U.S. Geothermal District Heating: Barriers and Enablers

by

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Abstract

Geothermal district heating experience in the U.S. is reviewed and evaluated to explore the potential impact of utilizing this frequently undervalued renewable energy resource for space and hot water heating. Although the first U.S. geothermal district heating system (GDHS) was constructed in the 1890s in Boise, Idaho, growth in the sector has been slow. Currently there are only twenty-one operating GDHS in the U.S. with a capacity of about 100 MW thermal. In this study the main barriers and enablers to the growth of district heating were identified and investigated. Initially a literature review and interviews with current U.S. district heating operators were used to collect data on various aspects of the systems and their development. Based on analysis of the data and the current structure of the geothermal district heating regulatory and market environment in the U.S. recommendations on how to advance geothermal district heating in the U.S. are developed.

Technical feasibility of increasing the geothermal district heating capacity to 10,000 MW_t was established by identifying the available resource and technology for utilization. Furthermore, the opportunity presented by Engineered Geothermal System (EGS) was briefly explored. Social feasibility was analyzed and the need for geothermal energy education and expanded resource exploration was recognized. Furthermore, it is hypothesized that most government support for GDHS will come from state governments in the future and the importance of well structured incentives that support the growth of sustainable GDHS emphasized. Legal and regulatory barriers were reviewed along with the economic feasibility of GDHS. The economic analysis revealed competitive levelized energy costs and that rising drilling costs might be a barrier to GDHS development. A modest investment of about five billion dollars is needed to increase U.S. GDHS capacity to 10,000 MW thermal.

Thesis supervisor: Jefferson W. Tester
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1 Introduction

In early winter of 1890 in Boise, Idaho, Boise Water Works began drilling wells just outside of town. The picked a spot where the ground "did not freeze […] in the winter, seemed warm near the surface and [where] cattle had stepped in the soft earth never to appear again" (Rafferty, 1992). Two 400 foot deep wells were drilled and combined they provided 550 gallons a minute of hot water (170°F / 77°C). This presented Boise Water Works with a unique opportunity for utilizing a natural geothermal resource. They could now offer their customers something else besides just drinking water – they had heat. The company built a wooden pipeline leading from the hot wells into town where they constructed a 65 by 125 foot enclosed swimming pool (K. Neely et al., 2006). The wooden pipeline was subsequently extended to other buildings in town and by 1892 the first U.S. geothermal district heating system (GDHS) was born. Within a few years the system was serving hot water to over 200 homes and 40 businesses in the area and now over a hundred years later it is still going strong (Rafferty, 1992). However, after a full century of development in the sector, there are only 22 GDHS operating in the U.S. providing about 100 MW_t[1]. The growth has been in sharp contrast with other nations like Iceland where the first GDHS was built in the 1930s and now about 90% of the country's space heating needs is supplied by geothermal energy (Loftsdottir & Thorarinsdottir, 2006).

Since the beginning of the industrial revolution in circa 1750, the world's greenhouse gas emissions have increased dramatically from about 280 ppm to 375 ppm in 2005. Of the world's anthropogenic greenhouse gases, carbon dioxide is the most important. The Intergovernmental Panel on Climate Change reported in 2007 that "the atmospheric concentration of carbon dioxide in 2005 exceeds by far the natural range over the last 650,000 years" and that CO_2 concentrations are growing at an increasingly rapid rate as a consequence of increased fossil fuel and land use (Intergovernmental Panel on Climate Change, 2007b). From 1970 to 2004 CO_2 emissions grew about 80% and in 2004 contributed about 77% of the world's anthropogenic greenhouse gas emissions

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[1] MW_t = Megawatts thermal

(Intergovernmental Panel on Climate Change, 2007a). Furthermore, instability in oil and gas producing regions and depleting fossil fuel resources in certain areas have led to volatile fuel prices and worries about energy security. To combat these issues, nations worldwide are reviewing their energy infrastructure and use patterns and looking for ways to conserve power and move their energy production towards increased use of local, sustainable resources. Geothermal is such a resource and geothermal district heating provides a local, sustainable, essentially emission free source of heat.

1.1 Energy Demand for Low Temperature Sources

Approximately 30% of the U.S. energy demand comes from sources utilizing the energy at temperatures below 300°C (572°F). Figure 1 shows the distribution of energy use versus temperture in the U.S. (J.W. Tester, 1982). A significant part of that energy demand stems from space and water heating. Figure 2 shows the end use sector shares of U.S. total energy consumption in 2006.

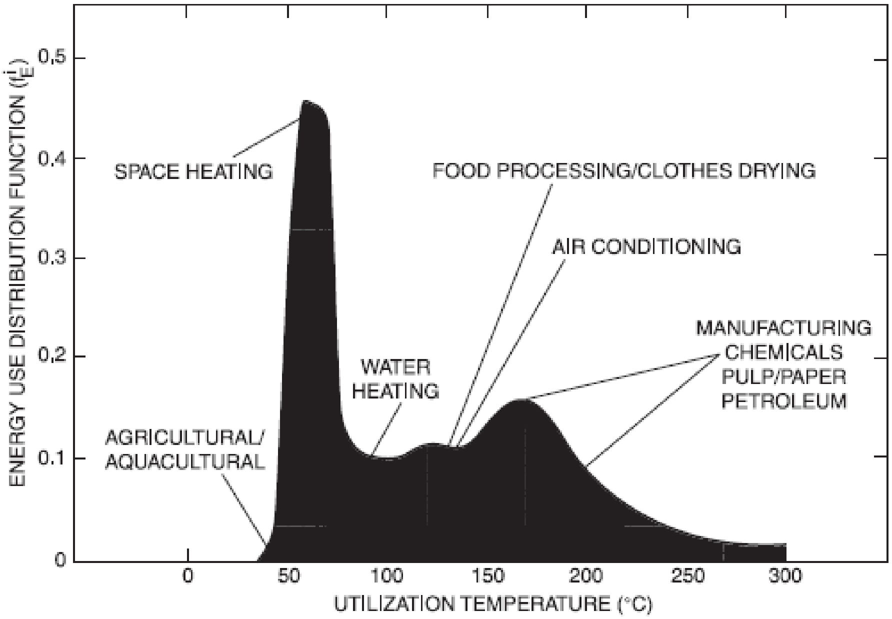

Figure 1 - Fractional energy use distribution as a function of end-use temperature for non-electric applications below 300°C. The function f_E^i at T_i is the derivative of the cumulative energy use at that specific temperature T_i (J.W. Tester, 1982).

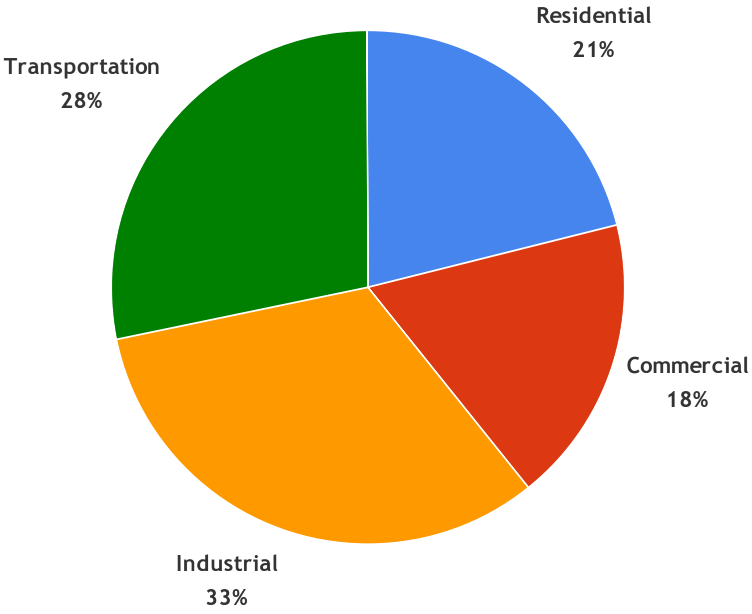

Figure 2 - End-use sector shares of total consumption, 2006 (Data from Table 2.1a (Energy Information Administration, 2007a)).

The residential sector represents 21% of the total energy consumption and about half of the residential load is due to space heating (see Figure 2 and Figure 3). District heating systems can also supply hot water heating[2] and combined space and hot water heating attribute 64% of the total residential energy demand in the U.S. The commercial sector which represents about 18% of the total U.S. energy load also contributes to the space heating load. In fact, about 30% of the total energy consumption of the commercial sector stems from space heating[3]. The most common fuels used for space heating in the U.S. are natural gas, electricity fuel oil, and propane (Energy Information Administration, 2007a). Other fuels include biomass, solar and geothermal energy.

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[2] Even though, geothermal district heating systems can moreover provide energy for cooling as for example in Kanaka Rapids, Idaho and the Oregon Institute of Technology, as a conservative estimate only heating and hot water applications are included here.

[3] Including all district heating for commercial buildings and assuming that all reported fuel oil and half of reported natural gas use in commercial buildings is utilized for space heating.

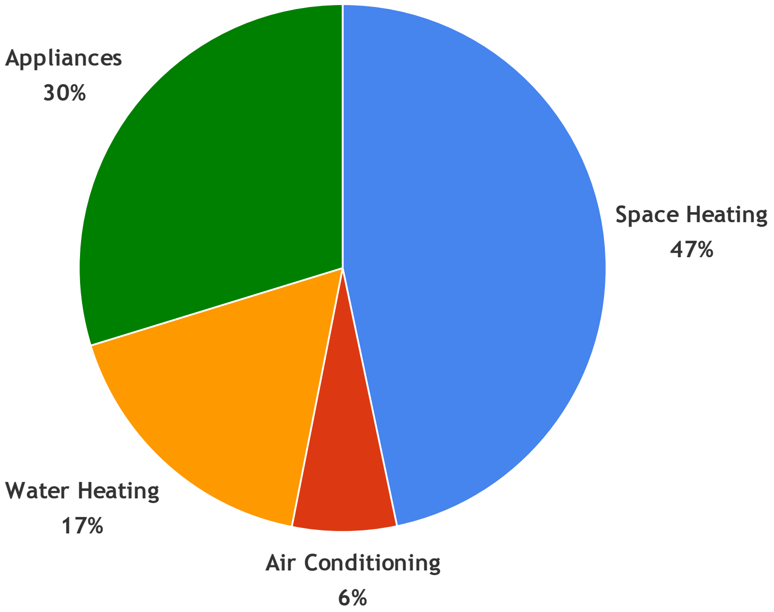

Figure 3 - Household energy consumption by end-use 2001 (Data from Table 2.5 (Energy Information Administration, 2007a)).

1.2 Geothermal Energy

Geothermal energy is harnessed from heat found beneath the earth's surface. It can be used to produce electricity, to provide heat and hot water for direct applications and indirectly by using geothermal heat pumps. To produce electricity, geothermal steam or brine is extracted from the ground through wells and used to run a turbine connected to a generator that produces electricity. Direct use includes district heating, industry applications and spas and geothermal heat pumps utilize the temperature gradient between the ground and air to heat or cool buildings.

1.2.1 U.S. Geothermal Potential and Utilization

The estimated potential for geothermal energy from identified natural hydrothermal resources in the U.S. is much higher than what is presently being used for direct use or electricity production. The United States Geological Survey (USGS) has estimated that the available accessible geothermal shallow resource, capable of producing electricity, is

30,000 MW_e[4] from identified shallow hydrothermal sources and a further 120,000 MW_e from unidentified shallow sources (Muffler & Guffanti, 1979). Furthermore, it is expected that geothermal energy in the U.S. could ultimately provide more than 60,000 MW_t from direct use. Besides conventional hydrothermal resources, geopressured, co-produced and engineered geothermal systems (EGS) provide further potential for geothermal energy utilization (Green & Nix, 2006)[5]. Estimates for the accessible geopressured and co-produced U.S. resource base amount to 130,000 MW_e and engineered geothermal systems (EGS) could provide more than 100,000 MW_e in the next 50 years[6] assuming an active development and deployment program during the next ten to fifteen years (Tester et al., 2006). Geothermal heat pumps could furthermore supply more than 1,000,000 MW_t (Green & Nix, 2006).

