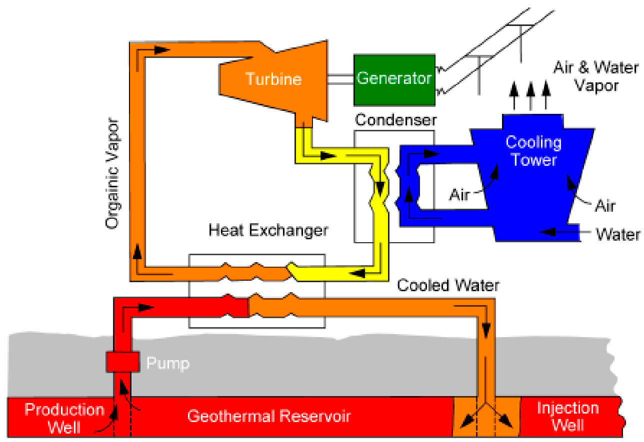

Figure 9. Binary power or organic Rankine cycle plant using a low temperature geothermal resource and a secondary fluid of a low boiling-point hydrocarbon.

MWe plant on Kamchatka. More recently, a 200 kWe binary plant using 74˚C geothermal water and 4˚C cooling water was installed at Chena Hot Springs Resort in Alaska (Lund, 2006). The operating capacity in the United States has increased since 1995 due to completion of the two effluent pipelines injecting treated sewage water at The Geysers. In an attempt to bring production back, the Southeast Geysers Effluent Recycling Project is now injecting 340 L/s of treated wastewater through a 48-km long pipeline from Clear Lake, adding 77 MWe. A second, 66-km long pipeline from Santa Rosa was placed on-line in 2004, injecting 480 L/s that are projected to add another 100 MWe to The Geyser's capacity. Table 4 lists the leading countries producing electric power.

A recent report (Bertani, 2007) indicates that geothermal installed capacity per power generation has increased to 9,732 MWe.

One of the more significant aspects of geothermal power development is the size of its contribution to national and regional capacity and production of countries. Table 5 shows the countries or regions that lead in this contribution with more than 5% of the electrical energy supplied by geothermal power based on data from WGC2005 (Bertani, 2005).

DIRECT UTILIZATION

Direct-use of geothermal resources is primarily for direct heating and cooling. The main utilization categories are: (1) swimming, bathing and balneology; (2) space heating and cooling including district energy systems; (3) agricultural applications such as greenhouse and soil heating; (4) aquaculture application such as pond and raceway water heating; (5) industrial applications such as mineral extraction, food and grain drying; and, (6) geothermal (ground-source) heat pumps (GHP), used for both heating and cooling.Direct-use of geothermal resources normally uses temperatures below 150˚C as illustrated in Figure 10. The main advantage of using geothermal energy for direct use projects in this low- to intermediate-temperature range is that these resources are more widespread and exists in at least 80 countries at economic drilling depths. In addition, there are no conversion

Table 4. Leading Countries in Electric Power Generation (>100 MWe) (Bertani, 2005)

Country	Installed Capacity, MWe	Running Capacity, MWe	Annual Energy Produced, GWh/yr	Running Capacity Factor	Number of Units Operating
United States*	2534	2133	17,840	0.95	209
Philippines	1930	1838	9,253	0.57	57
Mexico	953	953	6,282	0.75	36
Indonesia	797	838	6,085	0.83	15
Italy	791	699	5,340	0.87	32
Japan	535	530	3,467	0.75	19
New Zealand	435	403	2,774	0.79	33
Iceland	202	202	1,483	0.84	19
Costa Rica	163	163	1,145	0.80	5
El Salvador	151	119	967	0.93	5
Kenya	129	129	1,088	0.96	9

*USA figures revised based on (Lund, et al. 2005b)

Table 5. National and Regional Geothermal Power Contributions

Country or Region	% of National or Regional Capacity (MWe)	% of National or Regional Energy (GWh/yr)
Tibet	30.0	30.0
San Miguel Island, Azores	25.0	n/a
Tuscany, Italy	25.0	25.0
El Salvador	14.0	24.0
Iceland	13.7	16.6
Philippines	12.7	19.1
Nicaragua	11.2	9.8
Kenya	11.2	19.2
Lihir Island, Papua New Guinea	10.9	n/a
Guadeloupe (Caribbean)	9.0	9.0
Costa Rica	8.4	15.0
New Zealand	5.5	7.1

efficiency losses and projects commonly use conventional water-well drilling and off-the-shelf heating and cooling equipment (allowing for the temperature and chemistry of the fluid). Most projects can be on line in less than a year. Projects can be on a small scale ("mom and pop operations") such as for an individual home, single greenhouse or aquaculture pond, but can also be a large scale operation such as for district heating/cooling and for food and lumber drying, and mineral ore extraction. It is often necessary to isolate the geothermal fluid from the user side to prevent corrosion and scaling.

Care must be taken to prevent oxygen from entering the system (geothermal water normally is oxygen free), and dissolved gases and minerals such a boron, arsenic, and hydrogen sulfide must be removed or isolated as they are harmful to plants and animals. On the other hand, carbon dioxide, which often occurs in geothermal water, can be extracted and used for carbonated beverages or to enhance growth in greenhouses. The typical equipment for a direct-use system is illustrated in Figure 11, and includes, downhole and circulation pumps, heat exchangers (normally the plate type), transmission and distribution lines (normally insulated pipes), heat extraction equipment, peaking or back-up plants (usually fossil fuel fired) to reduce the use of geothermal fluids and reduce the number of wells required, and fluid disposal system (injection wells). Geothermal energy can usually meet 95% of the annual heating or cooling demand, yet only be sized for 50% of the peak load. Geothermal heat pumps include both open (using ground-water or lake water) and closed loop (either in horizontal or vertical configuration) systems as illustrated in Figure 12.

The world direct utilization of geothermal energy is difficult to determine; as, there are many diverse uses of the energy and these are sometimes small and located in remote areas. Finding someone, or even a group of people in a country who are knowledgeable on all the direct uses is difficult. In addition, even if the use can be determined, the flow rates and temperatures are usually not known or reported; thus, the capacity and energy use can only be estimated. This is especially true of geothermal waters used for swimming pools, bathing and balneology. Thus, it is difficult to compare changes from one report to the next. This was especially true of Japan and Hungary in the WGC 2000 country updates, as a significant portion of this use was not reported, and was obtained from other sources. For this reason, the values reported in Lund and Freeston (2001),

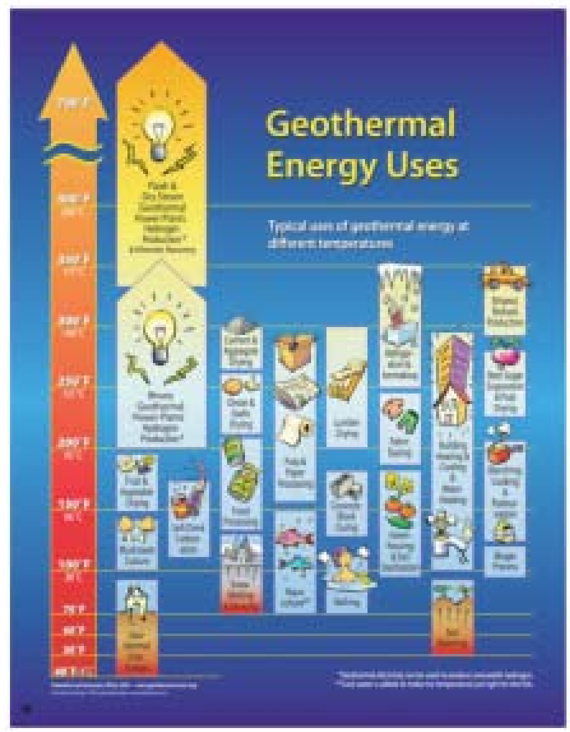

Figure 10. Geothermal energy uses. (Geothermal Education Office)

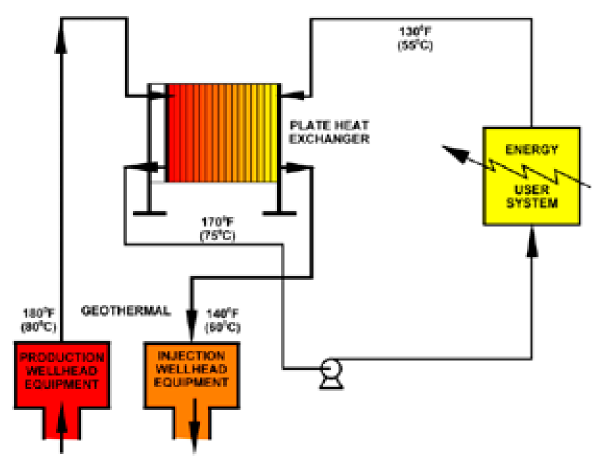

Figure 11. Typical direct use geothermal heating system configuration.

