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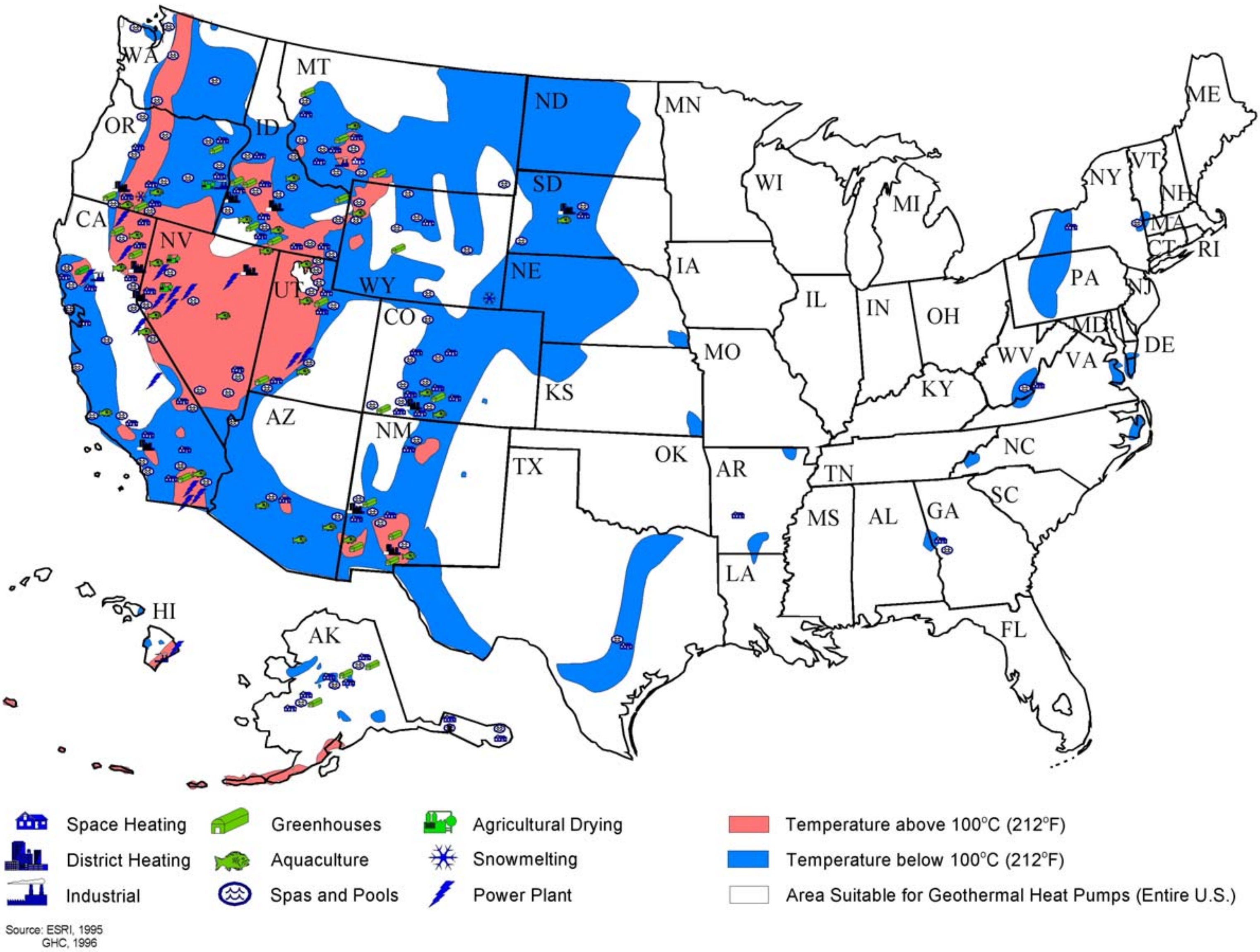
U.S GEOTHERMAL PROJECTS AND RESOURCE AREAS



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

CONTENTS

Cover: The U.S. Geothermal projects and Resources map identifies 23 operating geothermal power plants with a capacity of 2,817 MW and 15 planned power plants. The installed thermal power for direct-use is 1,874 MW including geothermal heat pumps (59%), and the following number of direct-use project sites: 17 district heating, 976 space heating, 38 greenhouses, 28 aquaculture, 12 industrial and 190 resort/spas. In many cases, the icons on the map represent multiple projects at individual sites. For example in Klamath Falls, there are 577 space heating projects and two district heating systems.

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THE ROLE OF GEOTHERMAL ENERGY IN THE WORLD

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INTRODUCTION

Geothermal energy, in the broadest sense, is the natural heat of the earth. Immense amounts of thermal energy are generated and stored in the earth's core, mantle, and crust. The heat is transferred from the interior towards the surface mostly by conduction, and this conductive heat flow makes temperatures rise with increasing depth in the crust on average 25 - 30ºC/km. This is called the geothermal gradient. The recoverable thermal energy theoretically suitable for direct applications has been estimated at 2.9 x 10^{24}> Joules, which is about 10,000 times the present annual world consumption of primary energy without regard to grade (Armstead, 1983). Most of the earth's heat is, however, far too deeply buried to be tapped by man, even under the most optimistic assumptions of technological development. Geothermal energy has at present a considerable economic potential only in areas where thermal water or steam is concentrated at depths less than 3 km (1.9 mi) in restricted volumes analogous to oil in commercial oil reservoirs. The drilling technology is similar for geothermal fluid as for oil. But as the energy content of a barrel of oil is much greater than an equivalent amount of hot water, the economic requirements for permeability of the formations and the productivity of the geothermal wells are much higher than for oil wells. Geothermal production wells are commonly 2 km (1.2 mi) deep, but rarely much over 3 km (1.9 mi) at present.

Exploitable geothermal systems occur in a number of geological environments. High-temperature fields used for conventional power production (with temperature above 150ºC) are largely confined to areas with young volcanism, seismic and magmatic activity. Low-temperature resources can, on the other hand, be found in most countries. They are formed by the deep circulation of meteoric water along the faults and fractures, and by water residing in high-porosity rocks, such as sandstone and limestone at sufficient depths for the water to be heated by the earth's geothermal gradient. Such formations are widespread in all continents, and for example in China, geothermal water can be produced from drillholes in most provinces. The heat resources in hot, but dry, (low porosity) rock formations are found in most countries, but are as yet not economically viable for utilization.

Geothermal utilization is commonly divided into two categories: electricity production and direct application. Conventional electric power production is limited to fluid temperatures above 150ºC, but considerably lower temperatures can be used with the application in binary fluids (outlet temperatures commonly about 70ºC). The ideal inlet temperature into houses for space heating is about 80ºC; but, by application of larger radiators in houses/or the application of heat pumps or auxiliary boilers, thermal water with temperatures only a few degrees above the ambient temperature can be used beneficially. The use of ground-source heat pumps for space heating and space cooling is, for example, expanding at a very fast rate both in the USA and in Europe. The direct utilization of geothermal heat utilizes mostly known technology and straightforward engineering. However, in some cases, the technology is complicated by dissolved solids or gases in the geothermal fluid. The technology, reliability, economics and environmental acceptability of geothermal steam and water has been demonstrated throughout the world.

WORLD DISTRIBUTION OF GEOTHERMAL UTILIZATION

The International Geothermal Association (IGA) was founded in 1989 and has about 2,000 members in all parts of the world. At the World Geothermal Congress (WGC'95) convened by the IGA in Florence (Italy) in May 1995, there were participants from over 70 countries, and country updates were presented from 48 countries. These were summarized by Freeston (1996) and Huttrer (1995). Evaluating available data after the WGC'95, Stefansson (1995) described the status of geothermal development in 83 countries and quantified the use of geothermal energy in 47 of these. He reported the worldwide installed capacity for electricity generation 6,543 MW_e and the installed capacity for direct use 9,047 MW_t. The figures for the produced (or consumed) energy are, however, quite similar. Annually, about 38 TWh are generated in geothermal power plants; whereas, the annual use of direct heat amounts to about 34 TWh (Stefansson, 1995). Table 1 shows the installed capacities and energy production in 1994 (electricity generation and direct use) in the 25 leading geothermal countries around the world (data from Stefansson, 1995).

Electricity is being produced from geothermal resources in 21 countries. There are 15 countries with an installed capacity over 10 MW_e, thereof 6 industrialized countries (total installed capacity 4,088 MW_e, Russia included), and 9 developing countries (total installed capacity 2,441 MW_e). There are 8 countries (4 developing and 4 industrialized) with over 100 MW_e, and 4 with over 500 MW_e installed (Italy 626 MW_e, Mexico 753 MW_e, Philippines 1,051 MW_e, and USA 2,817 MW_e).

Quantified direct use of geothermal resources is known in some 35 countries (Stefansson, 1995). There are 30 countries with an installed capacity of over 10 MW_t, thereof 12

Table 1. Electricity Generation and Direct Use of Geothermal Energy in 1994

	Electricity Generation		Direct Utilization	
	Installed Capacity MW_e	Annual Output GWh	Installed Capacity MW_e	Annual Output GWh
China	28	98	2,143	5,527
Costa Rica	60	447	--	--
El Salvador	105	419	--	--
France	4	24	456	2,006
Georgia	--	--	245	2,136
Hungary	--	--	638	2,795
Iceland	50	265	1,443	5,878
Indonesia	309	1,048	--	--
Italy	626	3,419	308	1,008
Japan	299	1,722	319	1,928
Kenya	45	348	--	--
Macedonia	--	--	70	142
Mexico	753	5,877	28	74
New Zealand	286	2,193	264	1,837
Nicaragua	70	--	--	--
Philippines	1,501	5,470	--	--
Poland	--	--	63	206
Romania	2	--	137	765
Russian Fed.	11	25	210	673
Serbia	--	--	80	600
Slovakia	--	--	100	502
Switzerland	--	--	110	243
Tunisia	--	--	90	788
Turkey	20	68	140	552
USA	2,817	16,491	1,874	3,859
Others	7	40	329	1,935
Total	6,543	37,952	9,047	33,514

industrialized countries (total 4,920 MW_t). There are 13 countries (2 developing, 4 central and eastern European, and 7 industrialized) with over 100 MW_t installed, and 4 countries with over 500 MW_t installed (China 2,143 MW_t, Hungary 638 MW_t, Iceland 1,443 MW_t, and USA 1,874 MW_t).

Based on this, one can generalize by saying that geothermal electricity production is equally common in industrialized and developing countries. Looking at the share of geothermally generated electricity in individual countries, it is clear that geothermal energy plays a much more significant role in the electricity production of the developing countries than the industrialized ones. Good examples of this are El Salvador, Kenya, Nicaragua, and the Philippines. In all of these countries, 10 - 20% of the electricity for the national grid is generated with geothermal steam. Costa Rica is likely to join this group of countries shortly, as Mainieri and Robles (1995) expect some 15% of the electricity of the country to be generated by geothermal in the year 2000. In Mexico, 4.6% of the electricity generated in 1994 was from geothermal (Quijano-Leon and Guiterrez, 1995). Geothermal electricity in Indonesia may reach a similar level (3 - 4%) in the next decade or so (Radja, 1995). Geothermal electricity is unlikely to be of equal significance for the energy sector of individual industrialized countries due to the high-electricity consumption per capita in these countries and the lack of sufficient geothermal resources. The only present exception to this statement is Iceland, where 5% of the electricity is being produced from geothermal (the remaining 95% by hydro).

The world distribution of direct utilization is different. With the exception of China, the direct utilization is a serious business mainly in the industrialized, and central and eastern European countries. This is to some extent understandable, as most of these countries have cold winters where a significant share of the overall energy budget is related to space heating. Furthermore, in many industrialized countries, the sun is not reliable for drying. Space heating is the dominant type of direct use (34%) of geothermal; but, other common types are bathing (14%), greenhouses (14%), heat pumps (13%) for air cooling and heating, fish farming (9%), and industry (9%). Freeston (1996), in his refined summary of the country updates of the WGC'95, states that it is evident from the papers that there is a large potential for the development of low-to-moderate enthalpy direct use across the world which is not being exploited due to financial constraints and low prices of competing forms of energy. The main potential for direct utilization in the developing countries is at present mainly in various drying processes (fruits, fish, etc.). Space cooling with geothermal energy will hopefully become an important sector for geothermal utilization in the future.

Electric generation cost with geothermal energy is commonly around 4 US cents/kWh. The production cost/kWh for direct utilization (space heating, horticulture, fish farming, industry, bathing, etc.) is highly variable, but commonly under 2 US cents/kWh.

Utilization of geothermal resources to supply electricity and direct heat is energy efficient and competitive with other energy sources both in terms of the economics and the thermodynamic efficiency. The cascade use of the thermal fluid, whereby the high-enthalpy fluid is used for electricity generation and the lower temperature fluid is passed through a series of different uses, is practiced in many countries (e.g., Iceland, Italy and Japan) raising the overall efficiency. There is also the prospect of extracting a number of valuable minerals from the thermal fluids. This is also done in an energy efficient manner.

COMPARISON WITH OTHER "NEW AND RENEWABLES"

Table 2 is compiled from the Survey of Energy Resources 1995 published by the World Energy Council in conjunction with the 16th World Energy Congress in Tokyo. Since the detailed data on the different energy resources and their application is given in the same units, the survey gives a good opportunity to compare the development of the different energy resources. The table shows the installed capacity (MW-electric) and the electricity production per year (GWh/y) for geothermal, wind, solar and tidal resources.

In comparison with wind, solar and tidal energy, geothermal is clearly an advanced energy source with 61% of the total installed capacity and 86% of the total electricity production of these four sources. The relatively high share in the electricity production reflects the reliability of geothermal plants which commonly have a load factor and availability factor of 80 - 90%. This demonstrates one of the strongest comparative points of geothermal energy (i.e., that it is available day in and day out throughout the year). It is not dependent on whether it is day or night as solar energy is, or whether the wind blows strongly or not. It has an inherent storage capability and can be used both for base load and peak power plants. However, in most cases, it is more economical to run the geothermal plants as base-load suppliers; but, turning the plants off during the rainy season, when hydropower plants have plenty of water, will in many cases serve to replenish the geothermal reservoir and lengthen its economically useful lifetime.

Table 2. Electricity From Four Energy Resources in 1994

	Installed Capacity		Production Per Year	
	MWe	%	GWh/y	%
Geothermal	6,456	61	37,976	86
Wind	3,517	33	4,878	11
Solar	366	3	897	2
Tidal	261	3	601	1
Total	10,600		44,352	

Source: WEC Survey of Energy Resources (WEC, 1995).

The question of geothermal resources being renewable can be debated. Due to the steady heat flow from the inner parts of the earth, geothermal resources can be regarded as renewable. But on the time scale normally used in human society, geothermal resources are not renewable. They are renewable only if the heat extraction rate does not exceed the replenishment rate. But the same can be said for fuel wood and many types of biomass. The tree that you burn is not renewable. It turns into energy, ash and gases; but, you can grow a new tree, given enough time. A geothermal system can in many cases be recharged as a battery.