Figure 4 shows the distribution of the geothermal hydrothermal resource in United States and Figure 5 maps the temperature at 6 km depth in the U.S. and thus illustrates the potential for exploitation of the earth's heat using EGS. Electricity can be produced from temperatures around 100°C and up and at 6 km depth almost all of the U.S. is at or above that temperature.

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[4] MW_e = Megawatts electric

[5] Assessments of hydrothermal and geopressured resources are mainly based on a geothermal energy resource assessment done by the USGS in 1978. Work is underway at the USGS to update that assessment.

[6] The ultimate potential of EGS is not resource limited because the actual heat resource stored in U.S. sedimentary layers equals more than 14 x 10^6 EJ (Jefferson W. Tester et al., 2006).

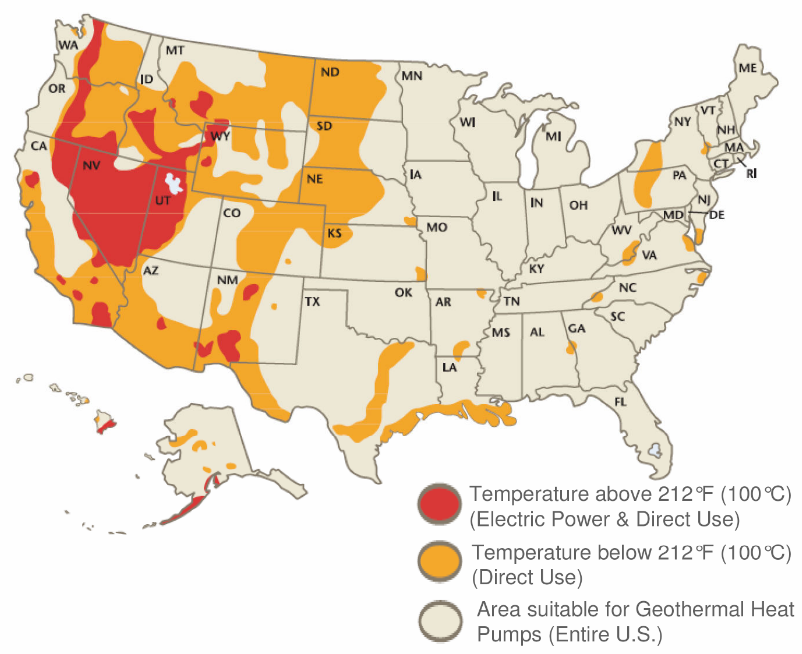

Figure 4 - Identified U.S. conventional hydrothermal resource (Richter, 2007).

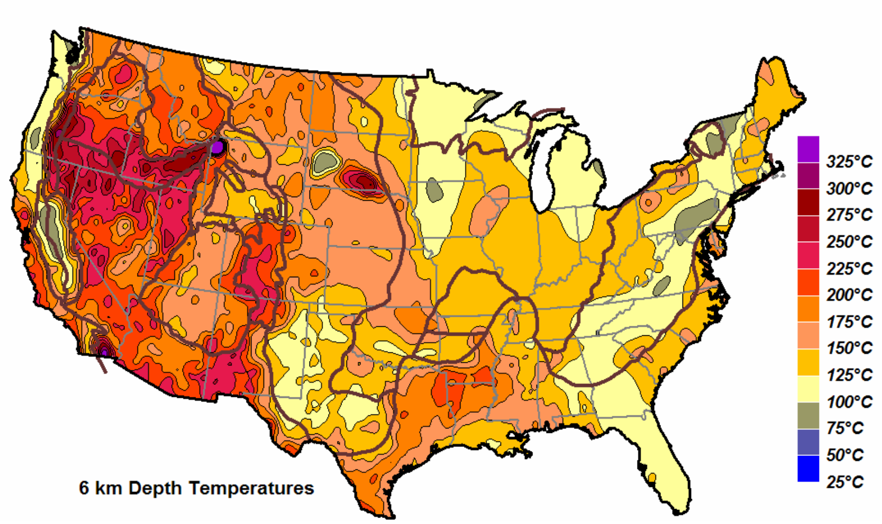

Figure 5 - Map shows the geographical layout of EGS resource grades in the continental U.S. defined in terms of stored thermal energy at 6 km (Blackwell & Richards, 2007).

In 2006 geothermal generation in the U.S. represented only 0.5% of the total U.S. energy mix (Energy Information Administration, 2007a). Table 1 shows U.S. installed capacity of geothermal energy in 2005 along with what the Department of Energy (DOE) estimates the potential of geothermal capacity in 2050 based on data from literature and conclusions of geothermal workshops held by the DOE. In 2005 U.S. geothermal electricity production was 2,285 MW_e, direct use 617 MW_t and geothermal heat pumps had an estimated capacity of 7,200 MW_t[7].

Table 1 - U.S. Geothermal capacity in 2005 and estimated potential in 2050 (Data from (Green & Nix, 2006)).

Generating Capacity	2005	2050
Shallow hydrothermal [MW_e]	2,544	30,000
Engineered Geothermal Systems [MW_e]	0	> 100,000
Co-produced & geopressured	2	130,000
Thermal		
Direct Use [MW_t]	617	45,000
Geothermal heat pumps [MW_t]	7,200	> 1,000,000

Growth in U.S. geothermal utilization was substantial in the 1980s, then leveled off in the 1990s and is now increasing again (see Figure 6). According to the Geothermal Energy Association (GEA) there are currently up to 2916 MW of new geothermal power plant capacity under development in the United States, including projects in the initial development phase, and about 251 MW that are currently under construction (Geothermal Energy Association, 2007). Today the fastest growing sector of U.S. geothermal utilization is the heat pump sector with 11% annual growth (Lund et al., 2005). Figure 6 shows U.S. geothermal, wind and solar PV energy consumption from 1960 to 2005.

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[7] Most of the heat pumps are oversized in heating capacity in order to accommodate for cooling loads in the summer.

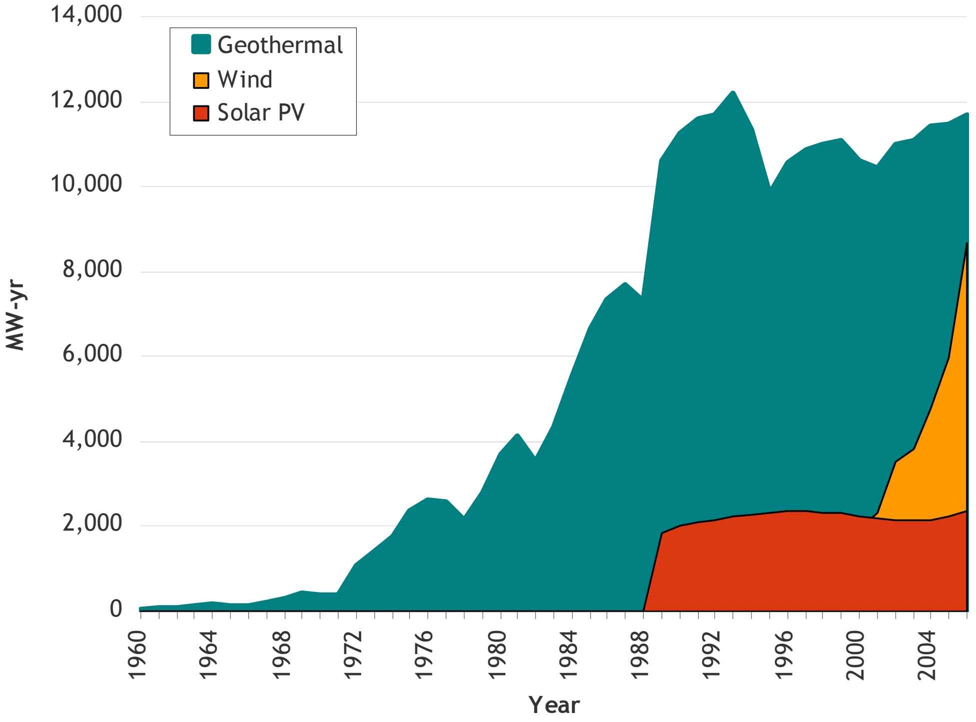

Figure 6 - U.S. geothermal, wind and solar PV energy consumption 1960-2006 (Data from table 10.1 (Energy Information Administration, 2007a)).

1.2.2 Geothermal Space Heating Applications

Geothermal space heating applications include direct use and geothermal heat pumps. Figure 7 shows the division of geothermal energy direct use applications in the United States by end use. Space heating represents the biggest portion of direct utilization (37%) but fish farming, bathing and swimming and greenhouse heating are also a significant fraction of the load.

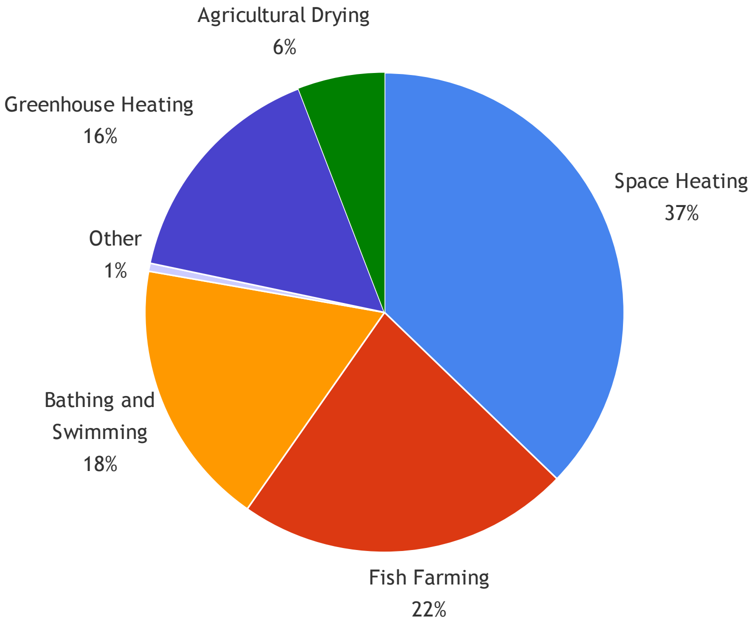

Figure 7 - Geothermal direct use in the U.S. 2004 (data from table 5 (Lund et al., 2005))[8].

Geothermal district heating systems mainly utilize direct use technology but are sometimes augmented using heat pumps. There are 21 operating GDHS in the United States. Figure 8 shows the location of these systems and how their location maps onto the U.S. hydrothermal resource. This thesis will focus on geothermal district heating systems and leave analysis of smaller space heating systems to other work. A geothermal district heating systems is defined here as a system that uses a geothermal resource as a heat source and distributes heat through a distribution network to five or more buildings. The average number of buildings connected to each GDHS in the U.S. is about 40. Note the number of buildings on the system does not necessarily represent the heat load or square footage of space heated but it does illustrate the distribution network needed to serve the system.

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[8] Other includes snow melting and industrial process heat.

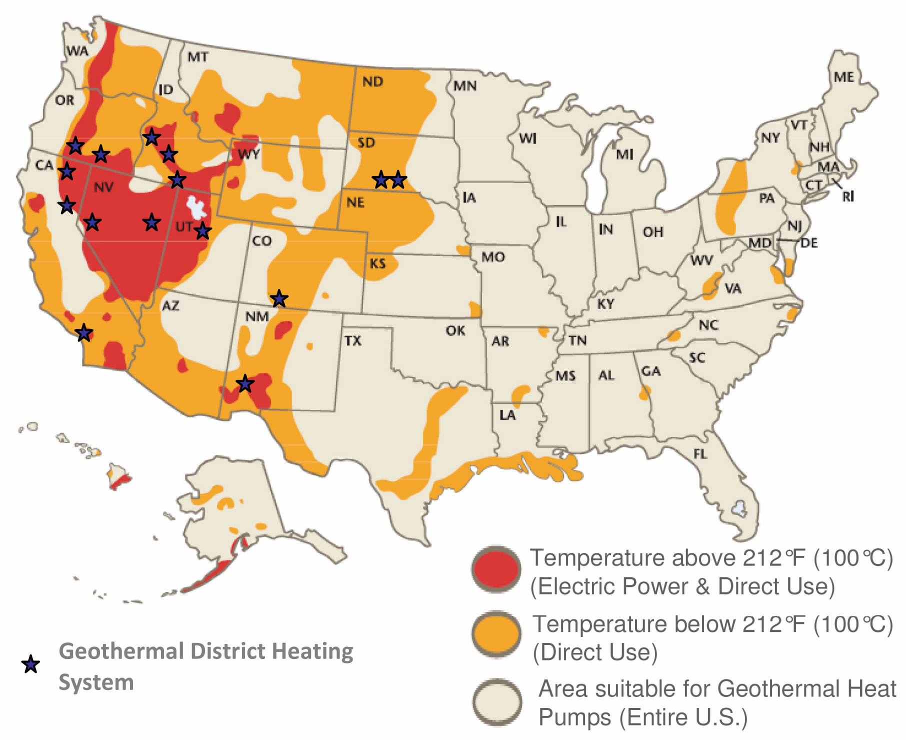

Figure 8 - U.S. Geothermal district heating system locations (resource map from (Richter, 2007)).