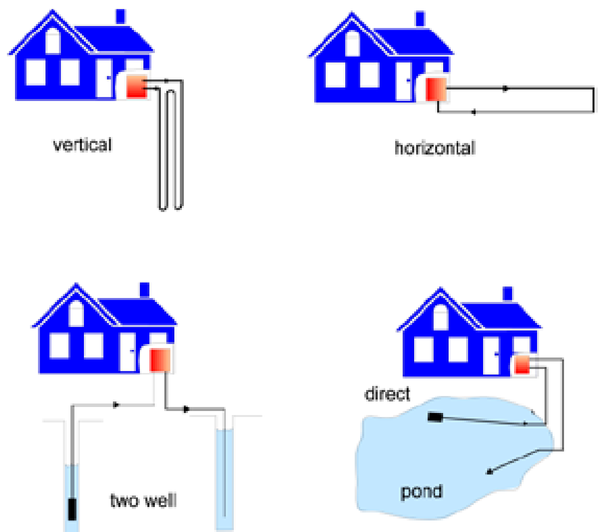

Figure 12. Examples of common geothermal heat pump installations.

have been updated for this paper based on data for WGC 2005 (Lund, et al., 2005a).

One of the significant changes for WGC2005 was the increase in the number of countries reporting use. Fourteen countries were added to the list in the current report as compared to 2000. In addition, the author is aware of four countries (Malaysia, Mozambique, South Africa, and Zambia) that have geothermal direct-uses, but did not provide a report for WGC2005. Thus, there are at least 76 countries with some form of direct utilization of geothermal energy. Table 6 lists the top direct-use countries.

Table 6. Top Direct-Use Countries

Country	GWh/yr	MWt	Main Applications
China	12,605	3,687	bathing
Sweden	12,000	4,200	GHP
USA	8,678	7,817	GHP
Turkey	6,900	1,495	district heating
Iceland	6,806	1,844	district heating
Japan	2,862	822	bathing (onsens)
Hungary	2,206	694	spas/greenhouses
Italy	2,098	607	spas/space heating
New Zealand	1,969	308	industrial uses

Another significant change from 2000 is the large increase in geothermal (ground-source) heat pump installations. They increased by 198% (24% annual growth) in capacity and 272% (30% annual growth) in energy produced over the five-year period to the year 2005. By 2005, they were the largest portion of the installed capacity (56.5%) and 33.2% of the annual energy use. The actual number of installed units is around 1,700,000 in 33 countries, mostly in the United States and Europe; however, the data are incomplete. The equivalent number of 12-kWt units installed (the average size) is approximately 1,500,000. The equivalent number of full-load heating operating hours per year varies from 1,200 in the U.S., to over 6,000 in Sweden and Finland, with a worldwide average of 2,200 full-load hours/year.

A summary of direct-use installed capacity and annual energy use are as follows: geothermal heat pumps 56.5% and 33.2%; bathing/swimming/spas 17.7% and 28.8%, space heating (including district heating) 14.9% and 20.2%; greenhouse heating 4.8% and 7.5%; aquaculture 2.2% and 4.2%; industrial 1.8% and 4.2%; agricultural drying 0.6% and 0.8%, cooling and snow melting 1.2% and 0.7%; and others 0.3% and 0.4%. District heating is approximately 80% of the space heating use.

In terms of the contribution of geothermal direct-use to the national energy budget, two countries stand out: Iceland and Turkey. In Iceland, it provides 89% of the country's space heating needs, which is important since heating is required almost all year and saves about 100 million US$ in imported oil. Turkey has increased their installed capacity over the past five years from 820 MWt to 1,495 MWt, most for district heating systems. A summary of some of the significant geothermal direct-use contributions to various countries is shown in Table 7.

Table 7. National Geothermal Direct-Use Contributions

Iceland	provides 89% of country's space heating needs;
Turkey	space heating has increased 50% in the past 5 years, supplying 65,000 equivalent residences and 30% of the country will be heated with geothermal by 2010
Tunisia	greenhouse heating has increased from 10 ha to 100 ha over the past 10 years
Japan	over 2,000 hot spring resorts (onsens), over 5,000 public bath houses, and over 15,000 hotels, visited by 14.5 million guests per year, use natural hot springs
Switzerland	has installed 30,000 geothermal heat pumps = one/two km^2, and 1,000 boreholes are drilled annually. Drain water from tunnels are used to heat nearby villages and they have also developed several geothermal projects to melt snow and ice on roads
United States	has installed 700,000 geothermal heat pump units, mainly in the midwestern and eastern states, with a 15% annual growth. Installation of these units is around 50,000 to 60,000 per year

ENVIRONMENTAL CONSIDERATIONS

Geothermal resources are considered renewable and "green" (Rybach, 2007); however, there are several environmental impacts that must be considered during utilization that are usually mitigated. These are emission of harmful gases, noise pollution, water use and quality, land use, and impact on natural phenomena, wildlife and vegetation (Kagel, et al., 2005).

Emissions: These are usually associated with steam power plant cooling towers that produce water vapor emission (steam), not smoke. The potential gases that can be released, depending upon the reservoir type are carbon dioxide, sulfur dioxide, nitrous oxides, hydrogen sulfide along with particulate matter. A coal- fired power plant produces the following kilograms of emissions per MWh as compared to a geothermal power plant: 994 vs. up to 40 for carbon dioxide, 4.71 vs. up to 0.16 for sulfur dioxide, 1.95 vs. 0 for nitrogen oxides, 0 vs. 0.08 for hydrogen sulfide (H_2S), and 1.01 vs. 0 for particulate matter. Hydrogen sulfide is routinely treated at geothermal power plants, and converted to elemental sulfur. In comparison, oil-fired power plants produce 814 kg and natural gas fired plants 550 kg of H_2S per MWh. Binary power plants and direct-use projects normally do not produce any pollutants, as the water is injected back into the ground after use without exposing it to the atmosphere.

Noise: The majority of the noise produced at a power plant or direct-use site is during the well drilling operation, which normally shuts down at night. The noise from a power plant is not considered an issue of concern, as it is extremely low, unless you are next to or inside the plant. Most of the noise comes from cooling fans and the rotating turbines.

Water use: Geothermal plants use about 20 liters of freshwater per MWh, while binary air-cooled plants use no fresh water, as compared to a coal plant that uses 1,370 liters per MWh. An oil plant uses about 15% less and nuclear about 25% more than the coal plant (www.cleanenergy.org). The only change in the fluid during use is to cool it, and usually the fluid is returned to the same aquifer so it does not mix with the shallow groundwater. At The Geysers facility in northern California, 42 million liters of treated wastewater from Santa Rosa are pumped daily for injection into the geothermal reservoir, reducing surface water pollution in the community and increasing the production of the geothermal field. A similar project supplies waste water from the Clear Lake area on the northeast side of the The Geysers. These projects have increased the capacity of the field by over 100 MWe.

Land use: Geothermal power plants are designed to "blend-in" with the surrounding landscape, and can be located near recreational areas with minimum land and visual impacts. They generally consist of small modular plants under 100 MWe as compared to coal or nuclear plants of around 1,000 MWe. Typically, a geothermal facility uses 404 square meters of land per GWh compared to a coal facility that uses 3,632 square meters per GWh and a wind farm that uses 1,335 square meters per GWh. Subsidence and induced seismicity are two land use issues that must be considered when withdrawing fluids from the ground. These are usually mitigated by injecting the spent fluid back into the same reservoir. There have been problems with subsidence at the Wairakei geothermal field in New Zealand; however, this has been checked by injection. Neither of these potential problems are associated with direct-use projects, as the fluid use is small and well and pipelines are usually hidden. In addition, utilizing geothermal resources eliminates the mining, processing and transporting required for electricity generation from fossil fuel and nuclear resources.