Utilizing the natural flow from geothermal springs does not affect them. Exploitation through drill holes and by the application of downhole pumps nearly always leads to some physical or chemical changes in the reservoir and/or its near vicinity which lead to a reduction and may lead to the depletion of the geothermal resource so far as a particular energy utility is concerned. The key to a successful geothermal project is to secure by careful reservoir evaluation and monitoring that the geothermal reservoir will last through the lifetime (or at least the depreciation time) of the respective geothermal installations.

Fridleifsson and Freeston (1994) referred to geothermal resources as being sustainable resources, where by careful matching of utilization with field performance, the enthalpy, temperature, mass removed, reservoir pressure, etc., can achieve an equilibrium and performance can be maintained, at least over the life of the mechanical plant. This may mean that the initial performance of a plant may exceed the equilibrium condition and as the field is developed and utilized, a run down occurs in these parameters down to the equilibrium condition. Each field is likely to be unique in this respect, and its performance will depend on many factors, including the amount and quantity of the recharge if any, whether there is reinjection and where it is sited relative to the production zone, reservoir characteristics of permeability, porosity, temperature, etc.

Properly implemented, geothermal energy is a sustainable resource and benign to the environment. The emission of greenhouse gases is minimal compared to fossil fuel. The removal of hydrogen sulphide from high-temperature steam and the reinjection of spent geothermal fluids into the ground make the potential negative environmental effects negligible.

INVESTMENTS AND FUTURE DEVELOPMENT

At least 80 countries are potentially interested in geothermal energy development. Of these, some 50 have quantifiable geothermal utilization at present. A worldwide survey (Fridleifsson and Freeston, 1994) showed the total investments in geothermal energy during 1973-1992 to amount to approximately US $22 billion. During the two decades, 30 countries invested each over US $20 million, 12 countries over US $200 million, and 5 countries over US $1 billion. During the first decade, 1973-1982, public funding amounted to US $4.6 billion and private funding to US $3 billion. During the second decade, 1983-1992, public funding amounted to US $6.6 billion and private funding to US $7.7 billion. It is of special interest to note that the private investments in geothermal rose by 160%; whereas, the public investments rose by 43% for the period 1983-1992 as compared to 1973-1982 respectively. This shows the confidence of private enterprises in this energy source and demonstrates that geothermal energy is commercially viable.

The growth rate of geothermal development has in the past been significantly affected by the prices of the competing fuels, especially oil and natural gas, on the world market. As long as the oil and gas prices stay at the present level, it is rather unlikely that we will see again the very high annual growth rate for geothermal electricity of 17% as was the case during the oil crises in 1978-1985. The growth rate is, however, quite high due to the fact that geothermally generated electricity is the lowest cost option for many countries. In 1990, there were about 5,800 MW_e operational in electric power plants in the world, and about 6,800 MW_e in 1995. This gives a growth of about 16% over the period. The WGC'95 country reports summarized by Huttrer (1995) indicate that the world installed capacity may rise to some 10,000 MW_e by the year 2000. The present author, however, finds the figure likely to become closer to 8,500 MW_e with the largest additions (already planned or under construction) in the Philippines, Indonesia, Mexico, and Costa Rica. The participation of private operators in steam field developments through BOT (Build, Operate and Transfer), BOO (Build, Own and Operate) contracts and JOC (Joint Operation Contracts) have significantly increased the speed of geothermal development in countries such as the Philippines (Javeliana, et al., 1995) and Indonesia (Radja, 1995).

For the direct applications, the growth rate situation is more speculative at present, but again, highly affected by the competing prices of oil and gas on the world market. The large potential and the growing interest for the development of direct applications in China for fish farming, greenhouses and municipal space heating, and the great surge of installations of geothermal heat pumps in recent years exemplified by the USA, Switzerland, etc., give a cause for optimism for the growth rate of direct applications. This growth rate should perhaps be expected to be higher than that for electric generation, both because low-temperature geothermal resources are available in a much greater number of countries, and because direct application projects tend to be less capital intensive than the electric development. But private enterprise has, as yet, focussed more on electricity production for the national grids than on direct utilization which is commonly more site specific.

The introduction of CO_2 and other pollution taxes would significantly benefit geothermal development, as geothermal is one of the cleanest energy sources available on the world market. This may have an effect on the development rate. Such an effect is clearly seen from the financial incentive schemes recently introduced by several electric utilities in the USA encouraging house owners to use groundwater heat pumps for space cooling/heating purposes, and thus, reduce the peak loads on their electric systems. The Geothermal Heat Pump Consortium has recently established a US $100-million 6-year program to increase the geothermal heat pump unit sales from 40,000 to 400,000 annually, and thus, reduce greenhouse gas emissions by 1.5 million metric tonnes of carbon equivalent annually (Pratsch, 1996). One-third of the funding comes from the U.S. Department of Energy and the Environmental Protection Agency; whereas, two-thirds come from the electric power industry. The same type of development might be seen in other parts of the world in the next decade or two.

Geothermal exploration and exploitation requires skills from many scientific and engineering disciplines. Significant experience in geothermal exploration and development is available in some 30 countries (Fridleifsson, 1995). But the man-power resources are unevenly distributed in the world. A large number of geothermal experts have become redundant in several of the industrialized countries since the mid-1980s, and turned to other work. The developing countries have kept relatively more of their experts in geothermal work. Several developing countries have built up strong groups of geothermal professionals. Many of the key people of these groups have received training at the international geothermal schools operated in Iceland, Italy, Japan and New Zealand; but, most of the training has taken place on the job in the respective countries. The international geothermal schools have less than 60-fully funded places each year. More training is needed for people from many developing countries and the countries of central and eastern Europe at both professional and technician levels. In addition to long and short courses at the international schools, regional courses and specialized courses traveling from country to country should be considered. Many of these countries have completed initial surveys, and in some cases, have started utilization projects of their geothermal resources, and are at a stage of wishing to develop the resources using up-to-date technology. They are, however, handicapped both by the lack of finance and an infrastructure of trained personnel.

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DIRECT HEAT UTILIZATION OF GEOTHERMAL RESOURCES

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INTRODUCTION

Direct or non-electric utilization of geothermal energy refers to the immediate use of the heat energy rather than to its conversion to some other form such as electrical energy. The primary forms of direct use include swimming, bathing and balneology (therapeutic use), space heating and cooling including district heating, agriculture (mainly greenhouse heating and some animal husbandry), aquaculture (mainly fish pond and raceway heating), industrial processes, and heat pumps (for both heating and cooling). In general, the geothermal fluid temperatures required for direct heat use are lower than those for economic electric power generation.

Most direct use applications use geothermal fluids in the low-to-moderate temperature range between 50 and 150ºC, and in general, the reservoir can be exploited by conventional water well drilling equipment. Low-temperature systems are also more widespread than high-temperature systems (above 150ºC), so they are more likely to be located near potential users. In the U.S., for example, of the 1,350 known or identified geothermal systems, 5% are above 150ºC, and 85% are below 90ºC (Muffler, 1979). In fact, almost every country in the world has some low-temperature systems; while, only a few have accessible high-temperature systems.

Traditionally, direct use of geothermal energy has been on a small scale by individuals. More recent developments involve large-scale projects, such as district heating (Iceland and France), greenhouse complexes (Hungary and Russia), or major industrial use (New Zealand and the U.S.). Heat exchangers are also becoming more efficient and better adapted to geothermal projects, allowing use of lower temperature water and highly saline fluids. Heat pumps utilizing very low-temperature fluids have extended geothermal developments into traditionally non-geothermal countries such as France, Switzerland and Sweden, as well as areas of the midwestern and eastern U.S. Most equipment used in this project is of standard, off-the-shelf design and need only slight modifications to handle geothermal fluids (Gudmundsson and Lund, 1985).

Worldwide, the installed capacity of direct geothermal utilization is 9,047 MW_t and the energy use is about 120,000 TJ/yr (33,514 GWh/yr) distributed among 38 countries. This amounts to saving an equivalent 3.65 million tonnes of fuel oil per year (TOE). The distribution of the energy use among the various types of use is shown in Figure 1 for the entire world and, for comparison, the U.S. The installed capacity in the U.S. is 1,875 MW_t and the annual energy use is 13,890 TJ

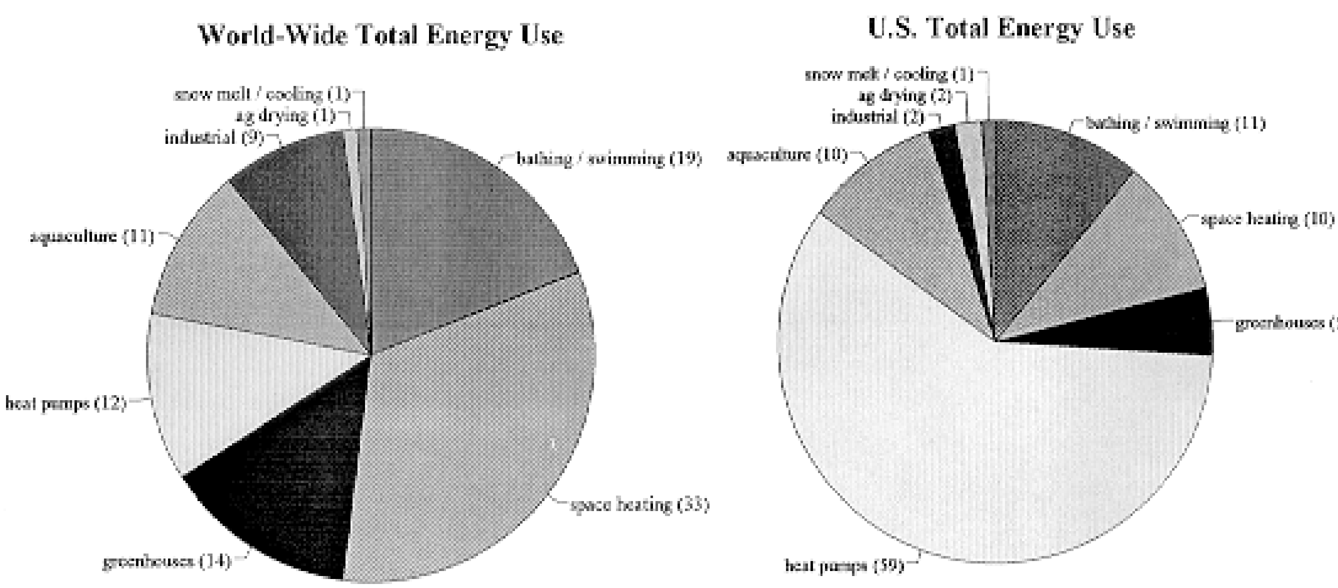

Figure 1. Distribution of geothermal energy use in the world and the U.S.

(3,860 GWh), saving 0.47 million TOE (Lienau, et al., 1995). Internationally, the largest uses are for space heating (33%) (3/4 of which is due to district heating), and for swimming, bathing and balneology (19%); whereas, in the U.S.. the largest use is for geothermal heat pumps (59%). In comparison, Iceland's largest geothermal energy use is 74% for space heating (4,530 GWh/yr)--primarily with district heating system (Ragnarsson, 1995). The worldwide use data is based on Freeston (1996), but have been modified according to Freeston (1990), country update reports from the World Geothermal Congress (1995), and the author's personal experience.

The Lindal diagram (Gudmundsson, et al., 1985), named for Baldur Lindal, the Icelandic engineer who first proposed it, indicates the temperature range suitable for various direct use activities (Figure 2). Typically, the agricultural and aquacultural uses require the lowest temperatures, with values from 25 to 90°C. The amounts and types of chemicals such as arsenic and dissolved gases such as boron, are a major problem with plants and animals; thus, heat exchangers are often necessary. Space heating requires temperatures in the range of 50 to 100°C, with 40°C useful in some marginal cases and ground-source heat pumps extending the range down to 4°C. Cooling and industrial processing normally require temperatures over 100°C. The leading user of geothermal energy, in terms of market penetration is Iceland, where more than 85% of the population enjoys geothermal heat in their homes from 27 municipal district heating services, and 44% of the country's total energy use is supplied by direct heat and electrical energy derived from geothermal resources (Ragnarsson, 1995).

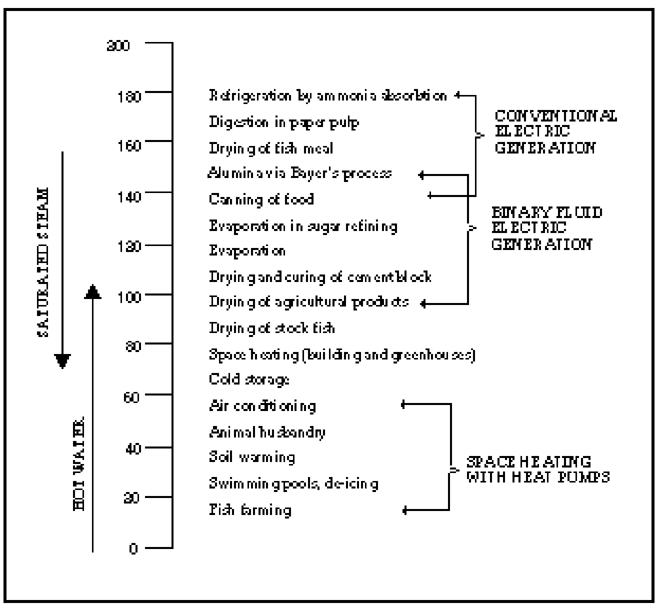

Figure 2. Lindal diagram.

Swimming, Bathing and Balneology

Romans, Chinese, Ottomans, Japanese and central Europeans have bathed in geothermal waters for centuries. Today, more than 2,200 hot springs resorts in Japan draw 100 million guests every year, and the "return-to-nature" movement in the U.S. has revitalized many hot springs resorts.

The geothermal water at Xiaotangshan Sanitarium, north-west of Bejing, China, has been used for medical purposes for over 500 years. Today, the 50°C water is used to treat high-blood pressure, rheumatism, skin disease, diseases of the nervous system, ulcers, and generally for recuperation after surgery. In Rotorua, New Zealand at the center of the Taupo Volcanic Zone of North Island, the Queen Elizabeth Hospital was built during World War II for U.S. servicemen and later became the national hospital for the treatment of rheumatic disease. The hospital has 2000 beds, and outpatient service, and a cerebral palsy unit. Both acidic and basic heated mud baths treat rheumatic diseases.

In Beppu, on the southern island of Kyushu, Japan, the hot water and steam meet many needs: heating, bathing, cooking, industrial operations, agriculture research, physical therapy, recreational bathing, and even a small zoo (Taguchi, et al., 1996). The waters are promoted for "digestive system troubles, nervous troubles, and skin troubles." Many sick and crippled people come to Beppu for rehabilitation and physical therapy. There are also eight Jigokus ("burning hells") in town showing various geothermal phenomena, used as tourist attractions.