The technology used for GDHS is mature and widely used. For instance in Iceland, about 90% of space heating need is met by GDHS. Once a potential geothermal resource has been identified, a well is drilled to access the hot water in the reservoir. The hot water is then either pumped from the well or in the case of artesian wells comes up without pumping on accord of pressure within the geothermal aquifer. When the hot fluid is on the surface it can either be directed straight through the geothermal district heating network (as in Figure 9) or it can be passed through a heat exchanger where it is used to heat up a secondary fluid that is then passed through the district heating network. The latter configuration can reduce corrosion effects due to chemicals often present in geothermal water, because it eliminates contact of the geothermal fluid to most of the system. The chemical composition of the geothermal water varies from aquifer to aquifer and must be measured to decide which kind of system is appropriate for the aquifer in question.

The hot fluid, whether it is geothermal fluid or water passed through a heat exchanger, is led to system customers through a series of pipelines that are usually buried underground and is used to heat buildings by flowing it through radiators or floor heating systems.

District heating systems can also be used to heat water for domestic use or used directly as domestic water.

Once the geothermal brine has been utilized in the system it is either injected back into the aquifer through an injection well or disposed of into a river, lake or ditch depending on local regulations, the chemical composition of the fluid and water levels in the aquifer. Figure 9 shows the schematic layout of an open loop GDHS. An open loop system is a system where the geothermal water is disposed of into a ditch, pond or waterway once it has been utilized. A closed loop system is a system where the geothermal fluid is collected after utilization and reinjected.

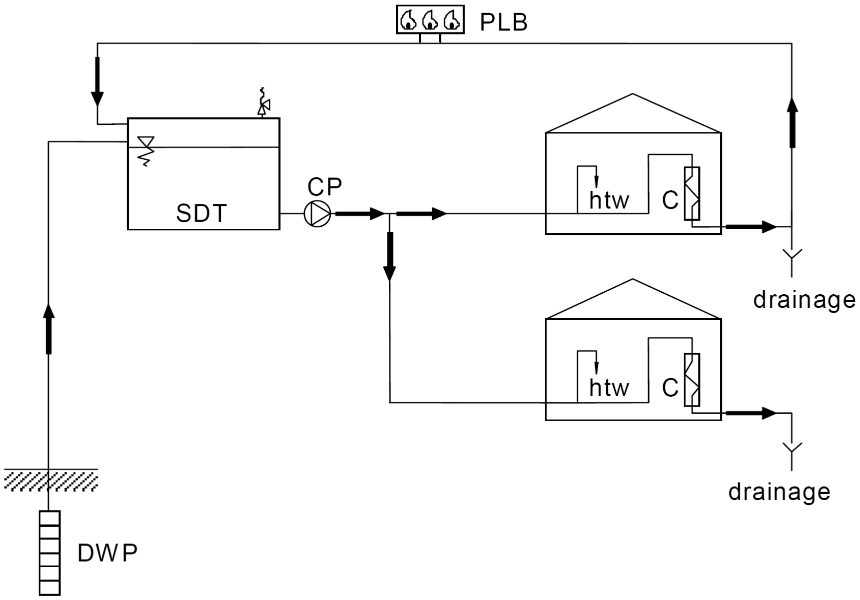

Figure 9 - Schematic layout of an open loop geothermal district heating system that uses the geothermal resource directly. DWP = deep well pump, SDT = storage and degassing tank, CP = circulation pump, PLB = peak load boiler, htw = hot water, C = convection heating (Marcel, 2007).

The energy produced from a geothermal system depends on the temperature and amount of flow of the geothermal fluid being utilized and the temperature drop of the geothermal fluid within the system. The temperature drop represents the amount of heat taken out of the fluid and used for heating purposes. This temperature drop is often called the delta T (ΔT) of the system.

1.2.3 Benefits of Geothermal District Heating Systems

Carbon dioxide emissions from the U.S. residential sector in 2006 amounted to 1,204 million metric tons and about 28% of those emissions or 338 million metric tons came from the use of petroleum products and natural gas for space heating and cooking in the residential sector. Furthermore, space and water heating accounts for approximately 130 million metric tons of the CO_2 emissions from the U.S. commercial sector[9] (Energy Information Administration, 2007b). Combining these numbers gives a total of about 470 million metric tons of annual CO_2 emissions from space and hot water heating and cooking in the United States. For comparison, that is five million tons more than the total CO_2 emissions of South Korea in 2004 (Watkins et al., 2008). GDHS provide a clean, essentially emission free form of space heating that could help offset U.S. CO_2 emissions, if deployed at a large scale.

The fluctuations in the price of substitute fossil fuels (see Figure 10) also present GDHS with a distinct advantage over their fossil fired counterparts. GDHS use an indigenous energy source that is insulated from fuel price fluctuations or supply interruptions. They provide a degree of energy security because delivered heating costs are not dependent on political or regional conflicts and GDHS are usually under the control of local companies or authorities. Since GDHS operators do not have to purchase fuel from outside sources, operating costs of GDHS are independent of the price of fuel in international and domestic markets. This provides the premise for long term stable space heating rates for GDHS which fossil fuel fired facilities cannot offer.

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[9] Assuming that all commercial CO_2 emissions from LPG, distillate fuel, residual fuel, kerosene and coal along with half of commercial CO_2 natural gas emissions, are due to space and hot water heating.

Figure 10 - Fluctuations in the average U.S. residential price for propane and no. 2 heating oil (fuel oil) for heating seasons 1990-2008. Data from (Energy Information Administration, 2008b).

1.2.4 Geothermal Space Heating at Large Scale – Iceland Case Study

Iceland, a country with a population of 300,000, is situated on the Atlantic Ridge in the middle of the North Atlantic Ocean and is blessed with a large hydro and geothermal energy resource. Iceland began utilizing these resources in the early 20th century at the same time as the industrial revolution was starting to set foot in the country. By 2005, 71.2% of Iceland's primary energy was fueled by its hydro and geothermal resources providing almost all of the country's heating needs and 99.9% of its electrical power (see Figure 11) (Loftsdottir & Thorarinsdottir, 2006; National Energy Authority of Iceland, 2007a).

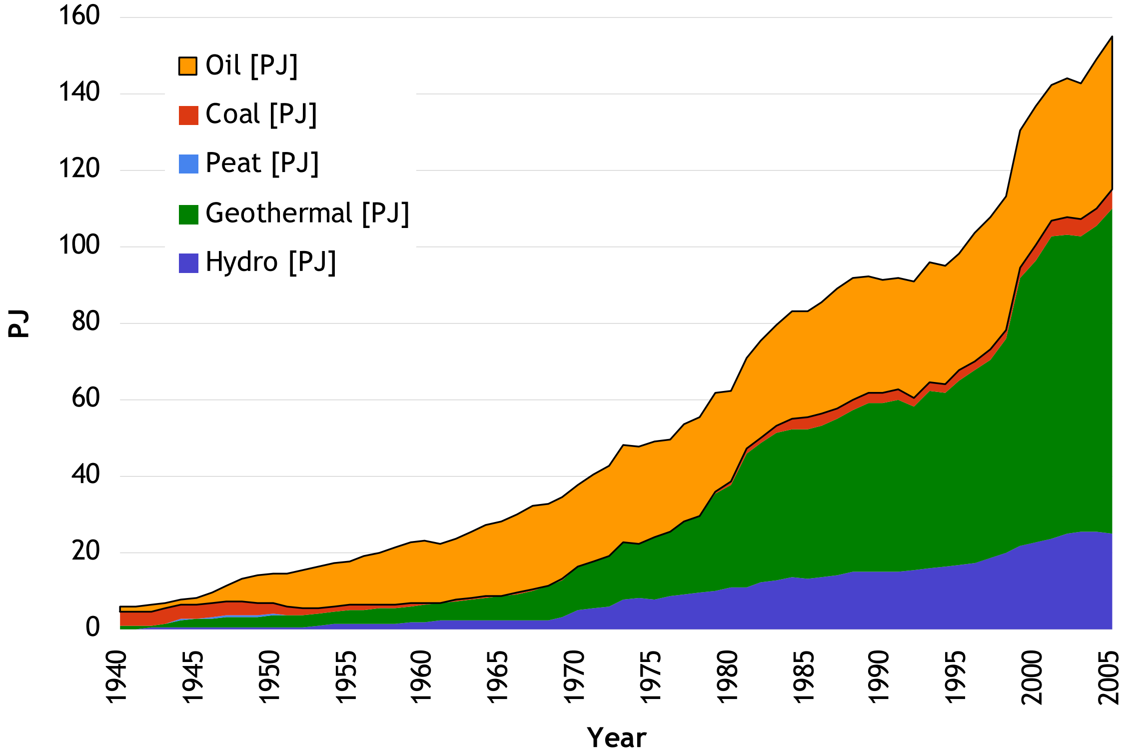

Figure 11 - Iceland's primary energy use 1940-2005. Data from (National Energy Authority of Iceland, 2007b).

GDHS operation began in Iceland in 1930 when a school building was connected to a geothermal heat source in Reykjavik. Soon after the main hospital in town along with a swimming pool and about 60 residential buildings were connected to the system and the first GDHS in Iceland was born (Gunnlaugsson et al., 2000). In 1970 geothermal energy provided 43% of Iceland's space heating needs. The 1970s oil crises increased emphasis on domestic energy sources and geothermal development increased significantly (see Figure 11) (Gunnlaugsson et al., 2001). Today about 89% of the country's space heating needs are provided by geothermal energy, with the other 11% provided by oil (1%) and by almost completely renewable electricity (10%). Geothermal district heating use is expected to grow to 92% in the long run (Bjornsson, 2006).

In 2006, there were 22 regulated geothermal district heating systems operating in Iceland. A regulated district heating utility in Iceland grants a monopoly to distribution of hot water for domestic use and space heating in a specified town or region. In addition to the regulated utilities there are about 200 small unregulated GDHS operating in the Iceland.

Icelandic geothermal district heating utilities regularly have close to 100% market penetration in the community that they are serving and are usually owned by one or more municipalities. The biggest GDHS in Iceland is the Reykjavik system which had an installed capacity of 1070 MW_t in 2004. Table 2 shows the number of wells, users and the amount of hot water distributed by the five largest GDHS in Iceland.

Table 2 - Five biggest GDHS in Iceland in 2006 (Sturludóttir, 2007).

Location[10]	Nr. of wells	Nr. of users	Hot water distributed [thousands of m^3]
Reykjavik	93	193,816	97,301
Sudurnes	10	21,687	12,501
Geothermal		18,116	11,096
Electricity/oil		3,571	1,405
North Iceland	18	18,886	7,524
Skagafjordur	10	3,305	3,540
Selfoss	7	7,172	3,376
Total	138	244,866	106,242
Other GDHS	172	33,258	19,458
Total all GDHS	310	278,124	125,700

Most GDHS water rates in Iceland are based on metered customer use in m^3 or a specified amount of liters per minute regulated by a valve. The average price per cubic meter of water in 2006 was about \$0.93 (65,23 ISK). Icelandic GDHS also charge users a fixed annual rate which is usually between \$85-\$115 (6,000-8,000 ISK) per year (Sturludóttir, 2007). Customers are not required to maintain their own back up systems and new users do not receive incentives to connect to a system.