Impact on natural phenomena, wildlife and vegetation: Plants are usually prevented from being located near geysers, fumaroles and hot springs, as the extraction of fluids to run the turbines, might impact these thermal manifestations. Most plants are located in areas with no natural surface discharges. If plants are located near these natural phenomena, the fluid extraction depth is planned from a different reservoir to prevent any impact. Designers and operators are especially sensitive about preserving manifestations considered sacred to indigenous people. Any site considered for a geothermal power plant, must be reviewed and considered for the impact on wildlife and vegetation, and if significant, provide a mitigation plan. Direct use projects are usually small and thus have no significant impact on natural features.

In summary, the use of geothermal energy is reliable, providing base load power; is renewable; has minimum air emission and offsets the high air emissions of fossil fuel-fired plants; has minimum environmental impacts; is combustion free; and is a domestic fuel source.

ENERGY SAVINGS

Using geothermal energy obviously replaces fossil fuel use and prevents the emission of greenhouse gases. If we assume that geothermal energy replaces electricity generation, the conversion efficiency is estimated at 0.35 (35%). These savings using geothermal energy at this efficiency level is summarized in Table 8 (Goddard and Goddard, 1990).

If the replacement energy for direct-use is provided by burning the fuel directly, then about half this amount would be saved in heating systems (35% vs. 70% efficiency). Savings in the cooling mode of geothermal heat pumps is also included in the figures in Table 8. The savings in fossil fuel

Table 8. Energy and Greenhouse Gas Savings from Geothermal Energy Production

	Fuel Oil (10^6)		Carbon (10^6 t)			CO_2 (10^6 t)			SO_X (10^6 t)			NO_X (10^3 t)		
	Barrels	**Tonnes**	**NG**	**Oil**	**Coal**	**NG**	**Oil**	**Coal**	**NG**	**Oil**	**Coal**	**NG**	**Oil**	**Coal**
Electric	96	15	3	13	15	12	51	59	0	0.3	0.3	2.8	9.6	9.6
Direct-use	174	26	5	24	27	16	67	78	0	0.5	0.5	3.8	12.4	12.4
TOTAL	270	41	8	37	42	28	118	137	0	0.8	0.8	6.6	22.0	22.0

oil is equivalent to about three days (1%) of the world's consumption.

It should be noted when considering these savings, that some geothermal plants do emit limited amounts of the various pollutants; however, these are reduced to near zero where gas injection is used and eliminated where binary power is installed for electric power generation. Since most direct-use projects use only hot water and the spent fluid injected, the above pollutants are essentially eliminated.

CONCLUSIONS

Geothermal growth and development of electricity generation has increased significantly over the past 30 years approaching 15% annually in the early part of this period, and dropping to 3% annually in the last ten years due to an economic slow down in the Far East and the low price of competing fuels. Direct-use has remained fairly steady over the 30-year period at 10% growth annually. The majority of the increase has been due to geothermal heat pumps. At the start of this 30-year period, only ten countries reported electrical production and/or direct utilization from geothermal energy. By the end of this period, 72 countries reported utilizing geothermal energy. This is over a seven-fold increase in participating countries. At least another 10 countries are actively exploring for geothermal resources and should be online by 2010.

Developments in the future will include greater emphases on combined heat and power plants, especially those using lower temperature fluids down to 100˚C. This low-temperature cascaded use will improve the economics and efficiency of these systems, such as shown by installations in Germany, Austria and at Chena Hot Springs, Alaska. Also, there is increased interest in agriculture crop drying and refrigeration in tropical climates to preserve products that might normally be wasted. Finally, the largest growth will include the installation and use of geothermal heat pumps, as they can be used anywhere in the world, as shown by the large developments in Switzerland, Sweden, Austria, Germany, Canada, and the United States.

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Klamath Falls Geothermal District Heating System at 25 Years

Brian Brown P.E., Brian Brown Engineering, Klamath Falls, OR

Figure 1. Klamath Falls Geothermal District Heating system location map, 2005

ABSTRACT

In 1976 the OIT Geo-Heat Center began investigating the feasibility of developing a geothermal district heating system to serve the Klamath Falls downtown. The district heating system was installed in 1981. Startup and operational problems prevented reliable operation until 1991. In 1992, the city began marketing the district heating system to other buildings in the downtown area.

By 2006 the system approached the original design capacity, and more growth is planned. After 25 years, the system is beginning to realize the economic benefits envisioned by the original feasibility studies in 1977.

INTRODUCTION

The City of Klamath Falls, Oregon, is located in a Known Geothermal Resource Area (KGRA) that has been directly used to heat homes, businesses, schools, and institutions since the early 1900s. In 1976, Klamath Falls and Klamath County became interested in establishing a geothermal district heating system to extend the benefits of the geothermal resource to government buildings and businesses in downtown Klamath Falls. This led to construction of the district heating system in 1981. After a difficult start-up period, the system has provided reliable service since 1991. For more information on the system development, see Lienau, et al., (1989 and 1991).

The district heating system was originally designed for a thermal capacity of 20 million Btu/hr (5.9 MWt). At peak heating, the original ten buildings on the system utilized only about 20 to 25 percent of the system thermal capacity.

Total annual heating revenue from those buildings in 1991 was about $23,800, which was inadequate to sustain system operation. This led the city to begin a marketing effort in 1992 to add more customers to the system (Rafferty, 1993).

The Klamath Falls geothermal district heating system currently serves process heating at the Klamath Falls wastewater treatment plant (WWTP), 24 buildings totaling about 400,000 sq. ft., greenhouses totaling 150,000 sq. ft., and about 105,000 sq. ft. of sidewalk snowmelt systems. Figure 1 shows the existing district heating service area.

The year 2006 marked 25 years since completion of the district heating system construction. This paper is intended to provide a retrospective on system development and lessons learned. The author has provided geothermal engineering consulting to the city since 1992.

District Heating System Timeline

- 1977: Feasibility study. (Lienau, et al., 1977).
- 1981: Construction of downtown district heating system completed.
- 1982: Construction of Michigan Street district heating system to serve low income neighborhood of 120 homes, funded by HUD. Only about 10 homes connected.
- 1981-1984: Public opposition delayed operation of the system until an aquifer study was completed.
- Nov. 1984: System operation begins.
- Feb. 1986: System operation halted after multiple failures of the distribution piping.
- Jan. 1991: System operation restarted after reconstruction of distribution piping.
- 1992: Beginning of marketing effort to add customers (Rafferty, 1993).
- Sep. 1993: Earthquake damages four County buildings, about half of connected heating load shut down.
- Nov. 1993: Pipeline extension to the Ross Ragland Theater completed; allows connection of six new customers.
- 1995-1998: Development of the Klamath Falls Main Street streetscape project, with geothermally heated sidewalks and crosswalks (Brown, 1995).
- 1996: Engineering evaluation of system condition, load, and capacity (Brown, 1996).
- 1999: Rehabilitation of the upper production well, CW-1.
- 2000: Repair of the injection well piping due to a corrosion failure.
- 2000: Addition of new circulation pump, CP-2.
- 2000-2001: Extension of district heating system to serve the Klamath Falls wastewater treatment plant and 100,000 sq. ft. greenhouse facility.
- 2001: Michigan Street system abandoned.
- 2003: Evaluation of capacity and improvements needed to support an expansion of the greenhouses (now at 4.0 acres). Partially funded by NREL.
- 2003-2004: System improvements including new heat exchangers, new automatic controls, improved pipe tunnel and vault ventilation, replacement of pipeline expansion joints, rehabilitation of the lower production well, CW-2. Partially funded by NREL.
- 2006: Addition of circulation pump, CP-3, to match the pump added in 2000.
- 2006: Expansion of the district heating system mains and development of a new sidewalk snowmelt system to serve the Timbermill Shores development on a former mill site.

The Klamath Falls district heating system is beginning to be financially viable and self-sustaining after 25 years of operation. The path to that point has been long and difficult, but thanks to the long-term commitment of the people of Klamath Falls, a difficult beginning has been turned into a successful system.

LESSONS LEARNED

The geothermal district heating system design and materials selection was based on a preliminary design study in 1979 by LLC Geothermal Consultants, Klamath Falls, OR. (Lund, et al., 1979). The engineer of record, Balzheiser/Hubbard & Associates, implemented the preliminary design recommendations with minor modifications.