In the former Czechoslovakia, the use of thermal waters has been traced back before the occupation of the Romans and has had a recorded use of almost 1,000 years. Today, there are 60 spa resorts located mainly in Slovakia, visited by 460,000 patients usually for an average of three weeks each. These spas have old and well-established therapeutic traditions. Depending on the chemical composition of the mineral waters and spring gas, availability of peat and sulfurous mud, and climatic conditions, each sanitarium is designated for the treatment of specific diseases. The therapeutic successes of these spas are based on centuries of healing tradition (balneology), systematically supplemented by the latest discoveries of modern medical science.

Bathing and therapeutic sites in the U.S. include: Saratoga Springs, New York; Warm Springs, Georgia; Hot Springs, Virginia; White Sulfur Springs, West Virginia; Hot Springs, Arkansas; Thermopolis, Wyoming and Calistoga, California. The original use of these sites were by Indians, where they bathed and recuperated from battle. There are over 190 major geothermal spas in the U.S. with an annual energy use of 1,600 TJ (Lienau, 1995).

Space Conditioning

Space conditioning includes both heating and cooling. Space heating with geothermal energy has widespread application, especially on an individual basis. Buildings heated from individual wells are popular in Klamath Falls, Oregon; Reno, Nevada, and Taupo and Rotorua, New Zealand. Absorption space cooling with geothermal energy has not been popular because of the high-temperature requirements and low efficiency. Geothermal heat pumps (groundwater and ground-coupled) have become popular in the U.S. and Switzerland, used for both heating and cooling.

An example of space heating and cooling with low-to-moderate temperature geothermal energy is the Oregon Institute of Technology in Klamath Falls, Oregon. Here, 11 buildings, approximately 62,000 square meters of floor space, are heated with water from three wells at 89°C. Up to 62 L/s of fluid can be provided to the campus, with the average heat utilization rate over 0.53 MW_t and the peak at 5.6 MW_t. In addition, a 541 kW (154 tons) chiller requiring up to 38 L/s of geothermal fluid produces 23 L/s of chilled fluid at 7°C to meet the campus cooling base load.

District Heating

District heating originates from a central location, and supplies hot water or steam through a network of pipes to individual dwellings or blocks of buildings. The heat is used for space heating and cooling, domestic water heating, and industrial process heat. A geothermal well field is the primary source of heat; however, depending on the temperature, the district may be a hybrid system, which would include fossil fuel and/or heat pump peaking.

Geothermal district heating systems are in operation in at least 12 countries, including Iceland, France, Poland, Hungary, Turkey, Japan and the U.S. The Warm Springs Avenue project in Boise, Idaho, dating back to 1892 and originally heated more than 400 homes, is the earliest formal project in the U.S. The Reykjavik, Iceland, district heating system is probably the most famous. This system supplies heat for a population of around 145,000 people. The installed capacity of 640 MW_t is designed to meet the heating load to about -10°C; however, during colder periods, the increased load is met by large storage tanks and an oil-fired booster station.

In France, production wells in sedimentary basins provide direct heat to more than 500,000 people from 40 projects. These wells provide from 40 to 100 L/s of 60 to 100°C water from depths of 1,500 to 2,000 m. In the Paris basin, a doublet system (one production and one injection well) provides 70°C water, with the peak load met by heat pumps and conventional fossil fuel burners.

Agribusiness Applications

Agribusiness applications (agriculture and aquaculture) are particularly attractive because they require heating at the lower end of the temperature range where there is an abundance of geothermal resources. Use of waste heat or the cascading of geothermal energy also has excellent possibilities. A number of agribusiness applications can be considered: greenhouse heating, aquaculture, animal husbandry, soil warming and irrigation, mushroom culture, and biogas generation.

Numerous commercially marketable crops have been raised in geothermally-heated greenhouses in Hungary, Russia, New Zealand, Japan, Iceland, China and the U.S. These include vegetables, such as cucumbers and tomatoes, flowers (both potted and bedded), house plants, tree seedlings, and cacti. Using geothermal energy for heating reduces operating costs (which can account for 35% of the product cost) and allows operation in colder climates where commercial greenhouses would not normally be economical.

The use of geothermal energy for raising catfish, shrimp, tilapia, eels, and tropical fish has produced crops faster than by conventional solar heating. Using geothermal heat allows better control of pond temperature, thus optimizing growth. Fish breeding has been successful in Japan, China and the U.S. A very successful prawn raising operation, producing 400 tonnes of Giant Malaysian freshwater prawns per year at U.S. $17 to 27/kg, has been developed near the Wairakei geothermal field in New Zealand (Lund and Klein, 1995). The most important factors to consider are the quality of the water and disease. If geothermal water is used directly, concentrations of dissolved heavy metals (fluorides, chlorides, arsenic, and boron) must be considered.

Livestock raising facilities can encourage the growth of domestic animals by a controlled heating and cooling environment. An indoor facility can lower mortality rate of newborn, enhance growth rates, control disease, increase litter size, make waste management and collection easier, and in most cases, improve the quality of the product. Geothermal fluids can also be used for cleaning, sanitizing and drying of animal shelters and waste, as well as assisting in the production of biogas from the waste.

Industrial Applications

Although the Lindal diagram shows many potential industrial and process applications of geothermal energy, the world's uses are relatively few. The oldest industrial use is at Larderello, Italy, where boric acid and other borate compounds have been extracted from geothermal brines since 1790. Today, the two largest industrial uses are the diatomaceous earth drying plant in northern Iceland, and a pulp, paper and wood processing plant at Kawerau, New Zealand. Notable U.S. examples are two onion dehydration plants in northern Nevada (Lund, 1995), and a sewage digestion facility in San Bernardino, California. Alcohol fuel production has been attempted in the U.S.; however, the economics were marginal and thus, this industry has not been successful.

Drying and dehydration are important moderate-temperature uses of geothermal energy. Various vegetable and fruit products are feasible with continuous belt conveyors or batch (truck) dryers with air temperatures from 40 to 100°C. Geothermally drying alfalfa, onions, pears, apples and seaweed are examples of this type of direct use. A new development in the use of geothermal fluids is for enhanced heat leaching of precious metals in Nevada by applying heat to the cyanide process (Trexler, et al., 1990). Using geothermal energy increases the efficiency of the process and extends the production into the winter months.

ECONOMIC CONSIDERATIONS

Geothermal projects require a relatively large initial capital investment, with small annual operating costs thereafter. Thus, a district heating project, including production wells, pipelines, heat exchangers, and injection wells, may cost several million dollars. By contrast, the initial investment in a fossil fuel system includes only the cost of a central boiler and distribution lines. The annual operation and maintenance costs for the two systems are similar, except that the fossil fuel system may continue to pay for fuel at an ever-increasing rate; while, the cost of geothermal fluid is stable. The two systems, one with a high-initial capital cost and the other with high-annual costs, must be compared.

Geothermal resources fill many needs: power generation, space heating, greenhouse heating, industrial processing, and bathing to name a few. Considered individually, however, some of the uses may not promise an attractive return on investment because of the high-initial capital cost. Thus, we may have to consider using a geothermal fluid several times to maximize benefits. This multi-stage utilization, where lower and lower water temperatures are used in successive steps, is called cascading or waste heat utilization. A simple form of cascading employs waste heat from a power plant for direct use projects.

Geothermal cascading has been proposed and successfully attempted on a limited scale throughout the world. In Rotorua, New Zealand, for example, after geothermal water and steam heat a home, the owner will often use the waste heat for a backyard swimming pool and steam cooker. At the Otake geothermal power plant in Japan, about 165 tonnes per hour of hot water flows to downstream communities for space heating, greenhouses, baths and cooling. In Sapporo, Hokkaido, Japan, the waste water from the pavement snow melting system is retained at 65°C and reused for bathing.

Recent international data (Freeston, 1996) gives US $270/kW of installed capacity for all projects reported, with a range from US $40 to US $1880/kW. In the U.S., the annual operation and maintenance cost is estimated at 5% of the installed cost.

FUTURE DEVELOPMENT

There appears to be a large potential for the development of low-to-moderate enthalpy geothermal direct use across the world which is not currently being exploited due to financial constraints and the low price of competing energy sources. Given the right environment, and as gas and oil supplies dwindle, the use of geothermal energy will provide a competitive, viable and economic alternative source of renewable energy. Future development will most likely occur under the following conditions:

1. Collocated resource and uses (within 10 km apart),
2. Sites with high heat and cooling load density (>36 MWt/sq km),
3. Food and grain dehydration (especially in tropical countries where spoilage is common),
4. Greenhouses in colder climates,
5. Aquaculture to optimize growth--even in warm climates, and
6. Ground-coupled and groundwater heat pump installations both for heating and cooling).

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SELECTED COST CONSIDERATIONS FOR GEOTHERMAL DISTRICT HEATING IN EXISTING SINGLE-FAMILY RESIDENTIAL AREAS

Kevin Rafferty
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INTRODUCTION

District heating in existing single-family residential areas has long been considered to be uneconomical due to the low heating load density. In comparison to the typical downtown business districts load density is low; however, there are some characteristics of residential areas which could serve to enhance the economics of district heating.

Among these are:

- Wide variety of heating fuels (and costs) which can result in a range of conventional heating costs of 3 or more to 1 for the same heating load density,
- Availability of unpaved areas for installation of the distribution system,
- Fewer utilities in the pipeline corridor,
- Less traffic control requirements during construction,
- Potential for the use of uninsulated piping, and
- Older, poorly insulated structures with high energy use.

In addition to these considerations, the Geo-Heat Center has recently completed work which identified 271 western U.S. population centers which are collocated with geothermal resources of greater than 50°C. In many of these sites, due to the absence of industrial facilities, district heating would be the most useful application of the resource.

With these factors in mind, this report explores some of the issues related to costs involved in the installation of geothermal district heating (GDH) in existing single-family residential areas.

Using an actual residential area as an example, individual sections of the report examine:

- Distribution piping costs and potential savings areas,
- Central plant vs. individual-home heat exchangers,
- Customer branch lines costs, and
- Current conventional heating costs vs. district system debt service revenue requirements.

DISTRIBUTION PIPING

In order to evaluate the opportunities for cost reductions in distribution piping, it is first necessary to determine the costs associated with conventional construction. To accomplish this, costs from the most recent GDH construction (Klamath Falls city district system line extensions) were used as the basis for conventional construction.

Recent line extensions on this system and others have been of the 6" size and employed preinsulated ductile iron material. Previous work (Rafferty, 1990b) has identified this material as being the least expensive alternative among the preinsulated options for this type of application.

Bids on the recent Klamath Falls work are not broken down by task. As a result, costs for similar installation were calculated using vendor quotes and standard industry estimating handbooks (Means, 1995, 1996). The results of this comparison were quite close (calculated cost $94.51 per foot, actual construction $100 per foot) with the calculated cost slightly less than the actual construction costs. This difference may be attributable to the relatively short length of the extensions compared to the size of a complete system. As a result of the close agreement, the same calculation method was used to develop costs for other line sizes in the 3" to 12" range. These calculations were then compared to the actual bid figures.

Costs for installation of preinsulated distribution piping were broken down into 11 categories: saw cutting of existing pavement, removal of pavement and trench spoils, hauling of pipe (local), trenching and backfill, pipe material, bedding, installation and connection of piping, valves, fittings, traffic control, and paving. Table 1 provides a summary of the current base case costs for installation of preinsulated ductile iron piping.

Figure 1 presents this data in the form of percentages for 6-inch pipe size. The distribution of the costs is fairly stable over the range of pipe sizes. Costs for the pipe and installation constitute a somewhat higher percentage at the upper end of the size range; but, the difference is not significant (50.2% @ 3", 56.9% @ 12").

Table 1. Base Case Cost Summary - Ductile Iron Distribution Piping

	Line Size (Supply and Return)					
	3"	4"	6"	8"	10"	12"
Cut	4.12	4.12	4.12	4.12	4.12	4.12
Remove	2.20	2.20	2.57	2.57	2.90	2.90
Haul	0.71	0.71	0.83	1.14	1.37	1.71
Trench and Backfill	8.83	8.83	10.01	10.01	16.31	16.31
Bed	2.57	2.65	3.84	3.87	3.98	4.06
Pipe (pre-insulated)	27.18	30.75	34.23	45.48	57.63	64.41
Install	10.68	12.53	14.38	22.31	26.45	33.00
Fittings	3.00	3.00	4.17	6.02	8.60	11.15
Valves	1.95	1.95	2.73	4.07	6.13	9.23
Thrust Blocks	0.37	0.37	1.22	2.81	4.44	6.22
Traffic	3.09	3.43	3.93	4.58	5.50	6.87
Repave	10.66	10.66	12.48	12.48	14.08	14.08
Total	75.36	81.20	94.51	119.46	151.51	174.06

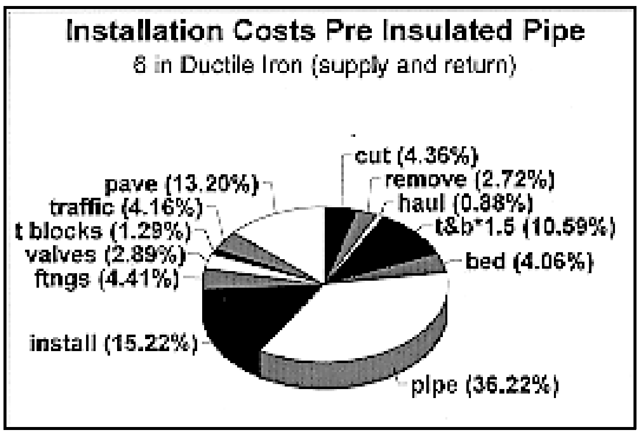

Figure 1.

Potential Cost Reduction

Figure 2 presents a simplified representation of installation costs (6") using only five cost categories. The three largest cost categories, and hence, largest potential areas for cost reduction are: pipe and installation, trenching and backfilling, and pavement related costs.

It is clear that installation in unpaved areas holds the potential of substantial (20%) cost reduction. In downtown business areas, the prospects for installation in unpaved areas is small. In residential areas, however, particularly areas developed prior to the 1960s, it is not uncommon to find unpaved alley ways between each block. Installation of distribution lines in these areas could, depending upon the line size, reduce per foot costs by 12% (12") to 22% (3"). In addition to these savings, it is possible that unpaved areas may not require the level of traffic control assumed for the downtown area in the basic cost calculations. If traffic control can be completely eliminated (such as closing the area during construction), a savings of approximately 4% could be realized.

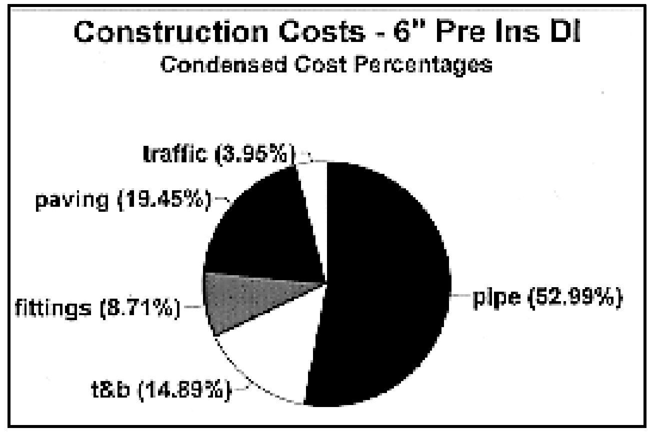

Figure 2.