The Icelandic State Electricity Authority, founded in the 1940s, began supporting geothermal energy development early on by developing geothermal exploration techniques and utilization methods. Following the oil crisis in the 1970s, Icelandic energy policy turned even more towards renewable resources. In the 1970s about 50% of Iceland's

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[10] The corresponding utilities are: Reykjavik = Orkuveita Reykjavikur (Reykjavik Energy), Sudurnes = Hitaveita Sudurnesja, North Iceland = Nordurorka hf, Skagafjordur = Skagafjardarveitur, Selfoss = Selfossveitur.

homes were heated with oil. As oil prices rose over the next two decades, the Icelandic government put more emphasis on developing local, sustainable resources. Importance was put on geothermal exploration and energy development. In 1967 the National Energy Authority (later Iceland GeoSurvey) became the successor of the State Electricity Agency. The National Energy Authority's mission was to acquire general knowledge about geothermal resources and to make the utilization of the nation's geothermal energy resource profitable for Iceland's economy. Also in 1967, the government established the "Icelandic" Energy Fund to increase the use of geothermal resources. The fund gives out loans for geothermal exploration and drilling and if the projects turn out to be unsuccessful the loans turn into grants. The fund is administered by the National Energy Authority. Moreover, government backed loans are available to geothermal developers in Iceland. However, as the geothermal energy industry in Iceland evolved and grew stronger, the government's role in promoting and financing geothermal energy development decreased with Iceland's many utilities now taking the lead in geothermal exploration and development activities (Sturludóttir, 2007).

The Icelandic public's attitude to geothermal energy development in Iceland is very positive. Geothermal is seen as a clean and reliable source of heat and electricity that has improved the population's quality of life in many ways. For instance, air quality has improved significantly. Figure 12 shows a dense plume of smoke over Reykjavik in 1940 caused by coal combustion, which was the power source for space heating at the time. Today the air over Reykjavik is quite clear (see Figure 13).

Figure 12 - Cloud of smoke from space heating by coal over Reykjavik in the 1940 (Sturludóttir, 2007).

Figure 13 - Clear day in modern Reykjavik (Stone, 2006).

By switching from oil to geothermal energy for space heating, Iceland reduced its CO_2 emissions in 2003 by approximately 37% and from 1970-2000 saved the Icelandic economy \$8.2 billion in fuel purchases, or three times the Icelandic national budget in 2000 (Bjornsson, 2006). Geothermal energy has allowed for the construction of numerous year round, outdoor, heated swimming pools. There are about 165 swimming pools in Iceland, of which 130 are heated with geothermal energy (Sturludóttir, 2007). Swimming is a very popular sport in Iceland and in 2002 each Icelandic citizen visited a pool on average fifteen times. Reykjavik City also constructed a man made beach in a little cove in Reykjavik. The cove is partly closed off from the open sea and the sea water in the cove is heated up with the spent brine from the Reykjavik GDHS. Hot tubs were constructed and showering facilities built. The average water temperature in the cove is about 64-68°F (18-20ºC) and 86-95°F (30-35°C) in the hot tubs (see Figure 14) (Department of Sports and Leisure in Reykjavík - ÍTR, 2008).

Snow melting using geothermal water is also becoming more popular and in 2006 about 430,000 square feet (40,000 m^2) in downtown Reykjavik were installed with a geothermal snow melting system (Bjornsson, 2006). Last but not least are geothermal spas. One of the best examples of this is the Blue Lagoon, a geothermal spa that utilizes affluent water from a geothermal power plant (see Figure 15). The Blue Lagoon has become one of Iceland's most popular tourist attractions and because of the medicinal powers of the geothermal water due to dissolved minerals, the affluent has also been used to develop a cosmetic skin care line. Figure 16 shows geothermal usage in Iceland in 2006 by end use.

Figure 14 - Man made beach in Reykjavik (Ylströndin, Nauthólsvík) (Nordic Adventure Travel, 2008).

Figure 15 - Blue Lagoon, Iceland (Blue Lagoon, 2008).

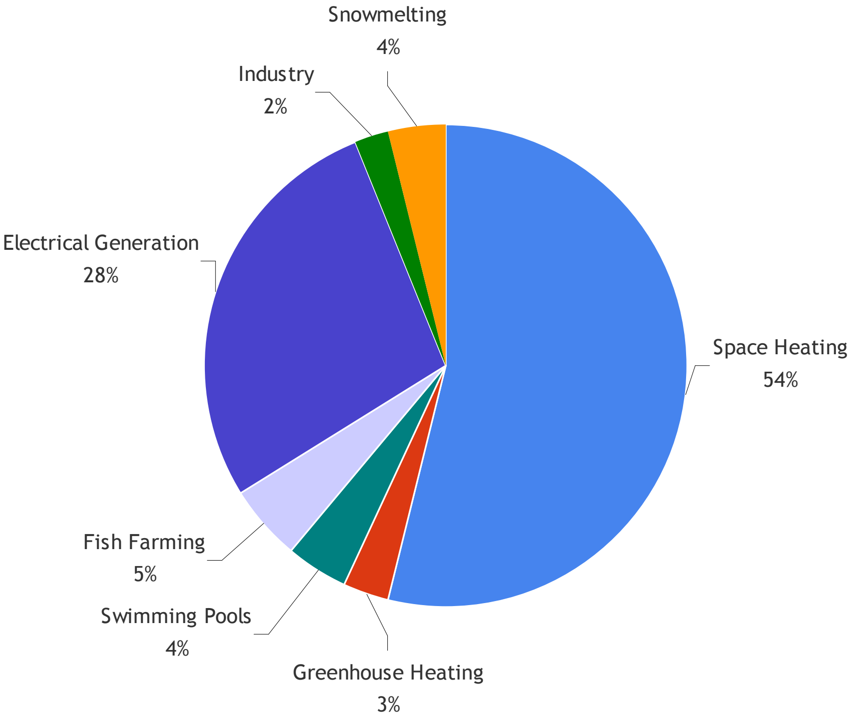

Figure 16 - Icelandic geothermal energy use in 2006 by end use (Sturludóttir, 2007).

1.3 Documentation Available on Geothermal District Heating Systems

Only a few books have been published specifically on geothermal heating (e.g. Harrison et al., 1990) while most books covering geothermal energy include a chapter or section with a general overview of geothermal heating applications (e.g. Dickson & Fanelli, 2003; Tester et al., 2005). Technological and economic aspects of geothermal heating applications are usually discussed in some detail in the literature but almost without exception geothermal district heating policy is ignored.

R. Gordon Bloomquist, is one of the few authors who has written extensively about U.S. geothermal policy. Bloomquist has written comprehensively about the U.S. legal and institutional environment of geothermal development and his work gives a good overview of the regulatory environment faced by geothermal developers in the U.S. (Bloomquist, 1986, 2003, 2004b, 2005a, 2005b). Kevin Rafferty's work on direct use applications in the U.S. provides case studies on various systems and documents the status of direct use and geothermal district heating economics (for example see Rafferty, 1992, 1993, 2003a, 2003b). The Geothermal Energy Association (GEA) has also been active in analyzing policy issues regarding geothermal energy development in the United States. The work includes a geothermal industry employment survey and analysis, stakeholder interviews to identify challenges to geothermal resource development and socioeconomics of geothermal energy (Fleischmann, 2006; Hance, 2005; Kagel, 2006)

In 1996 the findings of a U.S. DOE Low-Temperature Resource Assessment were published (Boyd, 1996). An important part of that assessment was a state by state study of areas where low temperature geothermal resources are collocated with potential users of the geothermal energy potential. 271 collocated communities were identified in the study. Letters introducing the geothermal resource located near the town or city were sent to each of the 271 communities in the hope of spurring interest within the community of developing the nearby geothermal resource. In 2000, Bloomquist and Lund published a paper emphasizing the need for a balanced approach to encourage district heating development (Bloomquist & Lund, 2000). They reported that of the 271 communities, contacted as part of the collocation study, only one community responded with interest in geothermal development. The article cites common potential barriers to GDHS development found by previous studies as local authorities unawareness of geothermal energy system benefits, the fact that GDHS are complex, high risk undertakings and that local leaders lack the necessary knowledge to develop GDHS (Brookhaven National Laboratory, 1993; Congressional Research Service, 1983).

The studies above identified potential barriers to further development by analyzing communities where geothermal resources were located but not being utilized. It is also important to look at communities where low-temperature geothermal resources are already being utilized for district heating and identify what kind of lessons can be learned from the current GDHS in the U.S. Many case studies have been written about U.S. systems, most of which are associated with the Geo Heat Center at the Oregon Institute of Technology. The Center led by John Lund has been very active in promoting and documenting geothermal direct use in the United States. Along with numerous case studies they have also assembled a database of geothermal direct utilization in the U.S. that is published on their web site and published manuals on how to develop a geothermal district heating system (Geo Heat Center, 2008).

1.4 Thesis Objectives and Approach

This thesis will build on the work by the Geo Heat Center and focus on what lessons can be learned from current GDHS in the United States. From analysis of current systems and market conditions it will try to identify what the main barriers and enablers are to increasing geothermal district heating system deployment in the U.S. As noted earlier, the USGS estimates that the ultimate potential for direct use applications in the United States is 60,000 MW_t. As geothermal direct use potential can used for a variety of applications besides space heating what is an appropriate target to set for geothermal district heating applications? Given the U.S. direct use geothermal resource and the current proportion of space heating to other geothermal direct use applications, a reasonable target for the near future could be to utilize one sixth of the resource for district heating applications and increase U.S. GDHS capacity hundred fold to 10,000 MW_t. There are currently about 800 buildings heated by GDHS in the U.S. Assuming the same size distribution between buildings and heat loads as for current systems a 100-fold capacity increase would translate into circa 80,000 buildings heated by geothermal district heating in the U.S. Another way to calculate the impact of increasing GDHS capacity to 10,000 MW_t is to compare it with the GDHS in Reykjavik, Iceland. The 2004 capacity of that system was about a 1,000 MW_t serving about 200,000 people. Consequently, increasing the U.S. GDHS capacity to 10,000 MW_t would translate to supplying about 2,000,000 people with GDHS service.

To answer whether 10,000 MW_t capacity of geothermal district heating systems in the U.S. is a feasible goal in the next few decades it first has to be established that no substantial technical barriers to widespread deployment are present. Moreover, even assuming technical feasibility will there be social or political barriers that hinder GDHS deployment on a large scale. Finally, the economic feasibility of installing 10,000 MW_t of GDHS capacity must be analyzed. This thesis will try to answer the question of the feasibility of 10,000 MW_t of installed capacity of U.S. geothermal district heating systems by analyzing barriers and enablers in each of the three areas mentioned.

Through interviews with current U.S. geothermal district heating systems operators the U.S. status and market environment of GDHS will be analyzed. Using data collected from these interviews a logistic regression will be performed to try to identify development barriers and enablers. Other important influential factors will be analyzed qualitatively in order to find important trends and issues. Comparisons between district heating development in Iceland and the U.S. will be made. Once important variables have been identified, these will be examined in more detail. Lessons drawn from this analysis will be presented and recommendations given on how to advance geothermal district heating systems in the United States.

2 Methodology

The geothermal district heating system (GDHS) sector in the U.S. was analyzed by first identifying performance metrics for the systems and variables that potentially influenced the success of projects. The metric and variables were used to construct a list of questions that were posed to all current geothermal district heating systems operators in the U.S. The data in these interviews were analyzed and evaluated to produce conclusions and recommendations.

2.1 Performance Metrics and Potential Influential Variables

The first step in analyzing the feasibility of increasing the U.S. GDHS capacity to 10,000 MW_t was to identify factors that influence the development of successful GDHS and to define what a successful geothermal system is, i.e. what attributes distinguish a successful system from an unsuccessful one. In order for a GDHS to be sustainable it needs to be economically viable. Its owners must be able to recoup the operational costs with revenues from the system or in the case of systems where the owner of the system is the system's only user, recoup the capital costs with savings from the system's operation. Consequently it was decided to identify a successful geothermal system as a running system that is able to cover its operational expenses, including required maintenance and capital stock investment costs, with its revenues or savings.

After selecting a success metric, factors that possibly influence the success of a system were identified. This was done by reviewing literature and case studies on GDHS systems and through discussions with experienced geothermal experts at the Geothermal Resources Council Meeting in 2007. Figure 17 shows the potential influential variables on GDHS success that were analyzed.