Photo 1: Drilling of CW-1 well (Geo-Heat Center)

Production Wells

Production well pumps are vertical line shaft pumps, oil lubricated, with variable-speed drives. The well pumps as originally designed were rated for 500 gpm each, and powered by 50 hp motors.

The well pump for CW-1 was removed and rehabilitated in 1999 and CW-2 was rehabilitated in 2004. Inspection of the pumps showed significant corrosion of the steel column pipe at and above the water level, but no corrosion significantly below the water level. The corroded column pipe was replaced and the rest of the column pipe was reused. The pump bowls, line shaft, bearings, and shaft tube were in good condition and were reused.

Photo 2: Well Pump (Brown)

The original 50 hp motors and Nelson fluid drive were removed and replaced with an adjustable frequency drive and a 75 hp motor. The adjustable frequency drive and larger motor give the capability to over-speed the pump by about 20% from the nominal design speed of 1750 rpm to 2100 rpm. The increased pump speed can provide about a 20% increase in pumping.

The original system used Nelson fluid drives for variable speed operation. City water which was used to cool the drive was discharged down the well. That cooling water kept the outside of the column pipe wet and introduced oxygen into the well, promoting corrosion. Replacement of the Nelson drives with adjustable frequency drives allowed elimination of the cooling water flow and the resulting corrosion.

Geothermal Transmission Pipeline

Geothermal flow from the production wells is conveyed to the heat exchanger building through an 8-inch steel pipeline, about 4400 feet long. The pipe is insulated with polyurethane foam insulation, protected by a fiber-wound FRP jacket. About one-third of the pipeline is direct-buried; the rest is enclosed in a concrete pipe tunnel.

Photo 3: Production Pipeline and Tunnel Construction (Babcock)

Pipe expansion in the direct-buried section is accommodated by expansion joints with stainless steel bellows, located in expansion joint vaults. Pipe expansion in the tunnel is accommodated by expansion joints and pipe roller-guides.

The interior of the pipe is in excellent condition with minimal corrosion. The exterior of the pipe has suffered varying degrees of corrosion damage, particularly at fittings, expansion joints, and pipe anchors where the steel has been exposed to moisture. The expansion joints and pipe tunnel were intended to protect the pipe by providing a dry environment. However, the atmosphere in the vaults and tunnel was extremely humid because of inadequate ventilation and infrequent maintenance of the vault drains. Moisture would condense on the vault and tunnel ceilings and then rain down on the pipe. There is evidence of past flooding, resulting in direct contact of water and sediment with the pipe.

The city installed two six-inch vent pipes to each expansion joint vault, with one pipe connected high in the vault and the other low. The vent pipes provide thermal and wind-driven ventilation of the vaults, which reduce the high humidity and condensation. Tunnel ventilation has been improved by installing a blower at the heat exchanger building to force air into the tunnel and a larger relief vent at the far end of the tunnel.

The city has had to repair two corrosion failures in the direct-buried portion of the pipeline. It appears that the FRP jacket is beginning to fail and allow soil moisture to contact the pipe. The City plans to replace the steel pipeline with pre-insulated ductile iron pipe as funds allow.

District Heating Distribution

The district heating distribution piping is a closed loop system with both supply and return pipelines. Almost half of the original system length was 10-inch, pre-insulated steel pipe. The rest of the piping, 8-inch and smaller, was key-lock fiberglass pipe.

The fiberglass pipe joints failed after the first heating season, possibly due to defective epoxy on the factory-glued joints, and were entirely replaced with pre-insulated ductile iron pipe. Where the ductile iron pipe has been inspected, it remains in good shape after 15 years of service.

The steel portion of the pipeline was protected by the insulation system and cathodic protection anodes, which have not been checked since construction. There have been recent corrosion failures in the steel pipelines; likely caused by failure of the FRP jacket coupled with diminished cathodic protection. The city plans to replace the pipe with pre-insulated ductile iron as funds allow.

Some customer service connections were installed using unprotected steel piping. Those connections have tended to fail after about ten years. Improved corrosion protection is being used on new and repaired connections.

District Heating System Controls

The control system was originally designed to maintain the district heating supply temperature at a constant 180˚F by controlling geothermal production and the flow through the heat exchanger. On decreasing temperature of the supply water, the system was intended to increase the geothermal production by increasing the well pump speed and automatically starting the second well pump if needed. On increasing temperature of the supply water, the system would reduce production, then modulate a three-way valve to bypass district heating water flow around the heat exchanger.

The geothermal water temperature is above boiling temperature at the project elevation, so a backpressure valve and control was designed to maintain enough pressure on the geothermal production piping to prevent flashing to steam in the system.

The original pneumatic control system was not capable of meeting the design control objectives. The fully automatic temperature control operation resulted in serious oscillations of well pump speed and starting/stopping. The resolution was to operate the well pumps manually, and limit the automatic temperature control to the three-way valve. The backpressure control was also unstable, partially due to inappropriate valve selection.

The control system was upgraded in 2003 to modern digital controls, using Allen Bradley programmable logic controls (PLC). The telephone telemetry link to the production wells was replaced with spread-spectrum radio telemetry. The control system is fully integrated with the city control system for water and wastewater system operation.

The original temperature control and backpressure control concepts were retained with the new controls. The increased power and tuning capability of the modern controls have largely been able to tame the unstable control loops.

Back-pressure control is a difficult control service, with the valve required to operate over a wide flow range, controlling hot fluids that can flash to steam or cause cavitation on the downstream side of the valve. There remains some instability in the backpressure control even with the new control system and a new control valve. More stable operation can likely be achieved by reprogramming the controls to operate the valve for temperature control, and control the well pumps to maintain a pressure set-point. On decreasing temperature the controls would open the valve, resulting in increased flow and reduced pressure. The controls would then increase the pump speed to compensate.

CAPACITY AND LOAD

The capacity of a closed-loop district heating system is fundamentally different than the capacity of a potable water system. The purpose of a water system is to deliver water, which is consumed in some way and not returned to the water system. What the customer does with the water is not a major consideration; the water system is sized for the capacity to deliver given design flow.

A district heating system is designed to deliver heating energy. The water flow is merely a means to convey the energy. The capacity to deliver heat is limited both by the flow capacity of the system and what the customer does with the heating water before sending it back. The capacity of the system is thus very much constrained by the action of the customers. The amount of heat delivered by the water depends on both the flow rate and the temperature change of the water. This can be expressed by the equation:

$$ENERGY\ (BTU/HR) = FLOW\ (GPM) \times \Delta T\ (°F) \times 500$$

Flow is essentially fixed by the hardware selected in the design: the pumps, pipes, control valves, heat exchangers, production wells, and injection well. Any significant increase in the flow requires larger equipment and increased power to operate.

Temperature change of the heating water (delta-T) is equally important to the delivery of heat. The delta-T is affected by physical constraints such as the temperature of the heat source, the temperature requirements of the heat load, and the sizing of the heat transfer device. The main cause of low delta-T is failure to properly control heating water flow, with the consequence of reduced thermal capacity and higher than necessary pumping costs.

The Klamath Falls geothermal district heating system was designed with a thermal capacity of 20×10^6 Btu/hr (5.9 MWt), based on 1,000 gpm of loop flow, 1,000 gpm of geothermal flow, and a design delta-T of 40°F. The load on the district heating system is approaching the original design thermal capacity. According to the system data log, the peak load for the 2005-2006 heating season was about 14.9×10^6 Btu/hr, on December 1, 2005 at 7:58 AM, at an outside air temperature of 10°F. Geothermal flow was 764 gpm. Loop flow was 819 gpm.

In another sense, the system was operating at near capacity in 1993 when the loop flow was about 900 gpm at a maximum 10°F delta-T, or in 1996 at a loop flow of 850 gpm and 16°F system delta-T. The ability to add customers to the system and thus increase revenue has primarily been possible because of improved flow control at customer connections, increasing the delta-T and freeing up flow capacity.

Recent improvements were intended to increase the nominal system capacity to about 36×10^6 Btu/hr (8.5 MWt), based on 1,200 gpm pumping capacity and 60°F delta-T. Some of that increased capacity is due to new heat exchangers and increased circulation pump capacity. However, most of the capacity increase is dependant on improvement in system delta-T. Proposed measures to achieve improved delta-T include:

- Continued improvement of flow control at existing customer connections
- Cascading flow from higher temperature uses to lower temperature users. For example, operating snowmelt systems off the district heating loop return line rather than supply line.
- Designing new connections to the system for a higher delta-T of 60°F.