In the area of trenching and backfilling, there is a small opportunity for cost reduction if the pipeline corridor is free of existing utilities. The costs shown in Table 1 for trenching and backfilling, incorporate a 50% cost penalty for working around existing utilities. It is unlikely, even in residential areas to find a pipeline corridor completely free of obstruction; however, the potential exists for savings, in the 6" size, of up to 3.5% of per foot costs. The savings ranges from 3.9% @ 3" pipe size to 3.1% at the 12" size.

The largest portion of the installed cost is related to the piping itself. The costs for pipe material, hauling, and installation amount to approximately 50% of total costs over the range of piping size (3" through 12") considered in this study. As a result, this area should offer the potential for savings.

Previous work (Rafferty, 1990a; Rafferty, 1989a) has identified preinsulated ductile iron as the lowest cost alternative to the previously used asbestos cement material. As a result, the opportunity to reduce costs through the use of an alternate preinsulated product is unlikely. In some cases, however, it may be possible to reduce costs by using uninsulated piping for distribution.

Due to corrosion considerations, any uninsulated piping would have to be of non-metallic construction. Uninsulated metallic piping operating at temperatures in the 120°F range can experience excessive exterior corrosion due to exposure to soil moisture.

Commercially available non-metallic materials suitable for the application include: fiberglass and CPVC piping. Cross-linked polyethylene (PEX) is a product which is suitable for the temperature and pressures employed in district heating. It is a European product and its availability in this country is limited to preinsulated products in the 4" and smaller nominal size range.

Table 2 presents cost data on uninsulated epoxy adhesive fiberglass piping compared to preinsulated ductile iron.

Table 2. Savings - Uninsulated Fiberglass Return Line

Size	FG Pipe Material	Labor & Joining Materials	Total	Preinsulated DI	$/ft Savings	% Savings
3	9.21	2.39	11.60	18.93	7.33	9.7
4	11.28	3.14	14.42	21.64	7.22	8.9
6	16.56	5.00	21.56	24.30	2.74	2.9
8	27.60	7.05	34.65	33.89	- 0.76	- 0.6
10	40.98	9.89	50.87	42.04	-8.83	- 5.8
12	52.61	12.17	64.78	48.71	-16.07	- 9.2

Notes: Fiberglass piping as per vendor quote +25% O&P. Labor and material for joining epoxy adhesive type fiberglass, includes savings of $0.335/ft (3") and $0.035/ft (4") for elimination of thrust blocks and lower cost fiberglass fittings. Savings percentage indexed to base cost per foot (return line only) in Table 1.

The table assumes the use of only an uninsulated return line. It is also possible to use uninsulated supply; however, the savings of this approach are reduced due to the requirement for installation of temperature-maintenance control valves at strategic points on the system to assure adequate supply temperature to customers. When the control valve costs are deducted from the piping cost savings, the results are marginal to negative. A similar comparison for CPVC piping was made but cost for this material actually exceeded the preinsulated ductile iron costs.

Figure 3 presents a summary of distribution piping costs on a per foot basis for sizes 3" through 12" assuming the optimistic case where all of the potential cost reductions identified in this section could be implemented. These would include: unpaved area for installation, no existing utilities in the pipe line corridor, uninsulated return lines (3" and 4" sizes), and no active traffic control requirement.

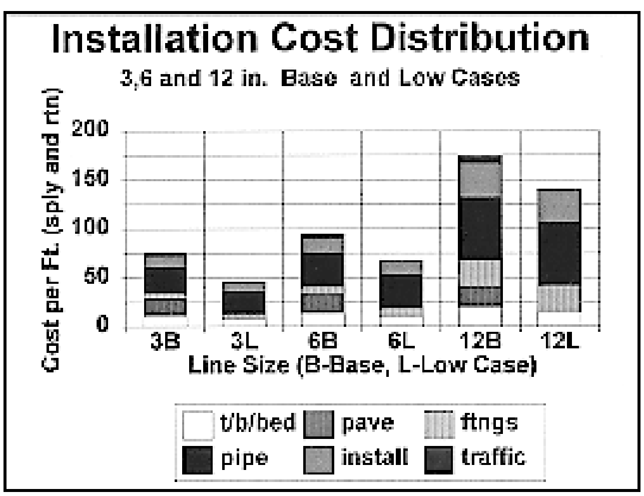

Figure 3.

This figure combines the individual cost areas into six basic groups. It is apparent that the largest savings potential occurs in the smallest piping sizes (3" and 4"), This occurrence benefits the residential distribution case since a majority of the distribution systems piping would be in the smaller pipe sizes.

INDIVIDUAL VS. CENTRAL HEAT EXCHANGER

It is advisable in all geothermal direct use systems to isolate the geothermal fluid from the building heating system it serves. This strategy greatly reduces the extent of geothermal fluid chemistry induced corrosion and scaling in the user's system. In district heating systems, there are two approaches to this isolation:

- Indirect system - central heat exchanger facility with a treated water loop serving the customers, and
- Direct system - geothermal fluid is delivered directly to the customer and an individual heat exchanger (or exchangers) is located at each user.

Due to the economics of scale in large heat exchangers and pumps, it is reasonable to assume that there will be a point when the cost of a large number of individual heat exchangers will exceed that of larger central equipment. This cross-over point is influenced by the loads served along with water temperature.

Space heating in residences is rarely accomplished with hot water heating in the western states. Most homes use some form of forced-air system (heat pump, propane, gas or electric furnace or electric baseboards units).

To accommodate the use of geothermal district heating, heat is transferred from the district system fluid, through the heat exchanger to the house loop. On the building side, a circulating pump provides flow to the terminal unit (or units) after which it is returned to the heat exchanger for reheating. To maintain pressurization, an expansion tank and domestic water pressure reducing valve are included on the loop. A room thermostat controls the circulating pump and heating water control valve on a call for heat.

The space heating equipment required can be reduced substantially if an indirect district system is employed. In this approach, the heat exchanger, expansion tank, pressure reducing valve, city water cross connection and circulating pump along with their associated fittings can be eliminated. For a typical home with a heating system designed for a load of 75,000 Btu/hr, a total of $1250 in mechanical components can be eliminated by using an indirect system design.

In order to eliminate these items, a central heat exchanger plant would be required to provide the same function (isolation of the building system from the geothermal fluid). The central plant would contain the same type of equipment (circulating pumps, heat exchangers, expansion tanks, controls and pressurization equipment), but on a larger, more economical scale.

Figure 4 compares the cost of the individual customer heat exchanger to the cost of the central plant. The plot is based on the assumption of a 75,000 Btu/hr load at each customer. It is apparent that a lower cost results for the use of a central plant under all conditions of 5,000,000 Btu/hr system capacity and above. This would correspond to a customer count of approximately 66 homes. Extrapolating these curves slightly suggests that the break-even point would occur at approximately 3,000,000 Btu/hr system capacity or about 40 homes at 75,000 Btu/hr each.

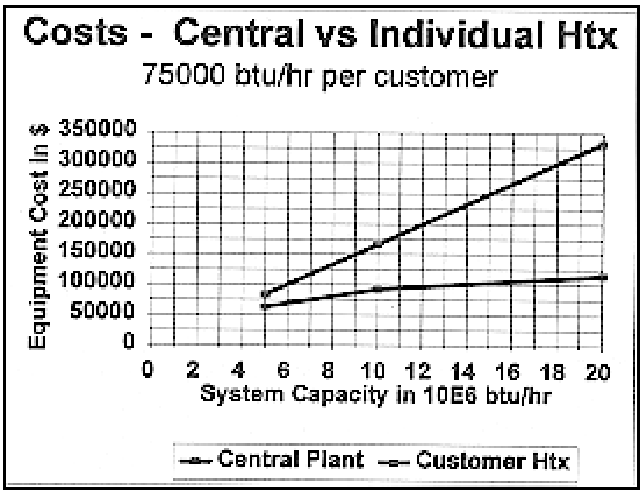

Figure 4.

CUSTOMER BRANCH LINES

One of the major cost items for small customers of a district heating system is branch lines. These lines connect the customer building with a curb valve box (and ultimately the distribution lines in the street).

In a single-family setting, these lines are likely to be a minimum of 60 feet in length (5,000 ft^2 lot with the home placed in center of lot) and due to their size (typically 3/4" to 1 1/2": nominal diameter) varying flow and potential damage to overlying vegetation, insulation is unavoidable.

Assuming a central plant design for the distribution system (treated water to customers), there are three realistic choices for the piping material: preinsulated copper, field insulated copper and preinsulated flexible polyethylene (cross-linked polyethylene or "PEX").

Table 3 provides a summary of the costs for the three materials.

It is apparent that the field insulated copper enjoys a cost advantage over the remaining materials, particularly preinsulated PEX.

Based on the use of the field-insulated copper branch piping, and a distance of 60 ft from the curb box to the house wall, a figure of approximately $1400 per house results.

Table 3. Cost Summary Branch Lines - 1"

	Field Insulated Copper (Type K)	Preinsulated (Type K)	Preinsulated Flexible PEX
Trench	1.30	1.30	1.30
Backfill	2.32	2.32	2.32
Material (pipe)	5.37	16.04	16.85
Insulation (incl. labor)	1.38	--	--
Fittings	--	--	3.45
Installation	9.04	3.35	2.04
Subtotal	19.41	23.01	25.96
20% contingency	3.88	4.60	5.19
Total	23.29	27.61	31.15

Economics of System Development

In order to evaluate the overall economics of district heating in moderate density residential areas, a specific section of Klamath Falls, known as the Mills Addition, provides a convenient example. This area is characterized by relatively small lot sizes (5000 ft^2) and includes unpaved alleyways between each block which could potentially be used for piping installation. This area is representative of similar single-family residential subdivisions in small-to-moderate sized western U.S. cities.

The example area contains 256 homes which average 1100 ft^2> in size. Using a value of 40 Btu/hr per ft^2 (uninsulated walls, single glass, R-19 attic insulation, 1 air change per hour (ACH) and allowing 30,000 Btu/hr for domestic hot water heating, results in a value of 74,000 Btu/hr per home. Using a 70% load diversity factor, the required plant capacity for 256 homes would amount to 13.3 x 106 Btu/hr. From Figure 4, the plant cost for this capacity would be approximately $225,000.

Tables 4 and 5 present a cost breakdown for the distribution system using the base case and low-case costs discussed earlier.

Table 4. Base Case Capital Cost - Mills Addition Distribution

Size	Length	Unit Cost	Total
3"	5,520'	$ 75.36	$ 415,987
4"	1,840'	81.20	149,408
6"	960'	94.51	90,730
8"	160'	119.46	19,114
			675,239
	Branch lines (street to curb box)		128,000
		Total	$ 803,239

Table 5. Low-Case Distribution Capital Cost - Mills Addition

Size	Length	Unit Cost(1)	Totals
3"	5,520'	$45.85	$ 253,092
4"	1,840'	51.63	94,999
6"	960'	67.46	64,762
8"	160'	90.96	14,554
			427,407
	Branch lines (street to curb box)		128,000
		Total	$ 555,407

(1) Assumes unpaved area, no existing utilities, uninsulated return line (3" and 4"only), no traffic control requirements.

Resource development costs can vary widely. To evaluate these costs a spreadsheet previously developed by the Geo-Heat Center (Rafferty, 1995) was used to evaluate several alternatives.

Table 6 presents the alternative cases considered for resource development.

Table 7 summarizes the range of costs for the three major portions of the district system. The low case assumes minimum resource development costs and distribution system installation costs. The high case incorporates the maximum value (used in this report) for resource development and distribution.

Table 7. Expected Cost Range for 256 Homes GDH System

	Low	High
Resource	$ 140,000	$ 540,000
Central plant	225,000	225,000
Distribution	555,000	803,000
Total	$ 920,000	$ 1,568,000

Given the range in potential capital costs to implement the system, it is possible to calculate the required revenue to support the financing of this cost. At prevailing interest rates (8%), the revenue required to cover the debt service only would amount to between $86,800 and $148,000. Assuming 75% subscribership, the necessary revenue per home would amount to a range of $452 to $771 (the low and high cases respectively).

In order to evaluate the feasibility of district heating, it is necessary to determine the current conventional heating costs in the service area. Previous work by the Geo-Heat Center (Rafferty, 1992) has identified an energy consumption for all gas homes in this area of approximately 0.80 therms per square foot for space and domestic hot water heating. Table 8 presents the current cost data for meeting the same loads based on the use of different fuels and fuel combinations.

Table 6. Variations in Geothermal Resource Development Costs

Well depth (ft)	1500	1000	1000	2000	2000	500	500
Water temperature (F)	170	170	170	170	170	170	170
Delta T (F)	40	50	40	50	40	50	40
Injection	Y	N	Y	N	Y	N	Y
Pumping required	Y	Y	Y	Y	Y	Y	Y
No. production wells	2	1	1	1	2	1	2
No. injection wells	1	0	1	0	1	0	1
Static level (ft)	200	200	200	300	300	100	100
Cost ($)	$406,000	230,000	390,000	330,000	540,000	140,000	310,000

Table 8. Annual Conventional Heating Costs

Fuel	$/yr
All gas	484
Gas with electric hot water	638
50% gas/50% wood/gas hot water	439
Fuel oil with electric hot water	716
50% fuel oil/50% wood/electric hot water	632
All propane	977
50% propane/50% wood/electric hot water	763
All electric	1,053
50% electric/50% wood/electric hot water	801

Notes:
Fuel oil @ $0.95/gal
Natural gas @ $0.55/therm
Propane @ $1.00/gal
Electricity @ $0.06/kWh
DHW @ 55º / 130º, 65% efficiency (fuels),
48 therms (840 kWh) standby tank loss
Fossil fuels @ 70% efficiency, wood @ 50% efficiency

For systems serving more than about 40 homes (@ 75,000 Btu/hr per home), an indirect distribution design (incorporating central heat exchangers) results in a lower total cost than a direct design (in which the geothermal fluid is delivered to the customer).

Branch service lines on the customer's property, are a significant cost item. Of the three principal piping installation methods available, preinsulated copper, field insulated copper and preinsulated flexible polyethylene (PEX), the field insulated copper has the lowest installed cost at approximately $23.00 per lineal foot (for supply and return).

Based on the example residential area evaluated in this paper, it appears that geothermal district heating in existing single-family residential areas could be feasible in situations where:

- Propane, fuel oil and electricity (or combination of these fuels with wood) dominate the conventional heating used,
- Small lot sizes (<5,000 ft^2),
- Subdivisions where unpaved areas are available for installation of some or all of the distribution system, and
- Customer penetration rate is high (>=75%).