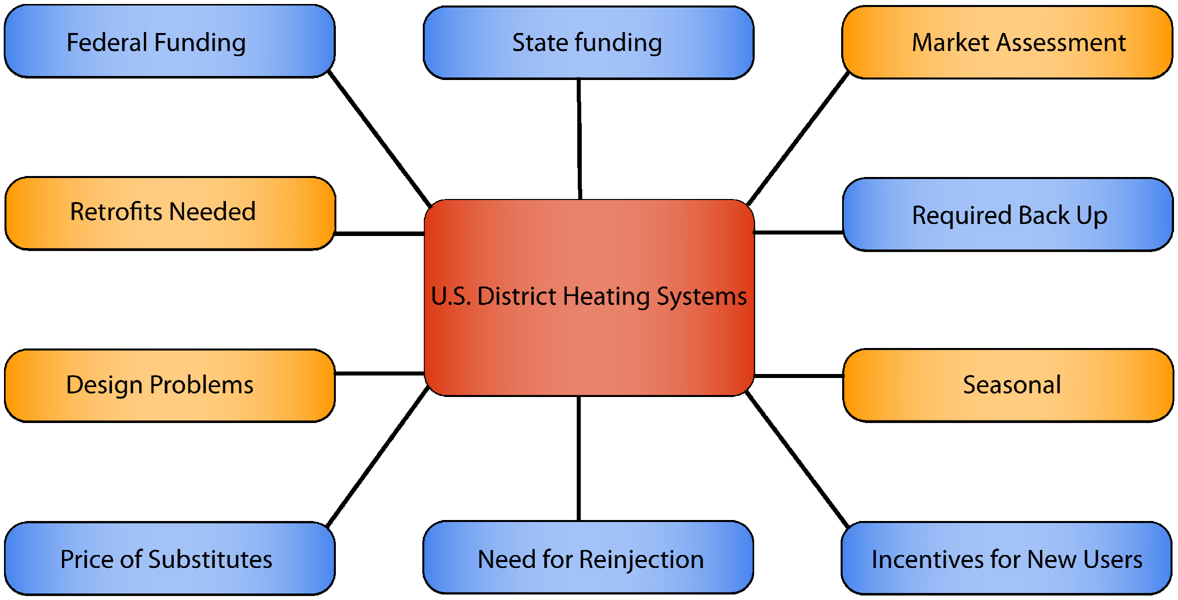

Figure 17 - Potential influential variables analyzed. Blue boxes = policy variables. Orange boxes = design variables.

2.2 Data Collection and Estimation

No comprehensive database was available to describe the current status of GDHS in the U.S. Given that the information available on existing systems varied significantly, we used the success metric and potential influential variables to build a data gathering tool. We constructed a list of questions that were used in semi-structured interviews with all current U.S. geothermal district heating operators (see Appendix A). Semi-structured interviews were chosen because of the relative ease of implementation both for the interviewer but more importantly for the interviewees. It was deemed important that the style of data collection was not too burdensome for the geothermal operators as their participation was completely voluntary.

Interviews with GDHS operators were conducted between December 2007 and April 2008 through phone calls and follow up emails. Interviews were conducted for all twenty-one operating systems along with information gathering for systems no longer in operation.

Notes taken during the interviews were subsequently typed into transcripts that were used for data analysis[11].

2.2.1 Cost Data Estimation

Costs were difficult to obtain for some systems for a number of reasons. These included operating costs, revenue or savings costs, whichever were applicable, and total capital costs and drilling costs. In several cases the age of the system resulted in limited information on project development costs. In other cases, the operational costs were integrated into the total costs of the facility using the system and proved impossible to disaggregate. Also, savings had often never been calculated or were estimated much earlier in the system's operation history. To fill in the data gaps, operating and drilling costs along with operational savings were estimated.

2.2.1.1 Operating Costs

For those systems where annual operating costs were not available the costs were estimated using electrical pump operating cost information from similar sized systems in the U.S. and the number of maintenance hours or staff working on the system. Annual costs for a maintenance worker were assumed to by $60,000 and the hourly rate for maintenance was assumed to be $30. Capital requirements for new equipment were for the most part ignored except if they were included in the data gathered during interviews.

2.2.1.2 Savings Estimation

Operational savings estimations were calculated using heating load information for the system along with price data for substitute heating fuels. It was assumed that other maintenance and operation costs, apart from fuel costs, were comparative to fossil fired systems and consequently the savings could be estimated simply as the cost of needed fossil fuel to produce the energy produced by the GDHS.

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[11] Transcripts are archived with Prof. Jefferson W. Tester.

2.2.1.3 Capital Costs

Although start up capital costs are very important for the initial economic feasibility of a system, once an installation is built and operating, the capital investment depreciates and is no longer a not a good measure of the success of the system. Consequently, if capital costs were not available for a system they were not estimated as part of this study.

2.2.1.4 Drilling Cost Estimation

Drilling cost data for the U.S. geothermal industry is sparse and insufficient to develop a geothermal drilling cost index to estimate geothermal drilling costs. On the other hand, the oil and gas industry is a well established industry in the U.S. with thousands of wells drilled each year. As the drilling process and equipment is similar in for all well types, oil and gas drilling cost data can be used to estimate geothermal drilling costs (Augustine et al., 2006).

Geothermal drilling cost estimations were based on data from the Joint Association Survey (JAS) on Drilling Costs for 1976-2005 (American Petroleum Institute, 1976-2005). The American Petroleum Institute (API) annually collects data on thousands of U.S. oil and gas wells. The dataset includes data on depth, type of well (oil, gas, or dry), location, number of wells drilled and cost and is categorized into depth intervals for each year. Onshore well data for oil and gas wells was used to approximate geothermal well costs. Using the JAS dataset, the average cost per foot for oil and gas wells was calculated for each depth interval and year.

Geothermal wells typically have a larger diameter than oil and gas wells. Oil and gas bottom hole diameters are usually 4 ½ inches or 5 inches while for geothermal wells, diameters are 7 inches, 9 $^{5}/_{8}$ inches or larger (Tester et al., 2006). Geothermal wells also often encounter higher temperatures. The larger diameter and elevated temperatures of geothermal wells lead to higher costs as a result of higher material costs for casings and longer drilling times with higher risks of failure. To account for the difference in costs between oil and gas and geothermal wells a geothermal multiplication factor was developed.

The factor was calculated by comparing actual geothermal well costs to cost estimates based on averages using JAS data. For each geothermal well the drilling cost was first estimated using only JAS data. This was done by multiplying the well's depth with the JAS estimated average cost per foot for that depth interval for the year of drilling. For example, for the Elko Heat Company well drilled to 869 ft in 1981 the JAS estimated cost was calculated as follows:

*JAS estimation = Depth in feet * JAS average cost per foot for interval 0-1249 ft in 1981*

= 869 ft * $47/ft = 0.041 M$

The estimated cost was compared to the real cost of the geothermal well and the ratio between the two taken. For instance in the case of the Elko Heat Company well the ratio was calculated as:

Ratio = Real cost in 1981$/ JAS estimated cost in 1981$ = 0.166 M$ / 0.041 M$ = 4.05

Table 3 - Geothermal well multiplication factor estimation.

Geothermal Well	Depth (feet)	Year	Actual well cost (M$)	JAS well cost (M$)	Ratio = Actual cost/JAS cost
Geysers Actual I	5,906	1976	0.486	0.179	2.72
Geysers Actual II	10,000	1989	2.275	1.033	2.20
Imperial Valley Wells (averaged)	5,250	1976	0.165	0.159	1.04
EE-2	15,289	1980	7.300	3.268	2.23
EE-3	13,944	1981	11.500	2.702	4.26
EE-3A	15,001	1988	5.160	2.856	1.81
Canby	2,100	2000	0.450	0.127	3.53
CSI I	1,800	1979	0.105	0.062	1.70
CSI II	1,800	1980	0.100	0.069	1.45
Elko Heat Company	869	1981	0.166	0.041	4.05
City of Boise	3,200	1998	0.650	0.195	3.33
Philip	4,266	1980	0.312	0.173	1.80
Geothermal well multiplication factor					**2.51**

The geothermal well multiplication factor was calculated by taking an average of the ratios between actual geothermal well costs and estimated JAS costs (see Table 3). It should be noted that not all of the geothermal wells were drilled for district heating purposes; the first six wells listed in Table 3 were drilled for geothermal energy electric power generation. Figure 18 compares the actual and estimated geothermal well costs for the six geothermal district heating wells. Also shown are the corresponding JAS estimated costs for an oil and gas wells drilled to the same depth.

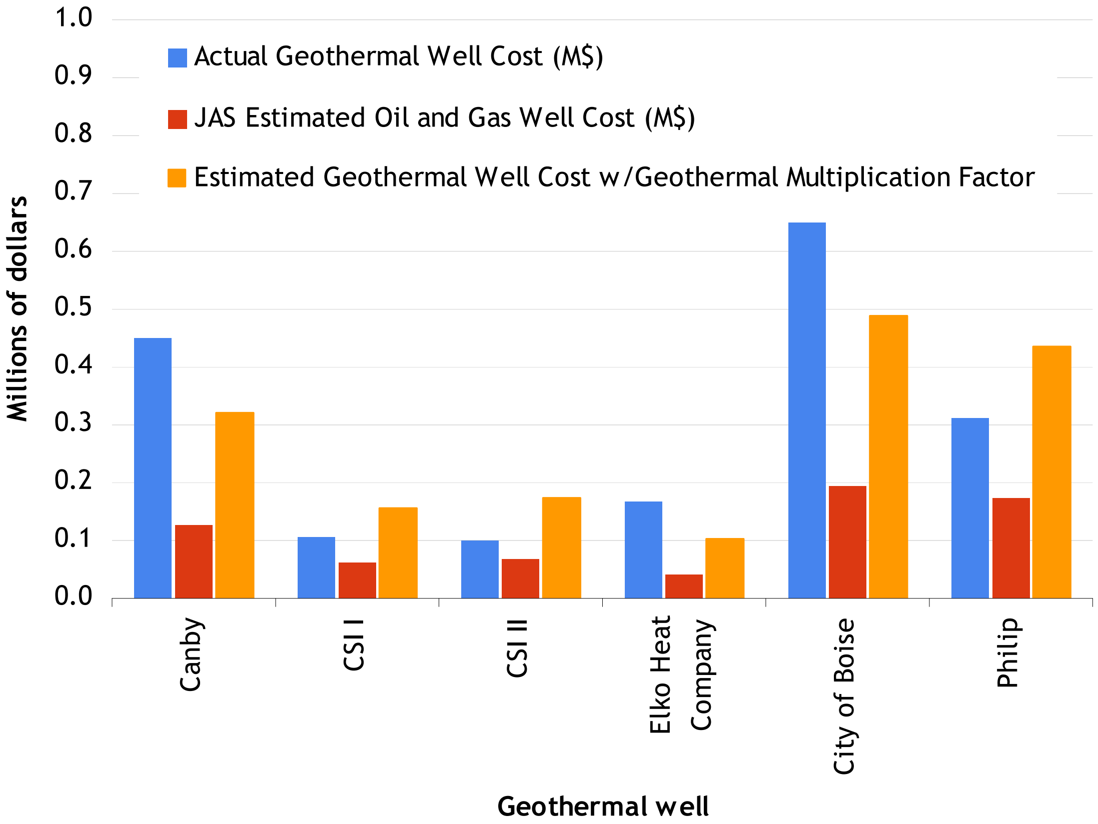


Figure 18 - Comparison between actual well costs, JAS estimated oil and gas well costs and estimated geothermal well costs with geothermal multiplication factor for the six district heating wells with available drilling cost information.

For those GDHS where well costs were unavailable, geothermal well costs were estimated using the information about the well's drilling year and depth along with the geothermal multiplication factor as follows:

$$A_{dy} \times D \times G = \mathit{Estimated\ Drilling\ Cost} \qquad (2.1)$$

Where:

$A_{d,y}$ = average drilling cost for appropriate depth interval for year in question

D = depth of wells

G = geothermal well multiplication factor

For example, in Pagosa Springs two wells were drilled to the depth of 300 and 274 feet in 1981. The Pagosa Springs drilling costs were estimated as:

$$A_{0-1249\,ft,1981} \times \left(D_{Well-nr1} + D_{Well-nr2}\right) \times G = 47\$/ft \times \left(300\,ft + 274\,ft\right) \times 2.51 = \$68{,}000$$

2.2.1.5 EGS Drilling Cost Estimation

To estimate drilling costs for the EGS economic analysis in Section 6.7, the MIT drilling index along with geothermal well cost prediction model from a drilling cost study done by Augustine et. al. in 2006 were used. The MIT drilling index was developed by Augustine et. al. using data on onshore oil and gas drilling costs data from the Joint Association Survey (JAS) discussed above and updated as part of this study to include the 0-1249 ft depth interval. The index shows drilling cost trends in the U.S. over a thirty year period (see Figure 32). The geothermal well cost prediction model can be seen as a red line in

Figure 20 (Augustine et al., 2006).