ECONOMICS

Original Projections

The geothermal district heating system was designed to initially serve 14 government buildings with planned expansion to serve additional buildings on 11 commercial blocks along the route, then the entire 54-block downtown commercial district. The anticipated system heating loads for the planned construction phases were: (Lienau, 1981)

Phase	Description	Peak heat load Btu/hr
I	14 Government Buildings	21×10^6
II	11 Commercial Blocks	34.8×10^6
III	54 Commercial Blocks	143×10^6

The system feasibility study was conducted during the late 1970s energy crisis, when there was sharp run-up in the cost of natural gas and other energy. Figure 2 shows a 20-year life-cycle cost comparison of the proposed project on a unit energy basis. (Lienau, 1981) Key assumptions included:

- System peak load: 34.8×10^6 Btu/hr (Phase II)
- Annual energy use: 60×10^9 Btu
- Capital cost: $3,753,259 at 8%
- O&M 6.2% of capital; inflated at 7%/year
- Natural gas inflation: 14.6% to 17.6% /year

The analysis calculated that the cost of the geothermal energy would match natural gas at about year five, at a cost of about $7.00 per 10^6 Btu, and simple payback would occur at ten years.

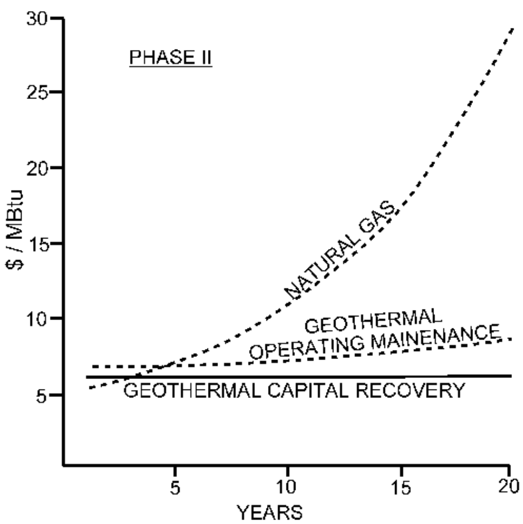

Figure 2. Phase II Unit Energy Cost Comparison (Lineau, 1981)

Initial Operation

Phase I was funded and constructed as a demonstration project, with most of the cost covered by grants. On that basis, the expectation was that the economics would be better than the Phase II analysis. Unfortunately, the system did not meet those expectations.

The first hurdle was concerns by home owners about the impact of operation of the geothermal system on their private wells. Klamath Falls has hundreds of private homes heated by private geothermal wells. The concern was that the city system would lower the water level and/or reduce geothermal temperatures, negatively affecting the private wells. The home owners initiated a city ordinance that effectively prohibited operation of the newly constructed district heating system. That problem was resolved by extensive aquifer testing, including full operational testing that showed no negative impact. However, start-up of the district heating system was delayed by three years to November 1984.

The next hurtle was failure of the fiberglass distribution system piping after only one heating season. The city was faced with the question: do they rebuild, or shut the system down. The decision was to borrow the needed funds and rebuild the distribution system. The system was restarted in January 1991.

Meanwhile, the cost of natural gas dropped from a high of $0.627/therm ($10^5$ Btu) in October 1982, to a low of $0.378/therm in December 1991. See Figure 3. That compares to a projected cost of about $1.10/therm at year ten in the original economic analysis. The total heating revenue for 1991 was about $23,800, which was well below the cost of system operation.

The city was again faced with a choice: shut the system down, or subsidize operation while attempting to grow the connected load and revenue. The city began a marketing push in 1992, and over the following 13 years the system load has been increased to near the original Phase I design capacity. The cost of conventional energy has also increased, making the renewable geothermal energy more valuable.

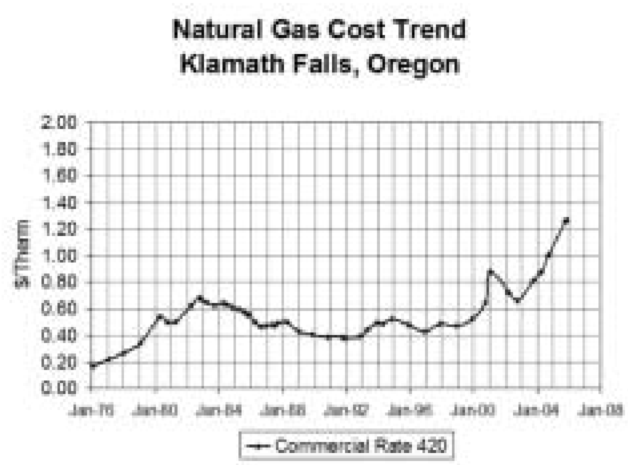

Figure 3. Local Natural Gas Cost Trend.

Current Status

The geothermal district heating system provides a significant financial impact on the local community. For 2005, the metered geothermal energy sales was about 26.1×10^9 Btu, and un-metered building energy use was about 5.3×10^9 Btu, for a total of 31.4×10^9 Btu. Currently, the commercial natural gas rate is $1.26353 per therm, or assuming a seasonal conversion efficiency of 67%, about $18.8/10^6 Btu. The direct economic value of using geothermal energy from the district heating system rather than fossil fuels was about $589,000.

Economic value is also realized indirectly by the contribution of the geothermal system to economic growth and downtown revitalization. The availability of geothermal energy was a major factor in the decision of the IFA Nurseries greenhouses to locate in Klamath Falls. The geothermal energy allows IFA to control their energy costs. In return they contribute jobs to the community and tree seedlings for local reforestation efforts. Geothermally heated sidewalk snowmelt systems are a very visible and popular feature of the downtown redevelopment project, which has helped turn around a formerly declining downtown area.

Photo 4: Geothermally Heated Sidewalk Snowmelt (Geo-Heat Center)

The economic value of the geothermal district heating system to the community is clearly significant. The other question is whether the revenue to the system operator is adequate to cover costs. The city cannot charge the full value of conventional energy, or there would be no incentive for customers to connect.

The city metered geothermal rate is set at 80% of the current commercial natural gas rate, with rate increases limited to no more than 10% per year. The current standard rate is $8.828 /10^6 Btu. A significant portion of the load is still billed at long-term flat rates negotiated several years ago, of $5.40/10^6 Btu or $5.60/10^6 Btu. The 2004-2005 heating season average for metered accounts was $6.15/10^6 Btu. There are still several unmetered buildings that will be metered within the next couple years.

Total system revenue for the 2004-2005 heating season was $170,012. Direct operating expenses for the same period were $47,403. Additional deferred maintenance costs that should be included in the annual costs include about $15,000 annually for heat exchanger plate cleaning and regasketing, and about $70,000 annual financing costs for about $800,000 in needed pipeline repair and upsizing. The city should also be funding a maintenance reserve and greater staff time for managing system operation, system growth, and customer connection delta-T control.

After 25 years the system operation is at or near operational break-even. The revenue should continue to increase over the next few years as more customers are added and existing unmetered customers are switched to metered service. The increased revenue should help with funding of other operational needs.

In retrospect, the original economic analysis was not too bad; there was just a 20-year pause in the growth of energy costs, and a 15 year delay in geothermal system expansion. The people of Klamath Falls are to be commended for their perseverance through the lean times.