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KLAMATH FALLS GEOTHERMAL DISTRICT HEATING SYSTEM EVALUATION

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INTRODUCTION

The city of Klamath Falls, Oregon, is located near a geothermal resource that has provided heating for homes, businesses, schools, and institutions for many years. Almost 20 years ago, in 1977, 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.

The district heating system was constructed in 1981 to initially serve 14 government buildings with planned expansion to serve additional buildings along the route. The expectation at the time was that the system would have a high initial load and rapid expansion to full capacity. When the system feasibility was studied, the cost of natural gas was increasing rapidly; that trend was expected to continue, making geothermal energy highly attractive by comparison (Lienau, et al., 1977).

The promise of profitable operation has been elusive, even after fifteen years. More than once, financial and operational problems have resulted in serious consideration of shutting the system down. Challenges faced by the system have included:

- Initial opposition from other geothermal users to operating the system, resulting in a three year delay in system start-up to 1984,

- Failure of a portion of the distribution system piping after one season of operation, resulting in five years of downtime, reconstruction cost, and poor public perception of the system,

- Low-load factor, with the system operating at only about 15-20 percent of design capacity, and

- Low-natural gas cost, resulting in pressure to keep district heating energy costs low and leaving little incentive for new customers to connect.

While the district heating system has had more than its share of problems, there has been a strong underlying support for geothermal energy and the will to work through the problems.

- The initial opposition to system operation was resolved by extensive testing of the aquifer, requiring reinjection of geothermal fluids to stabilize well levels, and formation of a citizen Geothermal Advisory Committee to oversee geothermal development. That committee is now very supportive of the system,

- The perception of poor reliability after the pipeline failure has been eased by five years of reliable operation since system reconstruction in 1991, and

- The low load factor is being addressed by a system expansion effort, which has more than doubled the customers on the system.

The city began a marketing effort in 1992 to add more customers to the system. The initial focus was adding buildings along the pipeline because of the high cost of line extensions (Rafferty, 1993). The expansion effort got a huge boost from a community fund raising drive to extend the district heating mains to serve the Ross Ragland Theater, a community performing arts center. Most of the new connections and increased system load is served by that main extension. Geothermal heated sidewalks and crosswalks have been incorporated into a downtown redevelopment project along Main Street. The snowmelt system has generated considerable favorable press for the geothermal system and the city (Brown, 1995). Figure 1 shows the service area of the district heating system.

The Klamath Falls geothermal district heating system has been discussed in several publications. For more information, see Lienau, et al.,(1989 and 1991) or contact the Geo-Heat Center at Oregon Institute of Technology, Klamath Falls, Oregon.

Thanks to a great deal of hard work and perseverance, the Klamath Falls district heating system is back on track toward a bright future. It is important to keep it on track with reliable service and additional system expansion.

Need for System Evaluation

The winter of 1995 to 1996 was not a particularly severe winter, with no temperature excursions below 0°F. However, there were times that the district heating loop failed to maintain the differential pressure necessary to deliver design heating

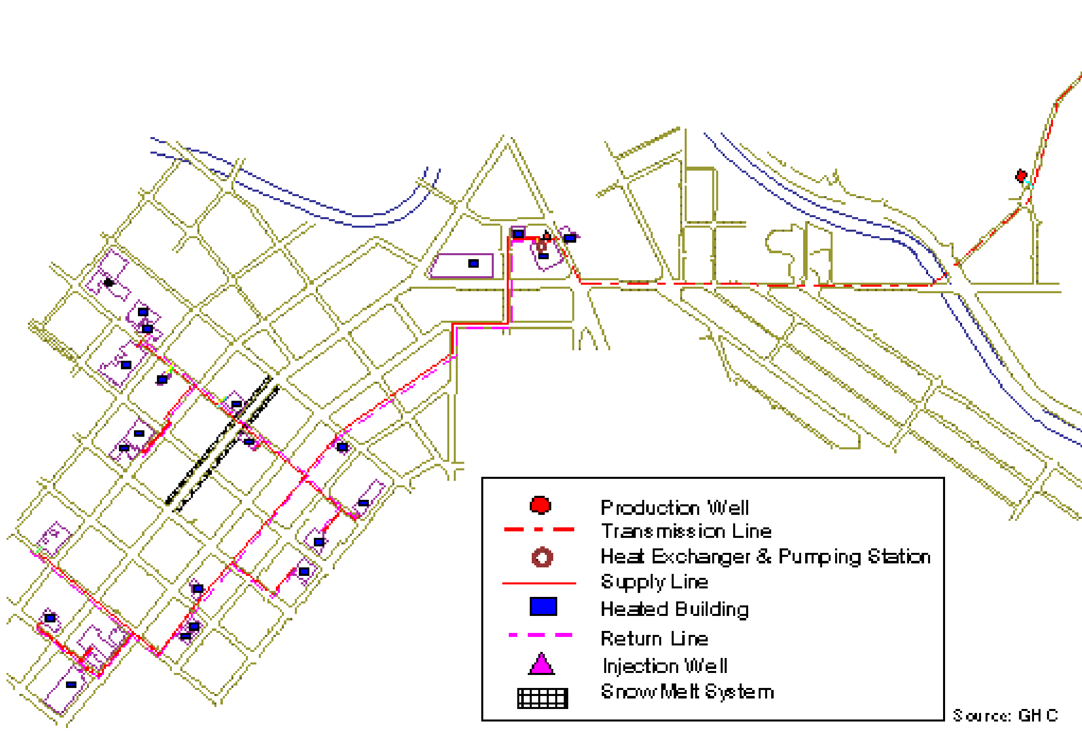

Figure 1. Klamath Falls geothermal district heating system location map, 1995.

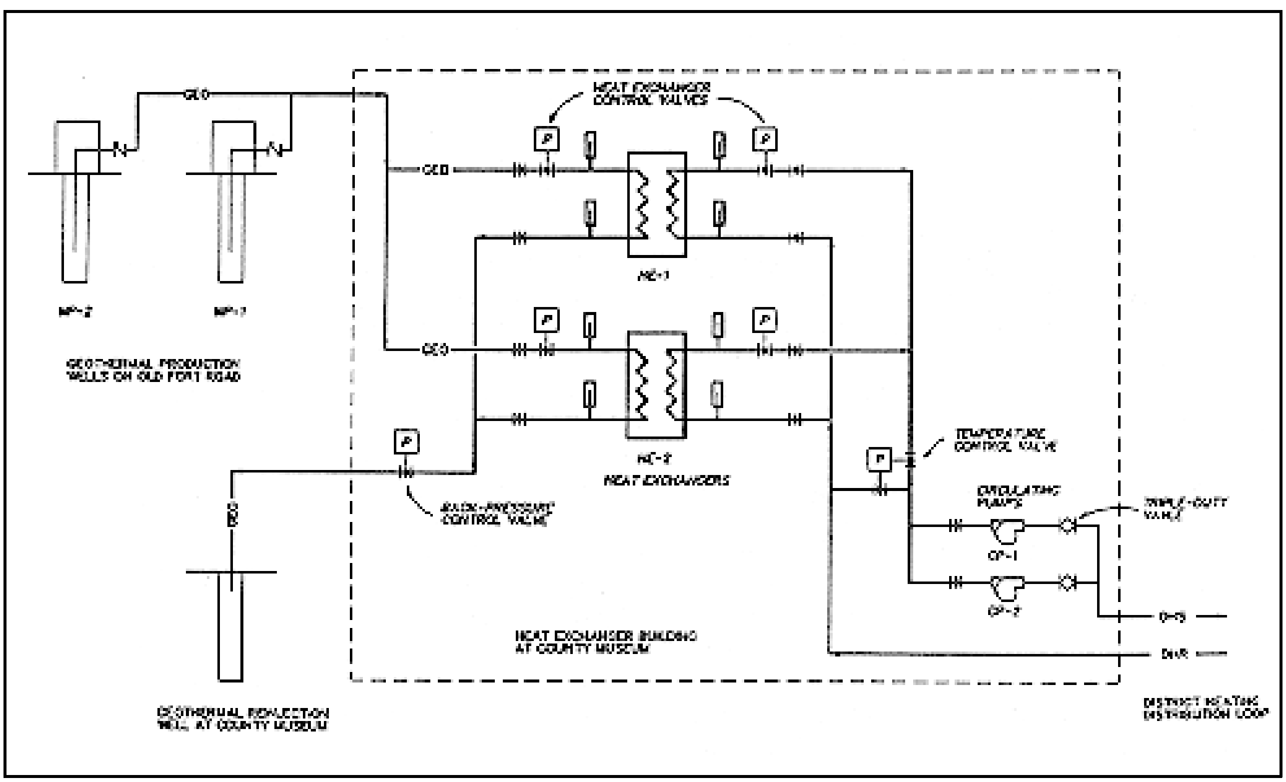

Figure 2. District heating system schematic.

capacity to many of the buildings. On one occasion, on a relatively mild night, the system circulation pump tripped out, leaving the customers with no heat. These incidents were little noticed by the district heating customers, but are indicative of problems that must be solved prior to another heating season or further expansion of the system. Questions to be addressed include:

- **System capacity:** What is the system heating capacity; what portion of the capacity is currently being used; how much further expansion is possible; and how can system capacity be increased if necessary?

- **System operation and controls:** How effective are existing automatic controls and operating procedures; how can they be improved to increase reliability and reduce operating costs?

- **System condition:** What is the condition of system facilities and equipment; what maintenance or improvements are necessary to provide continued reliable operation?

SYSTEM CAPACITY

Additional expansion is planned and is necessary for the financial stability of the district heating system. Yet, the operation of the system in the winter of 1995-1996 showed an apparent lack of capacity to meet currently connected loads. The apparent lack of capacity is primarily due to uncontrolled flow at several of the buildings and low system temperature differential (ΔT). This section discusses the effect of flow and ΔT on system capacity, the original design capacity of the Klamath Falls system, how much of that design capacity was used by the original system, the effect of system expansion, capacity improvements available with better flow control, and the system capacity limits.

Capacity, Flow and ΔT

Heating with water is based on circulating hot water to the heating equipment, transferring heat in the heating equipment to the heated space with resulting cooling of the water, and returning the water to the heat source to be reheated. 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; for example pumps, pipes, control valves, heat exchangers, production wells, and reinjection well. As long as the equipment is maintained in good condition, the system will generally deliver the design flow. Any significant increase in the flow requires larger equipment and increased power to operate. The feasible increase in flow is limited by such things as pipeline size or well capacity that are too costly to economically increase.

Temperature change of the heating water (ΔT) is equally important to the delivery of heat. The ΔT 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. However, the main cause of low ΔT or lower than design ΔT is failure to properly control heating water flow. Poor flow control will result in low ΔT, with the consequence of reduced thermal capacity and higher than necessary pumping costs.

Constant Flow-Variable ΔT: A boiler-based hydronic heating system is often designed for constant flow, with variable ΔT. The pump runs continuously, with a relatively constant flow. At the heating coils, 3-way valves direct the flow either through the coil when heating is required, or bypass the flow around the coil and back to the boiler and pump. If all of the heating coils happen to be operating at peak design conditions at the same time, then the overall system will operate at the design ΔT, and the boiler will operate at peak output to keep up with the load. If some or all of the heating coils are operating at less than full load, the flow remains constant, but the overall system ΔT and heat output decreases.

The constant flow-variable ΔT approach works fine for a single, small building. The boiler is sized to handle the peak output of the heating system, and works fine at reduced ΔT. Also, pumping cost is a relatively small part of the operation cost. However, this approach is not well suited for a district heating system:

- Pumping power is the most significant operating cost of a geothermal district heating system and is much greater with constant flow,

- Once a flow rate to a building is set, that in effect "locks up" a share of the total system capacity. With fixed, constant flow, there is no way to take advantage of building load diversity, and

- There is a tendency to over-specify the flow requirements of a building during design, committing more system capacity than the building really needs.

A constant flow system often results in low ΔT at full load and even lower ΔT at part load. This results in unnecessarily high pumping costs, and limits the thermal capacity of the system.

Constant ΔT-Variable Flow: A better approach for district heating is to design for constant ΔT-variable flow. Features of this approach include:

- Flow is controlled at the point of heat use by 2-way control valves; when no heat is needed, no flow is permitted,

- System-wide ΔT is constant or even increases at part load; flow is variable depending on load and ΔT,

- A variable flow system provides better allowance for load diversity; flow capacity not needed at a particular building at a particular time is available to be used elsewhere,

- Variable flow results in reduced pumping power cost; pumping power is proportional to the cube of the flow, a 50% reduction in flow can produce an 88% reduction in power use, and

- Proper flow control results in better heat transfer in heat exchangers and primary-secondary pumping loops.

Design Capacity

The Klamath Falls geothermal district heating system was designed with a thermal capacity of 20 million Btu/hr on both the production side and the distribution side of the heat exchangers.

Table 1. Klamath Falls District Heating Design Capacity

	Flow	Temperature F			Heat
Pump	gpm	Supply	Return	ΔT	Btu/hr
Production					
WP-1	500				
WP-2	500				
Maximum	1000	210	170	40	20×10^6
Distribution					
CP-1	1000				
CP-2	500				
Maximum	1000	180	140	40	20×10^6

Original System Operation

The building heating systems in the original system were designed for constant flow-variable ΔT. In addition to the main circulation pumps in the heat exchanger building, each connected building had a circulation pump connected in series.

Table 2 shows the design flow, ΔT, and heat load of the original buildings. The design values are based on the balance valve flow schedule in the construction drawings, and 40ºF ΔT. The fire station is included in the total heat load, but not the flow, because its return flow is pumped back into the system supply main. The total projected load was about 90 percent of the system design capacity.

Also shown on Table 2 is the measured or estimated maximum monthly average flows, heat load, and ΔT of each of the buildings and the overall system. Flow rate and average load are calculated from the monthly meter readings for total BTUs and gallons, divided by the estimated hours between meter readings. Readings for January 1985 were used if available. Buildings showing no flow were never connected to the system.

As shown, the metered maximum month heating load was substantially less than the design basis. The flow is less than the design flow only due to operation of the smaller circulation pump, CP-2. Since the smaller pump is unable the supply the total design flow, the system worked because each building had a booster pump, operating in series with the main loop circulation pump. The maximum observed system load is based on the highest system ΔT recorded in the daily logs, in January 1991.

Table 2. Klamath Falls District Heating System: Heating Load For Original Buildings

	Original Design			Maximum Month		
Building	Flow gpm	ΔT ºF	Load MBH	Flow gpm	ΔT ºF	Load MBH
Fire Station	-	-	529	-	-	286
Employment	46	40.0	920	0	0.0	0
Post Office	198	40.0	3,960	36	20.0	360
City Annex	30	40.0	600	22	7.7	85
City Hall	72	40.0	1,440	68	6.2	211
Vet. Memorial	82	40.0	1,640	21	14.5	152
Courthouse	201	40.0	4,020	157	7.1	557
Library	107	40.0	2,140	35	28.3	501
County Annex	25	40.0	500	29	8.4	122
Vet Services	16	40.0	320	0	0.0	0
State Offices	100	40.0	2,000	0	0.0	0
Total	877	41.2	18,069	368	12.3	2,274
Maximum observed				368	24.0	4,421

Table 2 illustrates how a constant flow approach, which does not account for building heating system over-sizing and building load diversity, can result in a system ΔT and useable capacity that is much lower than design.