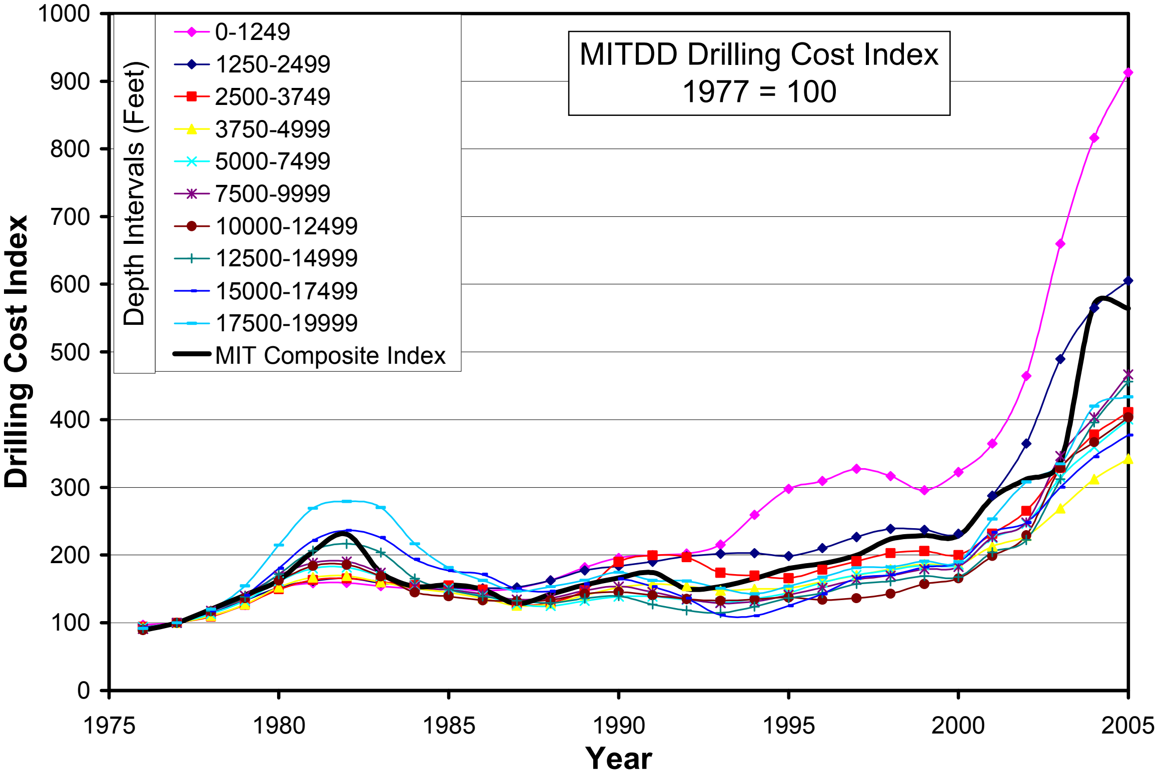
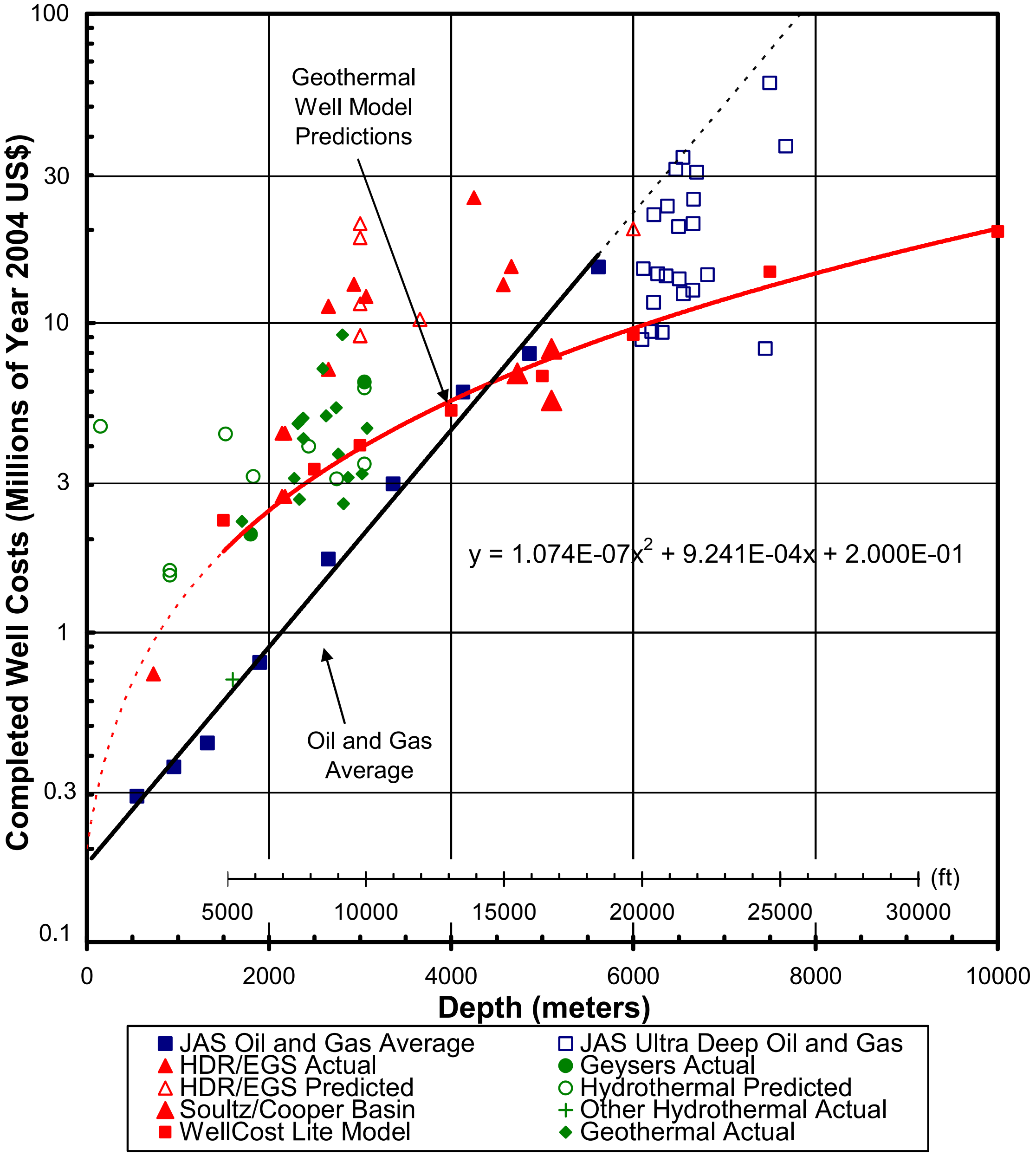


Figure 19 - MIT Drilling Costs Index – Three year moving average. 1975-2005 (updated from (Augustine et al., 2006)).



1. JAS = *Joint Association Survey on Drilling Costs* .
2. Well costs updated to US$ (yr. 2004) using index made from 3-year moving average for each depth interval listed in JAS (1976-2004) for onshore, completed US oil and gas wells. A 17% inflation rate was assumed for years pre-1976.
3. Ultra deep well data points for depth greater than 6 km are either individual wells or averages from a small number of wells listed in JAS (1994-2002).
4. "Geothermal Actual" data include some non-US wells (Mansure, 2004)

Figure 20 - Geothermal well cost prediction model (Augustine et al., 2006).

2.3 Cost Analysis

Geothermal district heating system costs were analyzed using payback period analysis and by estimating cost per kW installed and levelized energy costs. A payback period represents the minimum amount of time *t* it will take for the sum of the cash flows from a project to become positive or:

$$CF_1 + CF_2 + ... + CF_t \geq CF_0 \tag{2.2}$$

Where CF_i are the project cash flows at time *i.*

Costs per kW were estimated by inflating capital costs to year 2008$ using a 3% inflation rate and then dividing that cost by the kW capacity of the system in question.

Levelized energy costs are the present value of the project capital and operating costs over the project lifetime converted to equal annual payments and divided by the system's energy production. Levelized energy costs were estimated over thirty years using a 10% discount rate and 90% system efficiency. Annual energy production data from the operator and the Geo Heat Center were used along with operating costs inflated by 3% each year.

2.3.1 EGS Cost Evaluation

Costs per kW and levelized energy costs were also estimated for EGS geothermal district heating projects. It was assumed that the same surface technology would be used for EGS GDHS as for hydrothermal GDHS. Consequently, the only cost difference between EGS GDHS and hydrothermal systems was assumed to be increased drilling costs for EGS systems. Although this not entirely accurate because it ignores stimulation and fracturing costs, it was considered a close enough approximation for this study.

EGS GDHS costs were estimated using EGS drilling cost estimation as described in Section 2.2.1.5 and cost numbers from a recently built GDHS in Lakeview as a representative case of GDHS surface equipment costs. Energy production was estimated using the average ΔT for U.S. GDHS (40°F/22°C), the average temperature of U.S. GDHS (160°F/71°C) and a capacity factor of 0.25. Thermal gradient used to estimate the depth of well needed to reach the average GDHS fluid temperature (160°F/71°C) was 30°C/km.

The median geothermal fluid flow from U.S. GDHS wells is about 20 kg/s. EGS projects in Soultz, France and Cooper Basin, Australia have achieved a flow of 25 kg/s from EGS systems (Baria & Petty, 2008). As these flow numbers are comparable, current Lakeview operation costs were used as estimation for operation costs for an EGS system with today's EGS production capabilities.

To assess the effect of technology advancement and increased EGS flow rate capacity on EGS GDHS costs, costs per kW and levelized energy costs were also estimated assuming an 80 kg/s flow rate. This was done by scaling energy production numbers according to increased flow and, as a rough estimate, by doubling the operation costs from the current technology case. Higher operation costs were used to account for increased pumping costs and other operational cost factors related to energy production scale.

2.4 Logistic Regression Model

Regression models are widely used to evaluate the correlations between a response variable and potential influential factors (Montgomery & Runger, 2003). Regression has also been used in energy policy research, for example Menz and Vachon (Menz & Vachon, 2006) used it to evaluate the effectiveness of different state policy regimes for promoting wind power in the U.S. They used a linear regression to correlate variables for several renewable energy policies and a variable for wind potential with (1) the amount of wind capacity within a state, (2) the growth of wind capacity experienced in recent years, and (3) the number of projects larger than 25 MW developed in the last 5 years in the state.

The data they used included wind power capacity, policy regime and wind quality data for 39 U.S. states. The relationship between wind development and the various policies was tested using hierarchical linear regression analysis with coefficients estimated using least squares methods, i.e. the regression model was structured to report the incremental variance explained by the policy. Menz and Vachon found that the policies analyzed, when combined, had a significant impact on wind development within the states. The renewable portfolio standard and the mandatory green power option, that allows customers to buy renewable energy, had the most impact, while financial incentives and voluntary green power choice with competitive electricity markets did not stimulate wind power development over the 1998-2003 period.

In this study the dependent variable, the success of a GDHS, is binary, i.e. either the system is successful or not (modeled as 0 or 1)[12]. Linear regression is inappropriate in such cases because the model's predicted probabilities might fall outside of range of 0 and 1, it assumes that the dependent variable is normally distributed when in fact it is binomially distributed and it assumes a constant variance across groups (Patel, 2003; Welsch, 2007). Consequently, for the analysis of barriers and enablers of U.S. GDHS, it is better to use logistic regression where the response variable is binomially distributed so that it can only fall at 0 or 1 and variance is not constant.