ACKNOWLEDGMENTS

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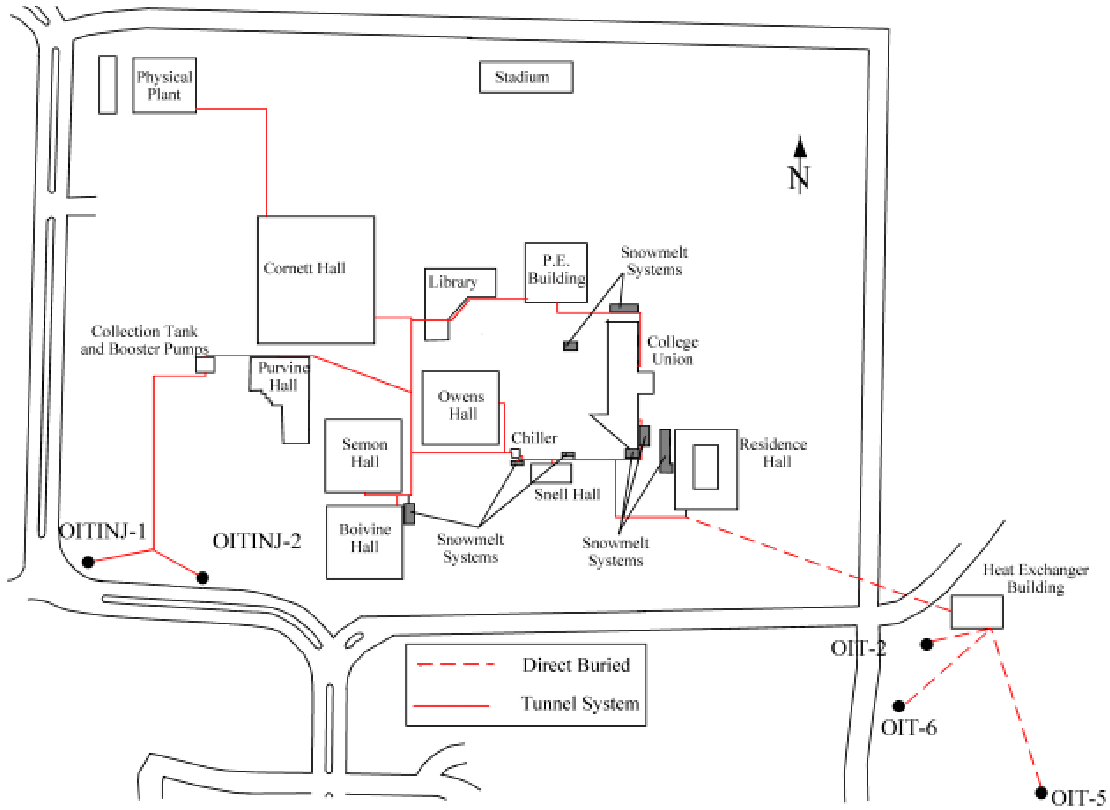
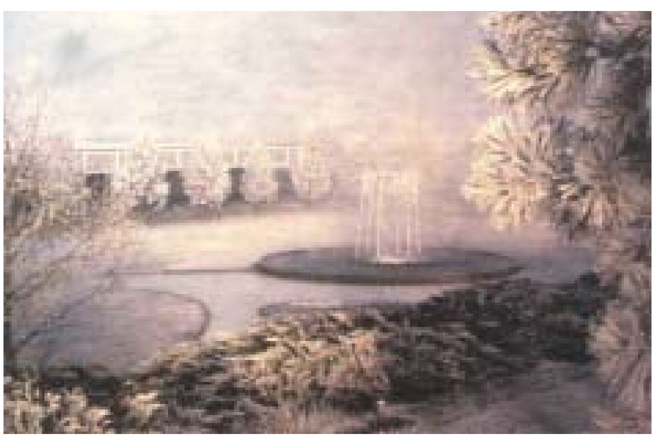
"CHILL OUT" - OREGON INSTITUTE OF TECHNOLOGY IS A WINNER

John W. Lund and Toni Boyd, Geo-Heat Center, Oregon Institute of Technology





OIT's geothermally heated fountain.

The National Wildlife Federation (NWF) hosted the first annual national competition called "Chill Out! Campus Solutions to Global Warming" with their partners, the Earth Day Network, Campus Climate Challenge and the Society for College and University Planning. The nation-wide contest was held throughout the fall and winter of the 2006-2007 school year. The "Chill Out" competition seeks to advance and celebrate the innovators of global warming solutions on college and university campuses all across the country. The purpose of the contest was to spotlight solutions to global warming on campuses and to share these with a national audience. Students, faculty or staff could either submit a short written blurb on the contest entry website or a short video segment on the linked YouTube site. Details on the contest can be found at www.nwf.org/chillout (you can also access the contest through NWF's Campus Ecology website at www.nwf.org/campusecology).

The following is what John Lund submitted to the contest:

"CHILL OUT!
CAMPUS SOLUTIONS TO GLOBAL WARMING"
OREGON INSTITUTE OF TECHNOLOGY
3201 CAMPUS DR.
KLAMATH FALLS, OR 97601

Oregon Institute of Technology, a state college of the Oregon University System, was founded in 1947. Due to high energy costs on the original campus, a new campus was constructed to take advantage of geothermal energy that was known to exist in the community. In the early 1960s, three deep wells were drilled taping geothermal hot water at 192°F (89°C). This hot water now heats the entire campus of about 650,000 sq. ft. (60,000 sq. m) saving about $1,000,000 annually in heating and domestic hot water costs. No other source of energy is available for heating thus; the campus is entirely energy independent of fossil fuel sources. The campus also uses the geothermal energy for melting snow on stairs and handicap ramps. The installed capacity of this system is 6.2 MWt and the annual energy use is about 47 billion Btus (14 GWh), saving 10,000 tonnes of CO_2 emissions annually (compared to producing it from petroleum).

This year, the campus administration is proposing to drill a well (5,000 to 6,000 ft – 1,500 to 1,800 m) deep into a fault that is known to have a geothermal resource around 300˚F (150˚C), to generate electricity. If this is successful, a one megawatt (MWe) geothermal power plant of either a flash steam or binary type will be installed to provide all the electricity needs on campus. This will provide an additional savings of around $500,000 and reduce CO_2 emissions by about 16,000 tonnes annually (compared to producing it from petroleum). The campus would then be 100% "green" by producing all of its energy needs from geothermal resources.

In addition, the campus will construct a geothermally heated greenhouse and aquaculture facility to train interested students and potential developers in the use of geothermal energy for agricultural purposes.

Snow melted stairs.

The Geo-Heat Center was established on campus in 1974 to provided information dissemination and technical assistance for persons and organizations nation-wide and internationally to develop and utilization geothermal energy (website: http://geoheat.oit.edu). The Center staff also provides tours of the campus and community geothermal uses to educate students and interested investors in the benefits of geothermal energy, as well as assisting in the development of the geothermal uses. The proposed power plants, greenhouse and aquaculture facilities will also be used as a training facility and showcase to help transfer geothermal use to other locations throughout the country. Even though, high temperature geothermal energy is generally only available in the western states, the Geo-Heat Center also provides information and training in geothermal (ground-source) heat pumps that can be installed anywhere in the country as they only require normal ground and groundwater temperature to be utilized for both heating and cooling. Our staff of four people has provided technical assistance on geothermal energy use to every state in the Union and well as over 50 countries.

In March 2007, the winning campuses of the contest were notified. In addition to grants and other prizes, winning campuses were to be featured in a national broadcast on the week of Earth Day (on April 18, 2007 at 3:00 eastern). Oregon Institute of Technology was one of the eight winners, and was requested to participate in a live webcast in Washington, D.C. on April 18, 2007. The other winning campus were California State University, Chico; Mount Wachusett Community College, Gardner, Massachusetts; Monmouth, West Long Branch, New Jersey; Richard Stockton College, Somers Point, New Jersey; University of California at Santa Barbara; Oberlin College, Oberlin, Ohio; and Lawrence School, Lawrence, New Jersey.

The National Wildlife Federation video team visited campus in March and filmed an interview with President Martha Anne Dow, Geo-Heat Center Director, John Lund, and Geo-Heat Center Engineer and OIT graduate Toni Boyd. They also filmed various geothermal uses on campus. This short video can be viewed on the National Wildlife Federation website: www.nsf.org/chillout.

The live "Chill Out" webcast which was broadcast to over 160 college campuses throughout the country brought together thousands of college students, faculty and staff to celebrate real and practical solutions to global warming taking places on colleges today. It featured a special message from Al Gore to colleges and universities, the winning campuses and an interactive panel of sustainability heroes.

Toni Boyd, of the Geo-Heat Center, represented the campus at the live webcast in Washington, D.C. on April 18. She participated in one of two panel discussions during the live webcast with the other seven winners.

According to NWF, the nation's over 4,000 colleges and universities manage over 5 billion ft^2 of space and spend approximately $18 billion annually on energy costs and emit more than 19 million metric tons of CO_2 annually. The NWF estimated that the winning schools saved approximately $6 million annually along with eliminating over 20,000 tons (40 million pounds) of CO_2 from the atmosphere. Table 1 shows the conservative estimate made by NFW of CO_2 and cost savings.