System Expansion

Significant expansion to the district heating system began in November 1993 with the opening of the new distribution pipeline extension to the Ross Ragland Theater. In planning for connection of new customers, it was decided that the new connections would not include booster pumps. Instead, the main circulation pumps would be operated to provide a minimum of 5 psi differential pressure at the building connection. The building heating system conversions were designed to provide the required heating at that differential pressure and a ΔT of 40ºF. Controls were included to maintain the required minimum ΔT over the entire operating range, and shut off flow when no heating is required.

The addition of new buildings requiring a 5 psi pressure differential, in parallel with the original buildings with booster pumps and no flow control, made it necessary to operate the larger circulation pump CP-1 at all times. The smaller pump, CP-2, cannot meet even light winter loads, and can meet the summer hot water loads only if the service valves to the buildings without flow control are manually closed.

Table 3 shows the buildings currently connected to the system, with the estimated flow, ΔT, and peak heating load. The flows and loads in Table 3 are estimates based on rough flow measurements in June 1996, building heat load calculations, building system temperature monitoring, and meter readings. For buildings with metered monthly usage, a peak load of about 1½ times the maximum month average was used unless better information was available. The estimated loads are an attempt to allocate the observed system-wide peak load to individual buildings. They do not necessarily reflect the building design peak load or the relative total energy use or energy billings of the buildings.

Table 3. Klamath Falls District Heating System: Existing Heating Loads

	Existing Conditions				Improved ΔT		
Building	Flow gpm	ΔT ºF	Load MBH		Flow gpm	ΔT ºF	Load MBH
Fire Station[3]	-	-	429		-	-	429
Post Office[2]	270	4.0	540		27	40.0	540
City Annex	30	8.0	120		6	40.0	120
City Hall	75	8.5	320		16	40.0	320
Vet. Memorial[1]	0	0.0	0		0	40.0	0
Courthouse[1]	0	0.0	0		0	40.0	0
Library	60	20.0	600		30	40.0	600
County Annex	33	11.0	180		9	40.0	180
Subtotal Original	468	9.4	2,189		88	49.8	2,189
Balsiger	50	40.0	1,000		50	40.0	1,000
Eagles	10	40.0	200		10	40.0	200
Pacific Linen	125	24.0	1,500		75	40.0	1,500
US Bank	15	40.0	300		15	40.0	300
Snowmelt[3]	-	-	500		-	-	500
SVS Bank	24	40.0	489		24	40.0	489
Sacred Heart	127	22.0	1,400		70	40.0	1,400
1st Baptist	50	40.0	1,000		50	40.0	1,000
Ross Ragland	31	40.0	620		31	40.0	620
1st Presbyterian	20	40.0	390		20	40.0	390
Subtotal New Connections	452	32.7	7,399		345	42.9	7,399
Total System	920	20.8	9,588		433	44.3	9,588
Maximum Observed	850	16.0	6,800				

1. The Courthouse complex and Veterans Memorial building were on the system at the start of the system expansion, but were badly damaged by an earthquake. Those buildings have been demolished or are not heated.
2. The Post Office shows a substantially higher flow than metered due to an un-metered bypass valve.
3. The snowmelt system does not affect total flow because it works off of water pumped from, and returned to, the district heating return main. The load, however affects system-wide ΔT. Likewise, the Fire Station flow is returned to the supply main.

The district heating system operated during the 1995 - 1996 heating season with only one heat exchanger on line. Under those conditions, the calculated system-wide peak flow of 920 gpm is more than the larger pump, CP-1 can deliver. The maximum observed system load is based on the highest recorded ΔT, in February 1996, at the maximum calculated pump capacity.

Table 3 shows that the estimated and observed system peak load is one third to one half of the design thermal capacity. However, the system flow requirement is at or beyond the pumping capacity. To further increase heat delivery, either the flow or the system wide ΔT must be increased.

System Performance Improvement with Flow Control

The second part of Table 3 shows the conditions if the flow to the currently uncontrolled buildings is controlled to provide a 40ºF ΔT. The result is considerably reduced total system flow which frees system capacity for additional expansion, and reduces pumping costs.

Capacity Limits

With improvements to the system ΔT and improvements to the system operation and control, it should be feasible to expand the connected load to about double the existing load. Since the system expansion will not happen in one year, there will be opportunity to observe system performance with each stage of expansion and adjust the projected limit accordingly.

The ultimate potential service capacity within the constraints of the existing wells and pipelines is limited by the flow and ΔT capabilities of the production and distribution systems. The limiting factor in overall capacity is currently the production system, most notably the flow acceptance of the reinjection well. Without additional development of the well, the system is limited to close to the original design capacity of 1000 gpm (20 x 10^6 Btu/hr).

If production capacity is available, either by increased production or fossil fuel peaking, the district heating distribution system could support a peak load of about 27 x 10^6 Btu/hr. Additional development beyond that load would be feasible if selected large users were on interruptible service, supplementing the geothermal heat with their standby heating source at peak heating load. Peaking with fossil fuels is economically attractive because a geothermal system sized for 75 percent of the peak load will provide more than 95 percent of the annual energy requirement.

SYSTEM CONTROLS AND OPERATION

The main controls for the district heating system are located in the heat exchanger building. The control system was designed to monitor the temperatures, pressures, and flows of the district heating loop and the geothermal production system; and to automatically control loop circulation pump operation, loop supply and return temperature, production well pump operation and speed, heat exchanger operation, and geothermal system back pressure. Figure 2 shows the system piping and control schematic.

Circulation Pumps

The district heating loop is circulated by two pumps: CP-1, rated 1000 gpm; and CP-2, rated 500 gpm. The controls were intended to operate the pumps automatically in response to system load, as indicated by the loop return temperature. At less than 50 percent of design capacity, the smaller pump was to operate. At greater than 50 percent of capacity, the larger pump was to operate. Since system start-up, the pump controls have always been operated manually, and it is unknown if the automatic controls would or could work as designed.

With expansion of the system, new connections were designed for variable flow-constant ΔT control at the buildings, with no booster pump. Existing buildings are also being converted to that approach. As the original control system is not designed for that operation, the pump controls should be upgraded. Recommended changes include:

- Install an additional large circulating pump to provide backup operation at full load, and

- Use an adjustable frequency drive to vary the pump speed to match system flow; control the pump speed to maintain the required system pressure differential.

Temperature Control

The control system was 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, the system was intended to increase the geothermal production. On increasing temperature the system would reduce production, then modulate a 3-way valve to bypass district heating water flow around the heat exchanger.

The only portion of the temperature control that is currently functional is the control of the 3-way valve. Geothermal production is controlled manually. This provides reasonable, although not very precise, control as long as there is adequate geothermal production to meet the system heating demand. With manual control, the district heating system temperature drops during periods of high heating demand when the geothermal flow is inadequate to meet the demand. When system load is low, the geothermal reinjection temperature increases. This, on occasion, has resulted in the entire system shutting down due to a high temperature alarm.

Production Well Control

The temperature control system was intended to control operation and modulate the speed of the production well pumps in response to system load, as indicated by district heating supply temperature. A leased phone line was used to transmit a START/STOP signal and an analog SPEED signal to the well pump controls and receive back a RUNNING signal. On decreasing district heating supply temperature (increasing load), the controls would first modulate the lead pump to full speed, then start the lag pump and modulate the two pumps together. On increasing temperature, the speed of both pumps would be reduced, then the lag pump would stop and the lead pump speed would be modulated to match load.

The automatic well pump controls reportedly worked satisfactory at system start-up, with a single pump in operation. There was some flow instability that was attributed to the low system load and problems with the back-pressure control valve. The well pumps have been controlled manually since start-up, and the automatic control is currently not functional due to problems with the telemetry link.

Repair or upgrade of the well pump automatic control is needed to provide reliable district heating supply temperature control. The more the system load grows, the more important automatic well pump control becomes. For stable operation, the control system should respond to more complete information on system operation than just supply temperature. The pump control should respond very slowly to changes in load, increasing flow in small increments, and waiting for the system to stabilize before making another change. As this cannot be done by the existing controls, they should be replaced by a control system that can, such as a digital control (DDC) system.

Heat Exchanger Control

The flow to the two heat exchangers is designed to be coordinated with well pump operation. Automatic valves allow flow through one heat exchanger when one well pump is on, and both heat exchangers when both pumps are on. Since operation of both well pumps at once is currently never needed, the system forces all the district heating loop flow through a single heat exchanger. Modification of the control system to allow parallel operation of both heat exchangers will improve heat transfer and reduce pumping cost.

Back-pressure Control

Both of the production wells supply geothermal water hotter than the boiling temperature at the system altitude of 4,100 ft. The operation log for WP-2 shows temperatures as high as 228°F. The geothermal water is prevented from flashing to steam in the piping by a control valve which maintains a 25 psi back-pressure on the system. The control valve is a line-size, commercial-duty, 8-inch butterfly valve. This valve is not the most appropriate selection for the service, since most of the time the system operates at near minimum geothermal flow, requiring the valve to operate almost completely closed. This operation mode is hard on the valve and does not allow proper control.

At system start-up, the back-pressure control was extremely unstable. That instability was reduced by manual throttling of an isolation valve, and restricting the sensitivity of the control. This has worked acceptably at the low, fairly constant, geothermal flow with manual well pump control. It is unknown if the controls can work automatically over the entire design flow range.

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. The valve should be designed for the high temperature and cavitation, and sized to be at least 20 percent open at minimum flow. If a butterfly valve is used it should be an industrial quality valve, typically one or two sizes smaller than line-size.

Flow Measurement

The control system was designed with flow measurement on the geothermal water ahead of the injection well and at each heat exchanger, and on the district heating loop both at the supply and return. The flow meters are paddle-wheel type, inserted through a packing gland and ball valve into the bottom of the pipe. The flow meters only lasted for a short time, and sediment in the bottom of the pipes tended to fill in around the probe, making them near impossible to remove. Currently, none of the original six flow meters are functional.

Flow metering is valuable for tracking geothermal water usage and monitoring system operation and energy delivery. Installation of two new flow meters is recommended, one on the geothermal flow and one on the district heating loop. The meters should be industrial quality, rated for the temperature and service, with good turn-down. Vortex meters or magnetic flow meters would meet those requirements. Either the meters or the control system should have the ability to totalize both flow and BTUs.

Pneumatic vs. Electronic Controls

The existing control system is a pneumatic system, with electrical switches and relays as necessary to interface with the control panel switches, lights, and motor starters. Within the limitations of the designed control strategy, the pneumatic controls are working fairly well. However, the air compressor and control air dryer are in questionable condition, and much of the original control system is not functional or is in need of improvement.

The current state-of-the-art in control systems is electronic direct digital controls (DDC). Such a system can provide better, more accurate control, automatic logging of system operation parameters and alarms, automatic dial-out of critical alarms, and ability to provide dial-in access to adjust control set-points and operation. A DDC control system is being used successfully on the sidewalk snowmelt project. The district heating control system could be converted to fully electronic control, including valve actuators, or the existing pneumatic actuators could be used.

A properly operating control has the potential to improve system reliability and reduce operation and maintenance costs. Controls must be high quality, designed to be reliable in a hot, humid environment.

EVALUATION OF SYSTEM CONDITION

This section reviews the condition and maintenance needs of the district heating equipment and facilities. The system consists generally of geothermal production, geothermal transmission, the heat exchanger facility, and district heating distribution.

Production

Geothermal water is produced by two production wells. Production well pumps are vertical line shaft pumps, oil lubricated, with variable-speed fluid coupling drives. The pumps are rated for 500 gpm each, and are powered by 50 hp motors. The upper well supplies water at about 226°F, and the lower well supplies water at about 206°F. The pumps have provided excellent reliability, with no major maintenance requirement over the past 15 years. One drive motor has been rewound.

The well pumps are started manually at the well house and the speed is adjusted manually by adjusting the length of the control linkage. The automatic temperature control valve on the fluid drive oil cooler is not working, so the cooling water flow must be started and adjusted manually. The drip oiler for the pump line shaft is also checked on starting the pump and daily while operating.

Aside from repairing or replacing the non-functional controls, the only immediate maintenance need is repairing oil leaks in the pump and fluid drive. The pumps should be inspected by a qualified pump service company. The fluid drives used to control pump speed have been reliable, but are getting old, are expensive to repair, and are relatively inefficient. When any significant maintenance is required on the fluid drives, replacement of the drives by adjustable frequency electric motor control is recommended. An adjustable frequency drive will provide better control, better efficiency, and better reliability than the fluid drives.

Geothermal Transmission Pipeline

Geothermal flow from the production wells is conveyed to the heat exchanger building through an 8-inch pre-insulated steel pipeline, about 4400 feet long. About one-third of the pipeline is direct buried, the rest is enclosed in a concrete pipe tunnel.

Tapping of the line for a service connection in 1993 revealed that the interior of the pipe is in excellent condition with minimal corrosion. The exterior of the pipe, where enclosed in the fiberglass carrier pipe and urethane foam insulation should also be in good condition. Corrosion is most likely to be a problem at fittings, expansion joints and pipe anchors, where the steel can be exposed to soil moisture or water.

As far as we know, corrosion has not yet compromised the integrity of the geothermal pipeline. It is, however, a potential time bomb if not addressed. The pipeline should be thoroughly inspected for corrosion, and the cathodic protection system anodes should be dug up for inspection and renewal. Any corrosion problems must be corrected as soon as possible to maintain system reliability and to prevent more costly problems in the future.

Heat Exchanger Building

The heat exchanger building houses the heat exchangers, circulation pumps, and controls for the district heating system. Flow from the geothermal water pipeline enters the heat exchanger building, flows through a strainer, flows through the heat exchangers, through a back-pressure valve, and into the reinjection well. On the secondary side of the heat exchangers, clean city water is circulated through the heat exchangers and to the distribution system by two circulating pumps: CP-1 and CP-2.

Heat Exchangers: The heat exchangers are plate-and-frame heat exchangers with 316 SST plates. Each heat exchanger is designed for 10 x 10^6 Btu/hr heat transfer at 500 gpm, with 8 psi pressure drop. The heat exchangers have provided good service. They have been cleaned only once, in 1994. As the district heating load increases, more frequent cleaning will be needed to maintain performance. By comparison, the heat exchangers on the geothermal system at the hospital are cleaned annually. Capacity of the heat exchangers can be increased, if needed, by adding more plates.

Valves: Control valves and manual isolation valves in the geothermal and district heating loops are line size, commercial quality rubber-lined butterfly valves. The manual valves have provided good service and appear to be in good condition. The back pressure valve should be replaced with a higher quality valve, more appropriately sized, as discussed in the controls evaluation previously. The temperature control valve is a 3-way valve consisting of two linked butterfly valves. The stem seals are leaking badly, and the valves should be repaired or replaced.