Logistic regression has been utilized previously in energy policy analysis. For instance, Arkessteijn and Oerlemans used logistic regression to investigate which factors influence the likelihood of early adoption of green electricity by Dutch households (Arkesteijn & Oerlemans, 2005). Data were collected by a telephone survey conducted in June 2001. A total of 205 electricity consumers were contacted generating data for 115 respondents. Several variables thought to affect green electricity adoption were investigated including technical, social and economic factors. Five different logistic models were tested to analyze separately the impact of technical, social and economic factors along with a various combinations of these factors. All models proved to be relatively powerful predicting correctly 75.5% (technical model) to 86.5% (all variables combined model) of the cases analyzed. The study found that the perception of ease of switching between sources and use of the green electricity along with knowledge of renewable energy sources were the most influential in increasing the likelihood of adoption.

Logistic regression transforms the dependent variable into a logit variable, i.e. the natural log of the odds of the dependent variable occurring, and then applies maximum likelihood estimation (Menard, 2001). Unlike linear regression where the changes in the dependent

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[12] Binary levels of success were chosen to avoid over classification of a limited dataset.

variable are estimated, logistic regression estimates the changes in odds of a certain event happening. Logistic regression attempts to predict the probability that a case will be classified into one of two categories using the following equation:

$$P(Y=1)=\frac{e^{(\beta_0+\beta_1x_1+\beta_2x_2+...+\beta_ix_i)}}{1+e^{(\beta_0+\beta_1x_1+\beta_2x_2+...+\beta_ix_i)}}=\pi(x_i) \tag{2.3}$$

Where Y is the dependent variable whose probability of taking on a specific value is being predicted, x_i is an independent variable whose values are being used to predict the probability that Y will take on a specific value and β_i represents the population coefficients being estimated.

To estimate the success of U.S. GDHS stepwise regression using forward selection followed by backward elimination was implemented. As suggested by Hosmer and Lemeshow (Hosmer & Lemeshow, 2000), a chi-square test, called the likelihood ratio test or G was used as a measure of variable applicability.

$$G\ =2\{L_{x+1}-L_x\} \tag{2.4}$$

Where

$$L=\sum_{i=1}^{n}[y_i\ln(\hat{\pi}_i)+(1-y_i)\ln(1-\hat{\pi}_i)] \tag{2.5}$$

And $\hat{\pi}_i$= maximum likelihood estimate of $\pi(x_i)$ and x+1 is the index number of the variable being tested.

The goodness of fit of the final model was tested by comparing the observed values of the response variable to the predicted values of the response variable obtained from models with and without the variable in question using the likelihood ratio test statistic. If G is statistically significant ($p \leq 0.10$), then the null hypothesis is rejected and it is concluded that information from the independent variables allow the model to better predict the success of a system than would be possible without it (Menard, 2001).

Once a model had been chosen each variable was tested using the univariate Wald test statistic to test the null hypothesis that the individual coefficient is zero.

$$W_i = \hat{\beta}_i / S\hat{E}(\hat{\beta}_i) \tag{2.6}$$

Where $\hat{\beta}_i$ is the maximum likelihood estimate of the coefficient β_i and $S\hat{E}$ an estimate of its standard error (Hosmer & Lemeshow, 2000).

The final test per formed to assess the validity of the model was to calculate the percentage of correctly predicted cases by the model.

$$\text{Percentage correct} = \frac{sum(\pi_i = Y_i)}{n} \tag{2.7}$$

Where n = the number of U.S. geothermal district heating systems (Menard, 2001).

The small number of GDHS in the U.S. limited the dataset available for the analysis to only 21 observations[13]. With this inherent limitation, the model only provides an indication of possible relationships between variables and cannot be validated quantitatively.

2.5 Survey

To assess the validity of barriers to development quoted in literature (see Section 1.3) 104 communities previously identified as being collocated with a low temperature geothermal resource were sent a short survey. That group of communities was selected for the survey because an email address of the mayor, a councilmember, town/city manager or chamber of commerce could be found through a web search or messages to those individuals could be sent through town/city websites. The survey results were analyzed to investigate whether the three main barriers quoted in literature, i.e. local authorities unawareness of geothermal energy system benefits, the fact that GDHS are complex, high risk

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[13] The Warren and Manzanita Estates were analyzed as one system because even though they have separate distribution systems they have always been operated by the same entity and have the same values for most of the parameters.

undertakings and that local leaders lack the necessary knowledge to develop GDHS quoted in the literature were accurate.

As survey participation was completely voluntary and no direct contact was made with potential responders, an effort was made to make the survey as simple and non-time consuming for respondents as possible. The survey can be found in Appendix B.

2.6 Other Analysis Methods Used

Some influential variables were not appropriate for analysis using logistic regression. For example, the price of space heating substitutes. Given that these prices vary significantly over time they cannot be modeled effectively in a static model. For parameters such as these comparison and qualitative analysis were used to assess their potential impacts on the success of GDHS.

3 U.S. Geothermal District Heating Systems

An empirical analysis of U.S. geothermal district heating systems (GDHS) can be helpful in identifying areas of interest along with areas where more emphasis should be put in GDHS development. Recall that the definition of a GDHS used here is a system that uses a geothermal resource as a heat source and distributes heat through a distribution network to five or more buildings. The GDHS researched in this study are tabulated in Table 4 along with their location, start up year, number of customers, capacity, annual energy use and temperature of the system. Figure 21 shows the annual energy use for the U.S. GDHS studied.

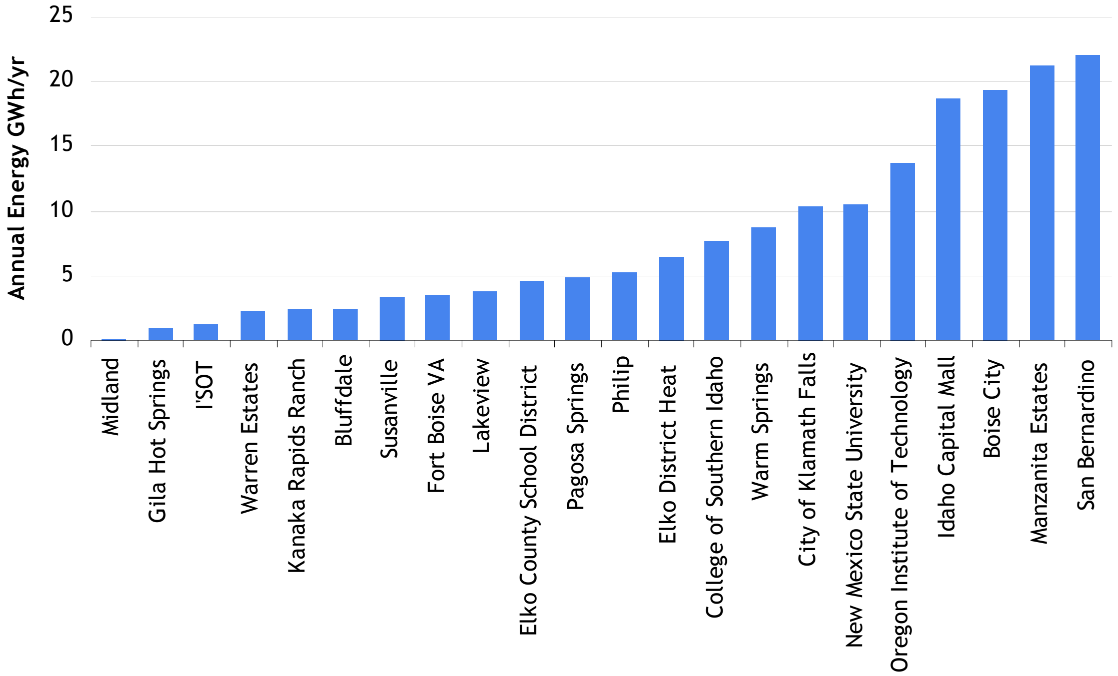

Figure 21 - Annual energy use for GDHS – (Data from Geo Heat Center and interviews conducted with GDHS operators).

Table 4 - U.S. geothermal district heating systems 2007 (Data from Geo Heat Center and interviews conducted).

System	State	Start up year	Number of Custo-mers	Capacity, MW_t	Annual Energy, GWh/yr	System Temp. [°F]
Susanville District Heating	CA	1982	7	5.60	3.4	168
San Bernardino District Heating	CA	1984	77	12.80	22	128
I'SOT District Heating System (Canby)	CA	2003	1	0.50	1.2	185
Pagosa Springs District Heating	CO	1982	22	5.10	4.8	146
Boise City Geothermal District Heating	ID	1983	58	31.20	19.4	170
Fort Boise Veteran's Hospital (Boise)	ID	1988	1	1.80	3.5	161
Idaho Capital Mall (Boise)	ID	1982	1	3.30	18.7	150
Warm Springs Water District (Boise)	ID	1892	275	3.60	8.8	175
College of Southern Idaho (Twin Falls)	ID	1980	1	6.34[3]	14	100
Kanaka Rapids Ranch (north of Buhl)	ID	1989	42	1.10[3,4]	2.4	98
Gila Hot Springs	NM	1987	<15[1]	0.30	0.9	140
New Mexico State University (Las Cruces)	NM	1982	1	2.70	10.5	143
Warren Estates (Reno)	NV	1983	110[2]	1.10	2.3	204
Manzanita Estates (Reno)	NV	1986	See Warren	3.60	21.2	204
Elko County School District	NV	1986	4	4.30	4.6	190
Elko District Heat	NV	1982	18	3.80	6.5	176
City of Klamath Falls District Heating	OR	1984	20	4.7	10.3	210
Oregon Institute of Technology (Klamath Falls)	OR	1964	1	6.20	13.7	192
Lakeview	OR	2005	1	2.44	3.8	206
Midland District Heating	SD	1969	12	0.09	0.2	152
Philip District Heating	SD	1980	7	2.50	5.2	151
Bluffdale	UT	2003	1	1.98	4.3	175

[1] There are 15 buildings on the system, the number of customers is probably a little smaller.
[2] The combined number of customers for the Warren and Manzanita Estates.
[3] Only includes geothermal capacity of the system and ignores capacity added by heat pumps.
[4] Assumes a ΔT of 10°F.

Each operating GDHS in the U.S. was contacted to collect information to try to assess which factors enabled or hindered the success of the system. Operators were asked about the geothermal resource being utilized, its temperature, whether it was reinjected after use or discharged in another way and how much the temperature of the geothermal fluid drops due to utilization in the system (ΔT). They were asked whether a market assessment was performed before developing the system and whether buildings had to be retrofitted to utilize the geothermal energy. It was inquired when system start up was and whether the system received any sort of state or federal incentives at the time of development. To assess the size of the system, data on the number of customers and square footage heated were sought along with information on whether the system has grown since it was first developed. Inquiries about system design or litigation problems were made to try to assess the commonality of such problems.

Questions were posed about capital, drilling, and operational and maintenance costs. Information about the annual revenue of the system or annual savings realized was similarly collected along with data on substitute heating fuels. User rates for the GDHS were investigated and information on whether incentives to hook up are provided for new customers and whether users were required to maintain their own back-up system was gathered. Finally, operators were asked whether the geothermal system has been used for any sort of sustainability public relations purposes for the community.

The information collected, augmented by data from case studies in the literature can be found in Sections 3.1 to 3.11. Sections 3.1 to 3.8 give details on each individual GDHS while Sections 3.9 to 3.11 summarize the cost, design and policy data gathered.

3.1 California

Three operating geothermal district heating systems are located in California, one of which was started up only five years ago. The City of Susanville and I'SOT systems are located in northern California, close to the Oregon border while the San Bernardino system is located in southern California.

3.1.1 City of Susanville

The City of Susanville District Heating System is operated by the City of Susanville and is located in northern California close to the Oregon border. It has been running since 1982 and was backed by a Housing and Urban Development (HUD) grant and U.S. Department of Energy (DOE) and California Energy Commission (CEC) funding at the time of development (Mike Naimo, personal communication, 02/26/2008) (California Energy

Commission, 2002). The system has two production wells but only utilizes one of them after a recent downsizing of the system. The older production well, which is known as Naef Well and is now out of service, was drilled in 1930 and is 450 feet (137 m). The younger production well, Susan I, was drilled in 1980 to a depth of 925 feet (282 m). The injection well, Richardson Well, was drilled in 1982 to a depth of 1200 feet (366 m). Currently the system pumps 325 gallons per minute (gpm) (21 kg/s) of 168°F (76°F) water during peak usage. The injection well has a capacity of 150 gpm (9 kg/s) so only about half the water from the system is reinjected. The other half is let out into irrigation ditches for agricultural uses on ranches in the area (Mike Naimo, personal communication, 02/26/2008, 03/12/2008, 03/13/2008).