Table 1. NWF Estimated CO_2 and Cost Savings

Campus	CO^2 Reduction Annual Tons	Annual Savings
California State University - Chico	100	$100,000
Mt. Wachusett CC	1,909	$500,000
Monmouth University	166	$150,000
Richard Stockton College		$433,500
Oregon Institute of Tech	11,000	$1,000,000
University of California - SB	8,150	$3,700,000
Oberlin College	140	$66,000
Lawrenceville School (HS)	199	
Totals	21,664	$5,949,500

The eight winners and a brief explanation of their written blurb, from NWF website, follow:

California State University—Chico, CA: Chico State has committed to focusing on institutionalizing sustainability into the education of students. Two buildings are registered with LEED, and all new buildings constructed will meet LEED silver requirements. A 300 kW solar array was installed on two campus rooftops. Students have taken the lead to promote sustainability on campus, through projects such as: creating a student fee to fund sustainability projects, retrofitting a residence hall, networking with the Chico community to create sustainability service learning programs, and installing energy saving software on computers.

Mount Wachusett Community College, Gardner, MA: The college conversion of its all-electrical campus to a biomass hydronic district heating system has drastically reduced GHG emissions. This conversion demonstrates the use of a sustainable and locally available feedstock and provided unique educational opportunities for students. This project, along with conservation measures, has resulted in a 24% reduction of GHG over the past four years. MWCC has a cumulative water savings of 12.2 million gallons. By eliminating electricity as a heat source, MWCC has reduced electricity use by 45.97% and saved $2 million. Four new renewable energy courses are in place. The College is coordinating with 11 states to encourage the use of biobased fuels. The College will soon install a 100kW PV array.

Monmouth University, West Long Branch, NJ: The University was just named 2006 New Jersey "Clean Energy School of the Year" after entering a statewide competition. Monmouth completed the largest solar installation east of the Mississippi in summer 2006. The solar panels will save $150,000 and 468,569 kWh/yr. The solar system covers 33,000 ft^2 on roofs of four campus buildings. To engage students, there is a computer generated station that shows energy conservation data in "real time" from the panels. Students were also involved in installing the solar panels.

Richard Stockton College, Somers Point, NJ: Projects include the world's largest closed-loop geothermal heating and cooling system, solar PV arrays, and a 200 kW fuel cell. The geothermal unit reduces the school's electric consumption by 25% and natural gas consumption by 70%. The unit has decreased the college's CO^2 emission by 13% since 1990 and saves the school $330,000 annually. The fuel cell was installed in 2002, and provides 10% of the total energy for the campus. The fuel cell is centrally located on campus and is covered in explanatory diagrams making it a teaching tool for students, faculty, staff and other professionals. The PV array (18kW) saves the college $3,500 a year.

Oregon Institute of Technology, Klamath Falls, OR: Due to the high energy costs on the original campus, a new campus was constructed to take advantage of geothermal energy that was known to exist in the community. In the early 1960s, three deep wells were drilled taping geothermal hot water. This hot water now heats the entire campus of 650,000 sq. ft., saving about $1,000,000 annually in heating and hot water costs. The Geo-Heat Center was established on campus in 1974 to provide information and technical assistance for people and organizations to develop and utilize geothermal energy, while also providing tours to the campus and community. The campus administration is proposing to drill a well into a fault to generate 100% of the campus's electricity and construct a geothermally heated greenhouse and aquaculture facility to train individuals. The proposals will be used as a training facility and showcase. The staff of four people has provided technical assistance on geothermal energy use to every state in the Union as well as over 50 countries.

University of California, Santa Barbara, CA: In 2005, students from the Bren School of Environmental Science and Management created a Master's group project entitled "Campus Climate Neutral" and sought to write their thesis on the feasibility of a carbon-neutral campus. One recommendation of this study was the certification of the campus's CO_2 emissions through the California Climate Action Registry. As a public university dealing with tightening budgets, Facilities began to implement energy conservation. Campus-wide lighting retrofits, motion sensors, efficient chillers, and variable frequencies, and efficient chillers are several projects that USCB initiated, resulting in a reduction of CO_2 by 8,100 tons per year. To educate the campus, Facilities operates sustainability and energy specific websites. In addition, the Green Campus Program runs the "Energy Conservation Competition" in residence halls, pitting halls against one another to lower energy use.

Oberlin College, Oberlin, OH: A group of students and a professor developed the "Campus Resource Monitoring System" (CRMS)—an automated monitoring system and website that gathers, processes and displays data on energy and water use in dormitories. The premise is that real-time data can be used to education, and motivate students to conserve resources. For a two week period in 2005, dorms competed to see who could reduce consumption the most, getting 80% of the student body to participate. During that period, students conserved 68,000 kWh, saving $5,100, and reducing emissions by 150,000 lbs of CO_2. A conservative estimate is that CRMS will save Oberlin $66,000/yr in electricity costs.

The Lawrenceville School (High School), Lawrence, NJ: Students for Environmental Leadership Coalition (SELF) is promoted the Green Cup Challenge, an inter-scholastic energy saving competition between 15 Northeastern boarding schools. Last year was the first year of the Green Cup Challenge, where three schools participated saving 398,370 lbs of CO_2. This year the plans are to increase the program substantially. SELF made a school-wide presentation regarding global warming and events for the month to promote the Challenge. Projects on campus involve a student biodiesel manufacturing group and the beginnings of an organic garden to provide food for a dining hall.

The event and award is certainly an honor for our campus, and was the only submittal featuring direct-use geothermal energy.

CONTINUING ADVANCES IN PEX DOWNHOLE EXCHANGERS FOR DIRECT-USE HEATING APPLICATIONS

Andrew Chiasson, Geo-Heat Center, Oregon Institute of Technology
Ron Swisher, Department of Natural Sciences, Oregon Institute of Technology

INTRODUCTION

Installation and monitoring of the first known cross-linked polyethylene (PEX) downhole heat exchanger (DHE) was described in previous work by Chiasson, et al., (2005). This article describes the second-known PEX DHE installation for direct-use heating applications.

PEX is a material known for its relatively high temperature and pressure rating, durability, and chemical resistance. The PEX DHE described in this article was designed and installed as a retrofit in a geothermal well providing space heating and domestic hot water to two residences in Klamath Falls, OR. The DHE was installed in October 2006, and monitored for one heating season. System temperatures were recorded at 15-minute intervals with a data logger, and no operating problems with the PEX have been encountered since its installation.

BACKGROUND

A DHE is a closed-loop pipe with a "U-bend" at the bottom, and is installed in geothermal wells to provide space heating and domestic hot water. Their most widespread use is in the United States, Turkey, and New Zealand, with less common and/or experimental uses reported in Iceland, Hungary, Russia, Italy, Greece, and Japan. In the United States, the most concentrated uses of DHEs are in Klamath Falls, OR (over 500 installations) and Reno, NV.

The most common construction of DHEs in Klamath Falls has been black iron pipe due to its low cost and availability. However, with the sharp price increases (i.e. more than double) of all metallic piping in the past few years, along with the limited life of metallic piping due to corrosion, PEX DHEs are emerging as an attractive alternative to black iron DHEs. With more suppliers entering the PEX market, PEX costs are decreasing. Another advantage of a PEX DHE is that the installation (and perhaps removal) can be a do-it-yourself project for the homeowner.

THE PEX DHE PROJECT

Project Overview

A homeowner in Klamath Falls, OR decided to replace a leaking DHE in October 2006. The leak was occurring down in the well, and was diagnosed with pressure gauges installed in the piping system. The DHE was constructed of 2-inch nominal diameter black iron pipe, and provided space heat and domestic hot water to two residences with plan areas of 960 ft^2 and 740 ft^2. Each home also has an "unconditioned" basement that is kept warm by the geothermal distribution piping serving the living space.

The space heat in each home is provided by hydronic radiant baseboard finned-tubes. Domestic hot water is provided directly by the DHE, and no hot water storage tanks are used. All the thermal energy is provided by passive thermosiphoning of water in the DHE, and thus no pumping is necessary. Based on field observations and a temperature log of the well by the Geo-Heat Center, the well depth is approximately 140 ft with a static water level of about 100 ft below grade. The average temperature of the water column in the well was measured at about 200°F. The age of the well is uncertain; no well log exists, suggesting that the well was drilled in the 1940s or earlier. An 8-inch steel well casing is visible, which extends to an unknown depth. It had been noted by the homeowner that the black iron DHE did not provide adequate heat on very cold days.