Pumps: The circulating pumps have provided good service and are in good condition. Pumps CP-1 and CP-2 are vertically mounted split-case pumps, rated for 1000 gpm and 500 gpm respectively. As previously noted in the discussion of system controls, addition of a third pump is recommended to provide standby capacity at design load, with adjustable speed control to reduce pumping energy cost.

Ventilation: The heat exchanger building is extremely hot inside due to the high heat gain from the hot water, and limited ventilation. Recorded temperatures in the basement of the building have exceeded 116°F. This high temperature is hard on equipment and maintenance personnel. Heat gain can be reduced by insulating the heat exchangers, bare piping and the air separator tank. Temperature and humidity in the building can be reduced by increasing the ventilation rate, adding exhaust fans and additional air intakes.

District Heating Distribution Piping

The district heating distribution 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 due to defective epoxy on the factory-glued joints. The fiberglass pipe was entirely replaced with pre-insulated ductile iron pipe.

As with the geothermal pipeline, the piping should be inspected for external corrosion, particularly in the expansion joint vaults for the steel pipe and in the customer service vaults.

CONCLUSIONS

The district heating system is currently operating at one third to one half of design thermal capacity. However, the distribution system is near hydraulic capacity due to uncontrolled flow at several buildings. With improved flow control resulting in increased system ΔT, the system can support significant additional expansion.

The district heating system is currently functioning adequately and reliably on mostly manual control. Control improvements would improve operation and reliability and reduce operating cost.

The system is basically mechanically sound. Maintenance is needed, especially in the area of corrosion control to keep the system sound.

Although the district heating system is not yet financially self-supporting, this study recommends additional investment in the system. The payback from that investment will come in the form of operational cost savings, continued reliability and community support, and ability to increase revenue with further system expansion.

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OIT GEOTHERMAL SYSTEM IMPROVEMENTS

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INTRODUCTION

Three geothermal wells drilled during the original campus construction vary from 396 m (1,300 ft) to 550 m (1,800 ft). These wells supply all of the heating and part of the cooling needs of the 11-building, 62,200 m^2 (670,000 ft^2) campus (Figure 1). The combined capacity of the well pumps is 62 L/s (980 gpm) of 89°C (192°F) geothermal fluids. Swimming pool and domestic hot water heating impose a small but nearly constant year-round flow requirement.

In addition to heating, a portion of the campus is also cooled using the geothermal resource. This is accomplished through the use of an absorption chiller. The chiller, which operates on the same principle as a gas refrigerator, requires a flow of 38 L/s (600 gpm) of geothermal fluid and produces 541 kW (154 tons) of cooling capacity (Rafferty, 1989).

The annual operating cost for the system is about $35,000 including maintenance salary, equipment replacement and cost of pumping. This amounts to about $0.05 per square foot per year.

PRODUCTION

Three geothermal wells produce the fluid for the campus geothermal system. These wells, OIT-2, OIT-5 and OIT-6 (Figure 1), are capable of producing an estimated 8 L/s (130 gpm), 32 L/s (500 gpm) and 22 L/s (350 gpm) respectively.

The three original pumps were basically irrigation well water pumps with direct-coupled motors, open lineshaft with rubber bearings and standard lateral (which is the axial movement of the impellers within the bowls) pumps with bronze bearings and impellers (Culver, 1994). The wellhead and motors were in pits or cellars below ground level. The wells are within about 122 m (400 ft) of each other and produce from the same aquifer. Water temperature is the same in all three--89°C (192°F).

Problems experienced were broken lineshafts, motors overheated, pump impellers loosened on the shaft due to differential expansion and bronze bearings corroded. Because there was a lack of lateral in the bowls, pumps that had been shut-off required preheating by pumping water from another well to thermally equilibrate the entire column and shaft.

In 1970, a program of upgrading the pumping system was initiated. The wellheads were raised above ground level and enclosed in well-ventilated well houses. Variable-speed fluid couplings were installed. New pumps with oil-lubricated enclosed lineshaft and bronze bearings with extra lateral bowls, and keyed colleted impellers were installed. This design has proven very successful, for example OIT-5 was overhauled in 1989, after 19 years 5 months of service, by replacing the impellers and bowl bearings. This pump was replaced in 1995 with the addition of a flow meter and water level air-line for monitoring.

For well OIT-2, a new pump was installed in 1974. This 35-stage pump is rated at 8 L/s (130 gpm). The pump has not been pulled since its installation in 1974, and is still running apparently smoothly. The pump in OIT-6 well was installed in March 1971. This pump has 26 stages and is rated at 22 L/s (350 gpm) at 650 TDH, 1720 rpm and has 107 mm (4.2 in.) of lateral. In June 1988, the pump was pulled and refurbished with new pump bearings and impellers. Actual run time of these two pumps is unknown since run times are not logged; but, it is estimated to be between 7-8 years with speed and flow rate varying with campus heating load (Culver, 1994).

The three wells deliver geothermal fluid through short underground pipelines to a tank located in the "heat exchange" building above the campus. In 1995, a backup oil-fired boiler was removed after it had never been used in 32 years. A diagram of the control scheme for the production facility appears in Figure 2.

The two control valves respond to a signal from the tank level control modulating toward the closed position as the tank level rises (decrease in campus heating demand). As the valves close, the pressure in the lines from the production wells increases. This increase in pressure signals the variable-speed drive units to begin slowing the production pumps, thus reducing their output. The opposite sequence would result in the event of a decrease in the tank water level. From the

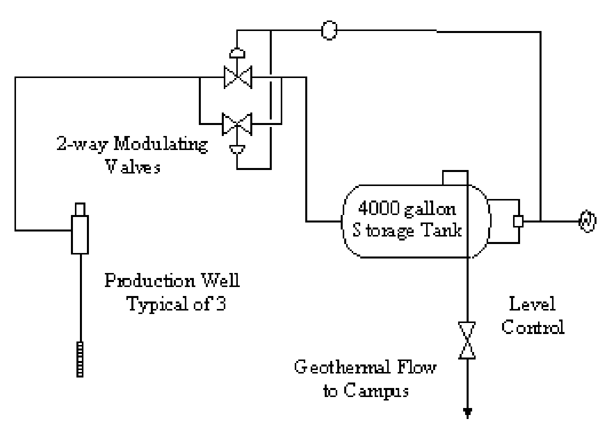

Figure 2. Diagram of the control scheme for the production facility.

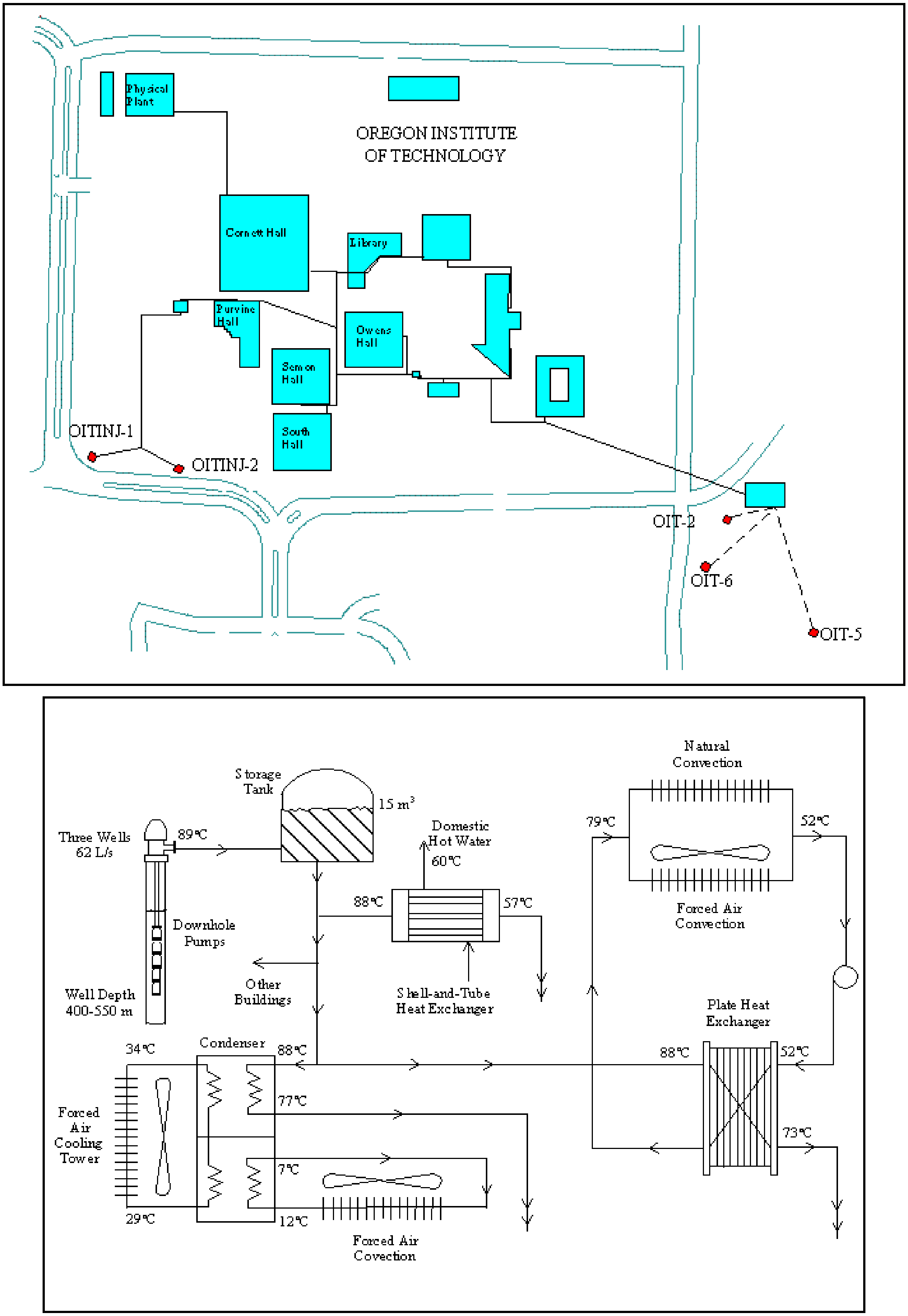

Figure 1. Oregon Institute of Technology geothermal heating system layout and flow diagram.

storage tank, the entire distribution system operates by gravity due to the elevation difference between the tank and the campus (Rafferty, 1989).

DISTRIBUTION SYSTEM

The original campus distribution system consisted of direct buried steel piping. This piping, which delivered the geothermal fluid to each building, was field insulated and covered with a bituminous mastic coating.

In the early-to-mid 1970s, it was discovered that the coating material was no longer intact in many locations. As a result, groundwater from the soil was able to penetrate the insulation and cause serious corrosion of the steel piping. This occurrence was most pronounced at the elbows in the piping system. Evidently, repeated expansion and contraction of the lines caused numerous cracks in the coating in those areas. A program of distribution system replacement and modification was initiated in the mid-to-late 1970s. The new hot water supply piping consisted of factory pre-insulated fiberglass piping. This piping, as shown in Figure 3, was installed in underground concrete tunnels which were located largely under the campus sidewalks. As such, the tunnels also provide snow melting system for the walkways.

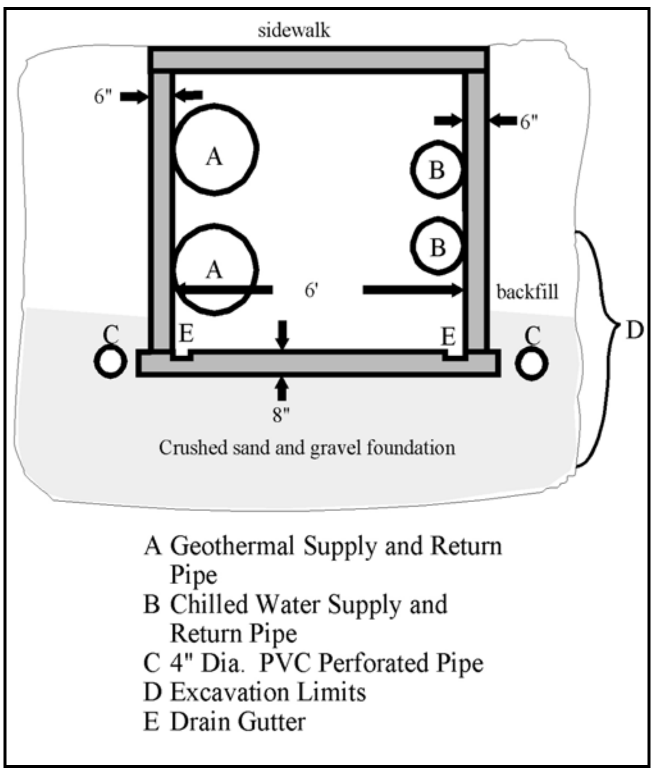

Figure 3. Tunnel construction detail.

The tunnel installation is expensive; however, it offers the opportunity to accommodate other utilities and affords much better piping access than direct burial. Completion of the tunnel system to all buildings occurred in 1992. Cost for the 1.8 m x 1.8 m (6 ft x 6 ft) tunnels was approximately $984 per m ($300 per linear ft) without piping. In most cases, the piping is hung from the walls of the tunnel. Epoxy adhesive joining is used on all fiberglass piping on the campus. This has been quite successful with no leaks reported.

In addition to changes in the hot water supply lines, the disposal side of the system has been completely redesigned. As originally constructed, each building discharged the "waste" geothermal fluid to the storm sewer. The storm sewer system then delivered this water along with roof and surface drainage to a ditch at the west side of the campus.

As a result of a Klamath Falls City ordinance, all geothermal systems had to employ injection for disposal of effluent by 1990. In response to this ordinance, the campus installed a dedicated geothermal-fluid collection network. This piping of 76 mm (3 in.) through 203 mm (8 in.), pre-insulated fiberglass material was installed in the campus tunnels along side the supply piping.

Completion of the collection system resulted in an innovative design of a new classroom building constructed in 1988. The building heating system was designed to use the "waste" water from the collection system rather than the primary geothermal supply water This design eliminated the need to increase total geothermal pumpage for the campus.

BUILDING HEATING SYSTEMS

The original design for the campus involved the use of the geothermal fluid directly in the individual building heating systems. After a few years of operation, it was apparent that use of the fluid directly would not be acceptable over the long term. Serious corrosion problems occurred, particularly in copper and copper alloys. Copper tubing, due to attack by hydrogen sulphide (H_2S), failed in as little as 5 years. In addition, various solders used for joining the copper piping were completely removed from fittings in as little as 2 years.

In response to this situation, plate heat exchangers have been installed in all buildings to isolate the building heating systems from exposure to the geothermal fluid. Most of the heat exchangers are constructed of Type 316 stainless steel and nitrile rubber gaskets.

COOLING

In addition to providing for the heating needs of the campus, the geothermal resource, in conjunction with an absorption chiller installed in 1980, supplies a portion of the cooling needs as well.