The well is located in a challenging position for DHE removal. The well was originally drilled in a yard to serve a single home, but the second home was subsequently built over the well, and the well was presumably cut down to grade at that time, where it now exists in the basement of the second home. The well is accessible from the ground surface by removing a wooden porch structure at the back door of the newer house, which exists in a completely enclosed backyard. Thus, it is not possible to access the DHE directly by truck, and the DHE had previously been removed (only two years prior) by a manually operated winch. In short, the homeowner sought a longer-term solution to potential frequent replacements of this difficult black iron DHE, and decided to install a PEX DHE.

Removal of the Old Black Iron DHE

As mentioned above, the only way to remove the black iron DHE was with a manually-operated winch. A photograph of the DHE removal process is shown in Figure 1. Figure 2 is a photograph from the basement location of the well, showing heavy scale and corrosion of the black-iron DHE as it is being pulled from the well. Not visible in the photograph are several pinholes that were observed in the black iron pipe, which were the cause of the water leaks.

Installation of the New PEX DHE

The two main design parameters controlling PEX DHE sizing are the length and diameter of the pipe. The length is the most important parameter affecting the overall heat extraction rate from the well, but given the relatively short water column (i.e. 40 ft), it was decided to install the PEX DHE such that it rested on the well bottom. Initially, there was some concern whether the DHE could be reliably installed to the well bottom by hand, but by weighting the DHE with a metallic object and then filling the PEX tubing with water once it had been inserted to the groundwater level in the well, the installation procedure was quite simple.

Two PEX loops of 1-inch nominal diameter pipe were installed. In addition, a single ¾-inch red PEX tube was also installed with the DHE to act as an access tube for well temperature monitoring and also to act as a convection promoter. To promote convection of hot water within the well, the ¾-inch PEX tube was perforated at its lower end and at the level of the water table.

Figure 1. Photograph of removal of old black iron DHE.

Figure 2. Photograph of removal of old black iron DHE, showing heavy scale deposits and corrosion.

Figure 3. Photograph of double u-tube PEX DHE assembly prior to insertion into the well with dark (red) promoter pipe.

Figure 4. Photograph of the completed double u-tube PEX DHE.

A photograph of the entire PEX DHE assembly prior to insertion into the well is shown in Figure 3. The final installation is shown in Figure 4. The entire installation process of the PEX DHE into the well was completed easily in less than an hour with three people.

Performance Monitoring of The New PEX DHE and Operating Experiences

Temperature sensors were installed at the inlet and outlet of the PEX DHE, and were connected to a data logger that was set to record temperatures at 15-minute intervals. Data have been recorded since October 29, 2006. Figure 5 shows the recorded temperatures for January 2007, the coldest month of the monitoring period, along with high and low ambient air temperatures for Klamath Falls, OR as recorded by the National Weather Service.

A review of the temperature data in Figure 5 shows that the DHE supply water temperatures to the houses are relatively stable on average. During cold days when the

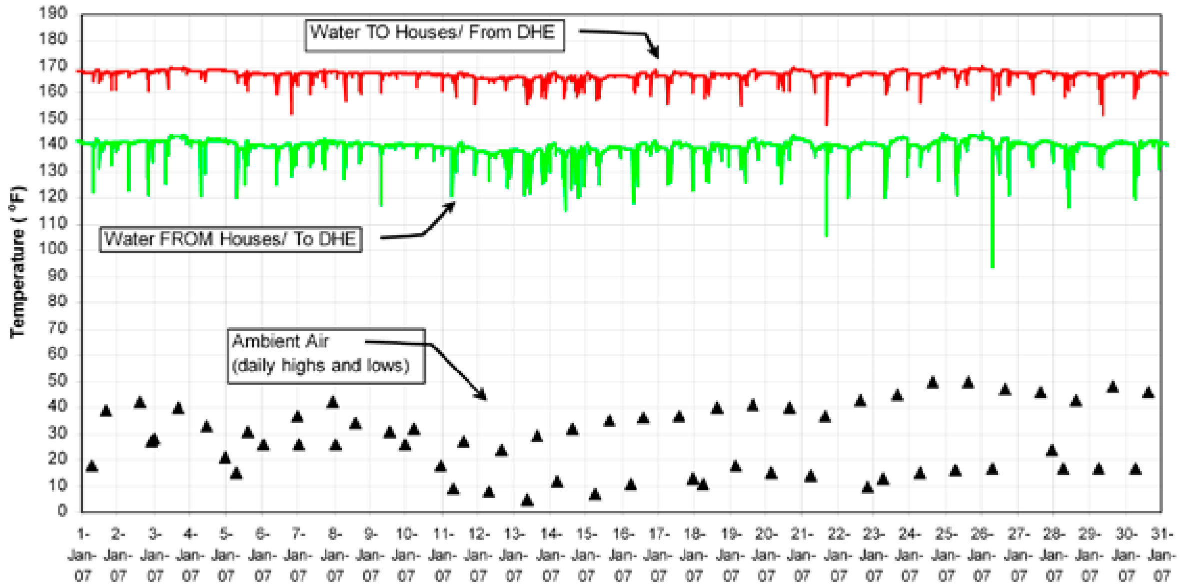


Figure 5. Measured PEX DHE inlet and outlet temperatures (15-minute intervals) along with daily high and low air temperatures for Klamath Falls, OR

outdoor air temperature dropped below 10˚F, the average DHE supply temperature was still above 160˚F. The temperature "spikes" are due to domestic water usage, as cold water from the city water main enters the DHE to be heated up. During the month of January, the lowest supply water temperature of 148˚F was recorded, which occurred during a time of heavy domestic water use. The temperature differential between the DHE supply and return is impressive, averaging about 30˚F throughout the study.

During very cold days, the occupants reported that the space temperature in one home drops to about 60˚F. The previous black iron DHE was also known to provide insufficient heat on cold days. This is actually surprising, given the adequately high supply water temperatures to the houses, and suggests other factors may be responsible for inadequate heat transfer to the home, such as insufficient length of baseboard radiant finned tubes. The homeowner installed more insulation in the attic space, which seemed to help maintain more comfortable space temperatures.

To estimate the useful heat extraction rate from the well during peak heating load, the combined heat losses from both homes (including basement heat losses) are estimated at 85,000 Btu/hr at an indoor-outdoor temperature differential of 52˚F (i.e. 72˚F-20˚F). Below about 20˚F outdoor air temperature, the indoor temperature reportedly begins to drop below 72˚F. With the observed DHE supply/return temperature differential of 30˚F, this means that the water in the DHE is thermosiphoning at 5 to 6 gpm.

UPDATED ECONOMICS OF PEX DHEs

This project has shed more light on the economics of PEX DHEs, rendering the economics previously reported by Chiasson, et al., (2005) outdated. With more market competition due to increased demand for PEX, PEX costs have dramatically decreased in recent years, while metallic piping prices have dramatically increased. As a result, a new PEX DHE is less expensive than an equivalent black iron DHE. Nominal 1-inch PEX can now be purchased for about $1/ft, while the cost of 1½-inch black iron pipe is about $3/ft. Thus, for a double U-tube PEX DHE the cost is about $4/ft as compared to $6/ft for a black iron DHE. Further, as demonstrated with this project, PEX DHE installation can be done by the homeowner, while a black iron DHE needs to be installed with a crane truck and crew at a cost of about $125-$150/hr (in southern Oregon).

CONCLUDING SUMMARY

This article has described installation and monitoring of the second known cross-linked polyethylene (PEX) plastic downhole heat exchanger (DHE) for direct-use heating in a geothermal well. The main differences between this installation described here and the first installation described by Chiasson et al. (2005), are that this second installation serves more than one home and provides domestic hot water in addition to space heating.

The main lessons learned with this second installation were that the PEX DHE can be installed by hand without the need of a crane truck, and that the DHE can be rested on the well bottom. The fact that the DHE can be placed on the well bottom is important because it eliminates tensile stress on the PEX potentially caused when the PEX is suspended in the well. Finally, this project has demonstrated PEX to be a cost-effective alternative to black iron DHEs.

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Oregon Institute of Technology
Klamath Falls, OR 97601-8801

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