The chiller, which works on the same principle as a gas-fired refrigerator supplies the base-load cooling needs of approximately 26,000 m^2 (280,000 ft^2) of buildings area. To accomplish this task, it requires 38 L/s (600 gpm) of 88°C (190°F) geothermal fluid. In comparison to a standard application, this machine produces only about 50% of its cooling capacity. This is due to the fact that absorption chillers are designed to operate on a 116°C (240°F) heat input. The OIT resource only produces 89°C (192°F) fluid and as a result, the machine capacity is reduced. Figure 4 gives a flow scheme for a typical lithium-bromide/water absorption cycle.

Due to the absorption chiller inefficiency, cost to operate the well pumps and concern about corrosion on the copper

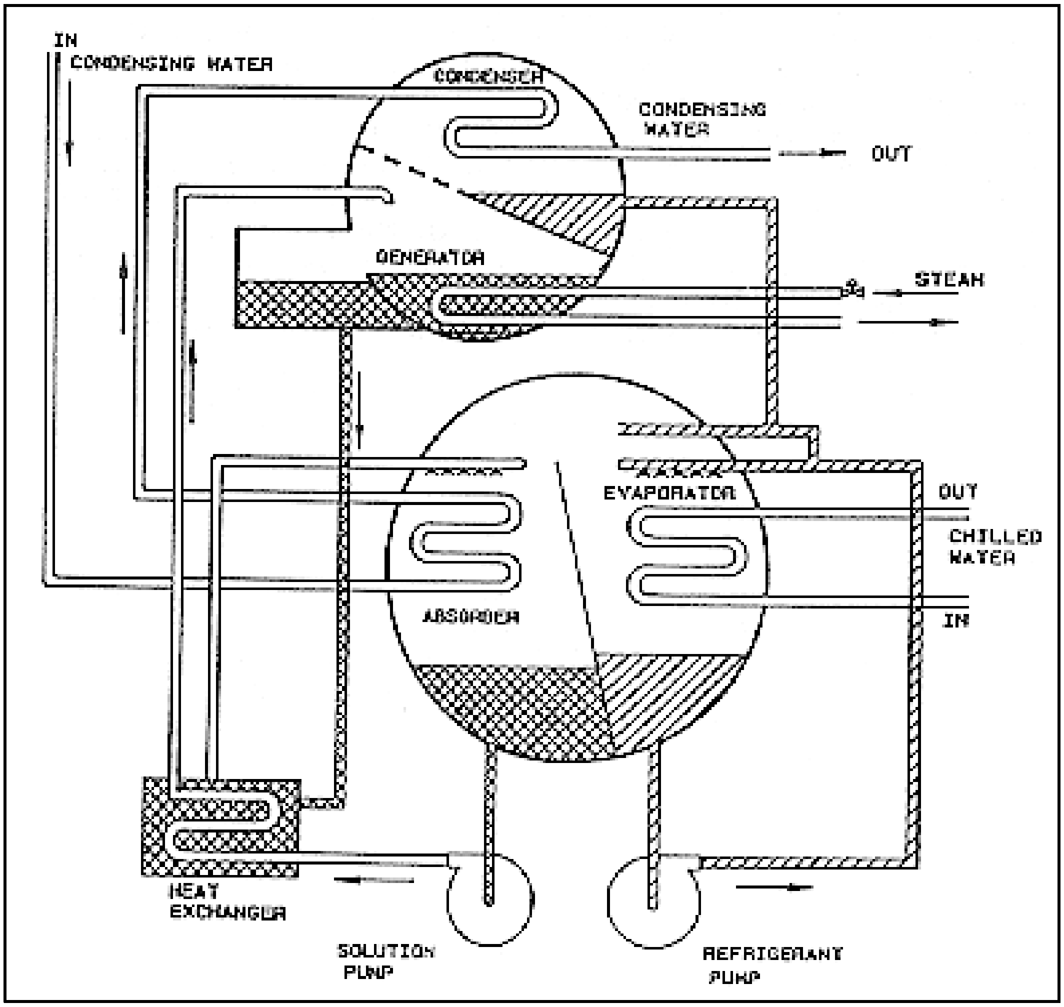

Figure 4. Typical absorption chiller components.

tubes in the generator section, this machine may be replaced in the next two years (Colahan, 1996). New electric chillers have had a huge increase in efficiency, approximately 50%, in recent years. It is estimated the cost to operate the new electric chillers will be slightly more than the geothermal absorption chiller; however, the capital cost for the electric chiller is much less (the electric chiller is less than half the cost of an absorption chiller for a 150-ton service). The absorption chiller and the 33-year-old backup centrifugal electric chiller will be replaced with two modern electric chillers--if funds are appropriated by the legislature.

DISPOSAL

Since its original construction, the OIT system has employed surface disposal. Geothermal waste water had historically been collected, either through the storm drains or more recently via dedicated collection network, and delivered to a drainage ditch on the west side of the campus.

Since 1990, all geothermal effluent has been injected. A new collection tank was installed just west of Purvine Hall (Figure 1). All waste flow is delivered from the collection system to the tank. From here, booster pumps delivered the flow through a 457-m (1,500-ft) pipeline to the injection well located at the southwest corner of the campus.

The first injection well was completed to a depth of 610 m (2,000 ft) in late-1988 at a cost of approximately $300,000. Testing of this well revealed that it was capable of accepting only about 22 L/s (350 gpm) on a long-term basis due to drilling mud invasion into rock fractures. As a result, a second well was air-drilled in 1992, about 82 m (270 ft) east of the first injection well, to a depth of 510 m (1,675 ft). This well is capable of accepting approximately 57 L/s (900 gpm) and it was possible to bypass the injection booster pumps.

CONCLUSIONS

The OIT campus has successfully used geothermal fluids for heating since 1964. A number of improvements to the system that have occurred over 32 years of operation could benefit potential developers of geothermal resources for similar applications. These include using lineshaft well pumps that use bronze bearings, oil-lubricated enclosed lineshaft, keyed-colleted impellers, and extra lateral. A distribution system employing utility tunnels proved desirable for the installation of additional utilities (i.e., return piping, chilled water supply and return pipelines, computer cables, electric power cables, cold-water supply lines, etc.) and maintenance; however, the installation cost of these systems is high. Fiberglass piping with epoxy adhesive joining has been successful. Isolation heat exchangers are necessary when a direct distribution system is used (i.e., geothermal fluids delivered to each building) to protect the heating units, which are primarily constructed of copper materials. Cooling of buildings is possible with geothermal fluids using absorption chillers; however, resource temperatures should be greater than 116^{o}C (240^{o}F). Due to inefficiency and operating costs, the OIT geothermal absorption chiller will eventually be replaced with electric chillers. Disposal of geothermal fluids by means of injection wells may be required to meet state or local regulations.

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GEOTHERMAL PIPELINE

Progress and Development Update
Geothermal Progress Monitor

MEETING ANNOUNCEMENTS

1. Geothermal Resources Council 1996 Annual Meeting features Geothermal Development in the Pacific Rim. September 29 - October 2, 1996, Portland Marriott Hotel, Portland, OR.

   Field Trip No. 1 - Klamath Falls Direct-Use and Newberry Volcano, September 28 and 29 (2-day trip). The first day will be dedicated to touring the direct-use facilities in Klamath Falls including the city's district heating system, snow melting facilities, heating and cooling system at OIT, a downhole heat exchanger system, Liskey Farms, and other nearby direct-use sites. The second day is a tour of the Newberry caldera and CE Exploration Company's drilling operation on the northwest flank of the caldera. This is a proposed site for a 30-MW power plant.

   For a copy of program and registration information, contact: GRC (916) 758-2360 or e-mail: geores@wheel.dcn.davis.ca.us.

2. ASTM Committee E-44 on Solar, Geothermal and Other Alternative Energy Sources will hold a meeting November 21-22, 1996 at Hyatt Regency, New Orleans, LA. ASTM meetings are open to all interested individuals. For a copy of the agenda or other information, please call or contact: Teresa Condrowska, ASTM (610) 832-9718 or e-mail: tcendrow@local.astm.org.

CALIFORNIA
Proposed and Past Geothermal Activities Within the Glass Mountain KGRA

Proposed Action

Calpine Corporation submitted a Plan of Utilization (POU) to the BLM for constructing, operating, and maintaining a 49.9-MW (gross) dual-flash geothermal power plant plant, with associated geothermal production and injection wells, well pads, roads, interconnected geothermal fluid pipelines, and an accompanying 24-mile 230-kV transmission line. This project, known as the Fourmile Hill Geothermal Development Project, would be located at the Glass Mountain Known Geothermal Resource Area (KGRA) on the Klamath and Modoc National Forests.

Location. The proposed geothermal power plant, well pads, and fluid pipelines would be located within federal geothermal leases CA21924, CA21925, and CA21926, all within the Glass Mountain KGRA. Leases CA21924 and CA21926 are located on the Klamath National Forest; while, lease CA21925 is located on the Modoc National Forest. The proposed power plant site would be located in Section 28 within a six-section area known as the Fourmile Hill project area, located in Section 21, 22, 23, 28, 29 and 30, Township 44 North, Range 3 East, MDB&M, Siskiyou County, California. The planned period of commercial operation for the proposed action is 45 years.

Power Plant and Associated Facilities. The proposed action would involve production of geothermal fluids (hot water and steam) from an underground reservoir. These fluids would be produced from 9 to 11 2-phase production wells located at five proposed production well sites (well pads 88-28, 84-28, 56-28, 26-28 and 18-28). The fluids would be transported via surface pipelines to the proposed dual flash geothermal power plant; where, the steam would be directed to two steam turbine-driven generators. Spent brine and condensate would be pumped through surface pipelines to the three proposed injection well pads (well pads 87-29, 13-28 and 67-21) for injection to the subsurface geothermal reservoir. There would be one injection well located at each injection well pad.

Each of the production and injection well pads would occupy approximately 2.5 acres, for a total well pad area of about 20 acres. The power plant site would occupy approximately 3.0 acres. There would be a total of 4.25 miles of surface pipelines (1.5 miles of production lines, and 2.75 miles of injection lines), and about 2.5 miles of new roads associated with the power plant and well pads.

The proposed action would also include development of a transmission line that would extend from the proposed geothermal power plant in an easterly direction for approximately 24 miles to a proposed intertie station along the BPA Malin-Warner transmission line. The Malin-Warner line is a 230-kV system that parallels Highway 139. The proposed transmission line would be constructed using H-frame wood poles with steel structures used at certain locations. The transmission line would be located primarily on the Modoc National Forest, with only a small portion of the line near the power plant site being located on the Klamath National Forest. Right-of-way width would be approximately 125 feet along the constructed length of the transmission line. Construction of access roads for installation of structures and maintenance would be required along portions of the right-of-way.

Past Activities

In 1981, the BLM, as lead federal agency for geothermal heating, issued numerous leases within the Medicine Lake area for the purpose of exploring and developing a geothermal resource within the project area (i.e., the Glass Mountain KGRA). As part of the authorization for leasing, the BLM and

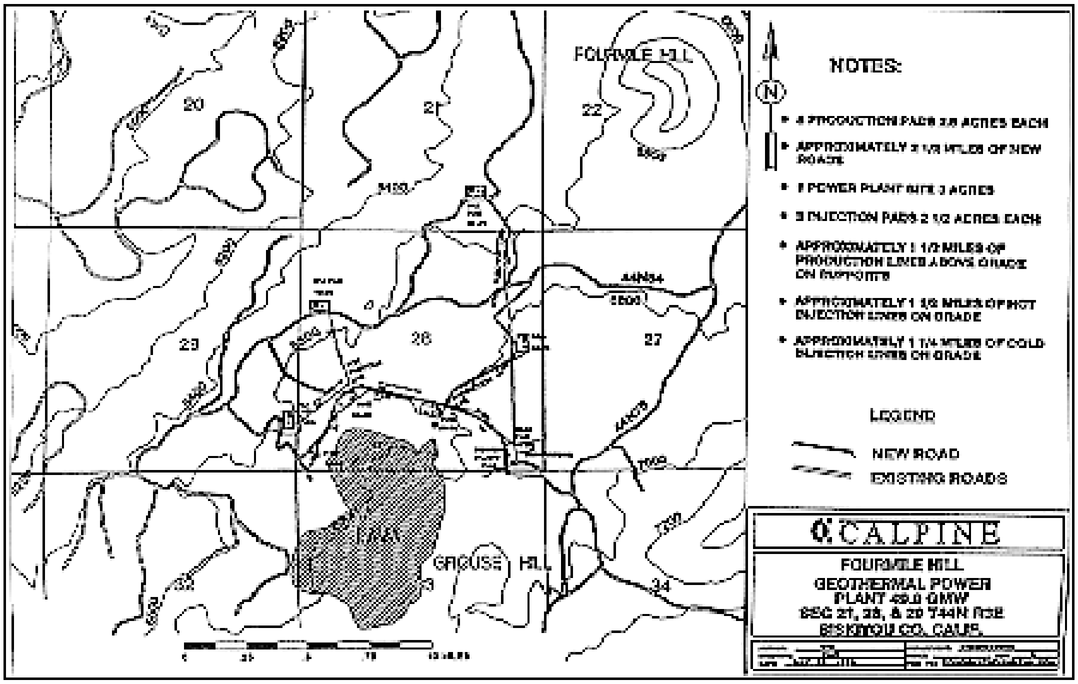

Figure 1.Fourmile Hill project area

USFS jointly prepared and issued an environmental assessment (EA) for the "casual use and exploration" of the geothermal resource. In 1984, the EA was supplemented to analyze additional potential leases and to address the impacts associated with geothermal development within the KGRA. The supplemental EA identified lease stipulations which provide for surface resource protection measures. These mitigations were and are incorporated as terms and conditions of use and development of the geothermal resource.

As of this date, there has been limited geothermal exploration within the Glass Mountain KGRA; however, within the past two years, there have been two exploration projects proposed in the project vicinity. The first was a proposed exploratory geothermal drilling project within the Glass Mountain KGRA, which was sponsored by the California Energy General Corporation (CEGC). The second project was Calpine's Fourmile Hill Geothermal Exploration Project, which examined the potential environmental effects that would result from an exploratory geothermal drilling program. Environmental assessments and Findings of No Significant Impact (FONSI) were prepared for both of these projects, and were distributed for public review. Records of Decisions (RODs) have been filed for each of these projects as well.

Scope of Analysis

This EIS/EIR for the proposed action will identify a reasonable range of alternative actions, analyze the proposed action and alternatives in terms of direct, indirect and cumulative effects, and identify appropriate mitigation measures for each type of significant effect. The analyses in the EIS/EIR will address potential impacts to geology, minerals, soils, geothermal resources, groundwater, surface water, cultural and paleontological resources, Native American resources, vegetation, wildlife, air quality, visual resources, noise levels, land use, recreation, traffic and access, human health and safety, and social and economic values related to development of the project. Cumulative effects will also be addressed; the EIS/ EIR will document the effects on the resources as the result of not only the proposed action, but also of previous actions, and any reasonable foreseeable activities in the vicinity of the proposed action. (Source: Bureau of Land Management, Alturas, CA, June 7, 1996)