The Susanville distribution system lies within a four block area. It currently serves seven large commercial customers: a 33 unit apartment complex, two high schools, the city repair shop, the county maintenance building, VA memorial building and a mid size office complex. Until recently the system also served a number of residential customers but they were switched to a natural gas system because it was not economic for the town to serve them using the geothermal system. The Susanville GDHS operates from about October/November through May. It used to be run all year but after the town's swimming pool was taken offline the system is turned off during the winter (Mike Naimo, personal communication, 02/26/2008).

When the system was constructed back in 1982 all the connected buildings were retrofitted for a GDHS. Because the geothermal system is considered a secondary source of heating all customers are required to have a back up heating system. However, when it came time to switch the residential customers over to natural gas heating it was discovered that many of the residential customers had neglected to maintain their back up system which increased the transition time to the natural gas system (Craig Platt, personal communication, 03/10/2008). The system has not really grown since its startup with only two new customers coming online since 1987. The City does not put much emphasis on growing the system and there are no incentives in place to attract new users (Mike Naimo, personal communication, 02/26/2008).

The current operators of the system were unsure what sort of market assessment was done before the project was started in the early 80s. Originally the system had about thirty customers most of which were located in a low income housing area. Rates for the system vary from \$0.028-\$0.058 a month, per square foot The rates are based on the square footage and age of the building being heated along with information about what the hot water is used for. In the beginning the system operated a metering system but in parts of the system where the geothermal water was used directly, sulfur in the geothermal fluid corroded the meters which resulted in failure of the metering system. The meters that failed have not been replaced (Craig Platt, personal communication, 03/10/2008).

Annual operation costs include about \$9-12,000 for pumping costs and about \$50,000 for maintenance. When the residential users were still online the system also operated the older well and paid about \$12-\$14 thousand annually for pumping costs for that well. Revenue from residential part was only \$2,200 annually and thus did not cover the added operational cost of serving the residential area. There were 16 residential customers with relatively small homes and a tight income. Revenue from commercial customers is about \$70,000 and the system is now run at a profit for the town (Craig Platt, personal communication, 03/10/2008).

3.1.2 San Bernardino

The San Bernardino District Heating system is run by the City of San Bernardino and was developed in 1984. When the City's wastewater treatment plant needed a new boiler a city council member remembered an old geothermal well close by that was being used for agriculture purposes. The city bought the well, drilled another one and developed a GDHS (David Archinega, personal communication, 12/04/2007). The wells used are 931 feet (284 m) and ca 950 feet (290 m) deep and produce 128°F (53°C) water at an average rate of about 1,500 gpm (95 kg/s) but can provide up to 2,150 gpm (136 kg/s) (California Energy Commission, 2003b). The DOE funded a feasibility study for the system and the California Energy Commission (CEC) provided development funds for the construction of the system (David Archinega, personal communication, 12/04/2007). System capital costs totaled about \$6,000,000 (California Energy Commission, 2003b).

The current operator does not think that any market assessment or overall plan was developed before construction was started, but instead the system developed incrementally. All but one of the buildings on the system were retrofitted before being hooked up. Currently the system serves 77 buildings on an 18 mile (29 km) distribution line (David Archinega, personal communication, 12/04/2007). After utilizing the geothermal fluid and lowering its temperature by 30°F (17°C) it is discharged into the Santa Ana Water System. The discharge is monitored 24 hours (California Energy Commission, 2003b). The system has grown slowly over the years with the latest new customer being added onto the system in ca 2004 (David Archinega, personal communication, 12/04/2007).

Monthly operation costs for each well are about $6000 on a slow month and up to $10,000 on a busy month. The monthly well costs are covered by system revenue but the salary for geothermal maintenance staff is covered by other city funds. Metering issues have been a significant barrier to adjusting customer rates to meet system operating costs. The geothermal water rates are tied to natural gas rates and are about 75% of the cost of natural gas, which is the substitute fuel in the area, and all customers are required to maintain a back up heating system (David Archinega, personal communication, 12/04/2007).

3.1.3 I'SOT

The I'SOT District Heating System started up in 2003. It is owned by I'SOT Inc. a non profit religious organization with a population of about 180 people (Merrick, 2006). The system is one of the youngest GDHS in the U.S. and is located in Canby, in northern California, close to the Nevada border. As the geothermal system is a community wide project it had 100% market penetration. Retrofitting was needed for all the buildings in the community but because many of the roads in the area are not paved the underground piping construction was cheaper than it would have been otherwise (Dale Merrick, personal communication, 11/08/2008).

The system is served by a single well drilled in 2000 to a depth of 2,100 feet (640 m). It supplies the community with 180-190°F (82-88°C) water at 37 gpm (2 kg/s) which is used for space heating and domestic hot water year round. The geothermal fluid contains arsenic levels that are above the regulated level for drinking water standard and measured mercury levels were significantly higher than the Environmental Protection Agency's (EPA) aquatic threshold. Therefore, I'SOT had to take steps to clean the fluid before discharging it to the Pit River. The arsenic was dealt with by defining a mixing zone for the arsenic contamination and 99% of the mercury is removed by a method using activated carbon (Merrick, 2002). The system operates a 140 kW propane generator in case of a power outage and a 1.7 million btu propane boiler in case of a geothermal production pump failure (Dale Merrick, personal communication 03/06/08).

Annual operating costs for the system are about $10,000 while annual savings about to about $46,000. The project received funding from the DOE, the CEC and National Renewable Energy Laboratory (NREL). The Geo-Heat Center at the Oregon Institute of Technology also provided assistance with preliminary work. The initial capital costs were $1,200,000 of which $300,000 came from the I'SOT community. The drilling costs for the production well totaled $450,000 (Dale Merrick, personal communication, 11/08/2008)

3.2 Colorado

Colorado only has one GDHS in the small town of Pagosa Springs close to the New Mexico border.

3.2.1 Pagosa Springs

The Pagosa Springs District Heating System is run by the town and has been operating since 1982 when the town received federal funding to construct the system. The town and the local county contributed $60,000 to the original development costs which totaled about $1.4 million (Garcia, 1997). Geothermal resources have been used in the area for about 100 years. Along with the GDHS there are a number of private geothermal wells operating for individual home heating in the surrounding region. When the Pagosa Springs GDHS was developed all connected buildings were retrofitted for geothermal space heating (Mark B. Garcia, personal communication, 02/07/2008).

The system owns two geothermal production wells but only uses one to serve the system. They are 250 and 314 feet (76 and 96 m). The production well provides geothermal fluid at about 146°F (63°C) and once the fluid has been used it is released into the San Juan River at about 115-118°F (46-47°C). The system uses about 98.3 mmBtu/year and services 22 customers. It has a small service area, about a half a mile (0.8 km) radius, and the schools on the systems are its biggest customer. A portion of the return water is leased to a recreational spa facility that owns a geothermal surface spring. The water that the facility leases is put into the spring to replace hotter water that is taken out for use in the spa to heat buildings, water and for operations. The Pagosa Springs GDHS is run for about two and a half seasons from October 1st to the end of April, early May depending on weather (Mark B. Garcia, personal communication, 02/07/2008).

When the system was set up the town made the promise that the geothermal price rate would always be at least 30% cheaper than the natural gas rate. There has not been a rating increase in about 5-6 years and because of the recent trends in natural gas prices Mr. Garcia believes that the geothermal system is now probably about 50% cheaper than natural gas heating. The system is run as a enterprise fund and in 2007 the operation costs were $25,000 and the system's revenue was $45,000 (Mark B. Garcia, personal communication, 02/07/2008).

To incentivize new users the system takes care of all connection work and pays for flow and btu meters when a new customer is connected. All the user has to do is to expose service lines and fit his/her house for geothermal heating. However, there has been some talk recently of transferring the cost of the meters over to new customers. Customers on the Pagosa Springs System are not required to have their own back up system (Mark B. Garcia, personal communication, 02/07/2008).

Litigation has been a big barrier for the Pagosa Springs system. The litigation was started by private geothermal well owners in the area because the permits for the two exploratory wells drilled for the system were questionable. The town had permits for the wells but the permits did not satisfy all the state requirements. The drilling then hit a fissure which brought the water level in all the other individual geothermal wells in the area down. Once the fissure was capped the water levels went back to normal but the incident raised awareness in the area and the state started to do more diligent reviews when it gave out permits. As a consequence, the system, which was designed as a 1,000 gpm system, only received a water right permit for 450 gpm. The town is currently trying to form a users' district to manage the resource in a sustainable way but it is proving to be difficult, mostly because of declining water, flow and temperature levels in the aquifer (Mark B. Garcia, personal communication, 02/07/2008).

Pagosa Spring's City Manager, Mark Garcia, is very interested in the sustainable nature of the geothermal resource and expects an increasing focus on a green community. Pagosa Spring's mayor signed the Mayor's Climate Initiative and the town recently employed a new graduate with a masters degree in sustainable government. Mr. Garcia, would also like to change the geothermal district heating system into a reinjecting system with no consumptive use. That would allow for expansion of the system and the city could use the 450 gpm consumptive use permit they hold to increase the recreational use of geothermal water in the town. Recreational use would bring the town revenue from spas, tourists and retail. However there has been political opposition to the plan because owners of recreational spas already located in town are major sales tax payers and oppose increased competition to their business (Mark B. Garcia, personal communication, 02/07/2008).

3.3 Idaho

Idaho has six operating geothermal district heating systems, four of which are located in the state capital of Boise.

3.3.1 Boise

There are four geothermal district heating systems in Boise, Idaho run by four separate operators. The oldest system serves a residential area and has been operating for over a hundred years. The other three systems came online in the 1980s following the energy crises in the late 1970s. One system is run by the state and serves the state capital buildings and another is run by the Veteran Administration and serves a hospital complex. The fourth system is run by the City of Boise. There is not much cooperation between the four operators but neither are they in direct competition as they serve different areas (Kent Johnson, personal communication, 12/04/2008). In 1987, the Idaho Department of Water Resources (IDWR) stepped in after water levels in the Boise geothermal aquifer dropped. They established the Boise Front Low Temperature Geothermal Resource Ground Area and in 1988 put in place a moratorium for the aquifer, banning all further geothermal development. Consequently, the operators now have to cooperate on some issues regarding utilization of the resource (K. Neely et al., 2006).

3.3.1.1 The Boise City System

The Boise City Geothermal District Heating system was started up in 1983 and is operated by the city. It now serves 58 customers with a total 3.8 million square feet (350,000 m^2) of space heating area. The oil price shocks of the 70s lead to considerable interest in alternative sources for energy and were a big driver for the three geothermal systems that came online in Boise in the 80s. Before the City system was constructed a presentation was made to the businesses in the area and a survey of interest performed. If building owners expressed interest, engineers did a quick calculation of the estimated cost to switch to geothermal heating. As a result, many businesses expressed interest in connecting to the system. However, just before the system came online energy prices fell again and interest in geothermal diminished markedly (Kent Johnson, personal communication, 12/04/2008).

The City of Boise developed their system in cooperation with a private entity and with the help of federal PON funding from the DOE (Frank W. Childs & Sanders, 1983). A private company developed the resource side while the City built the distribution network. The private entity was later bought out by the City. The system uses three production wells (880 ft/268 m, 1103 ft/336 m and 1897 ft/578 m) capable of producing about 4,000 gpm (252 kg/s) of 170°F fluid (77°C) (Kent Johnson, personal communication, 12/04/2008). . When the system came online in the 80s water levels in the geothermal aquifer dropped resulting in litigation and a moratorium on the aquifer. To alleviate the falling water levels a reinjection well was drilled in 1998 to 3,200 ft (975 m) (Johnson, 1998).

The customer rates for the system are tied to natural gas prices. The rate for geothermal heating is 70% of the rate for natural gas. This was done as an incentive to new customers as the operators have calculated that capital costs for a geothermal setup are about 15-20% higher than that for a natural gas system and was put into effect in 1987. By tying the rate to natural gas prices the geothermal system can show a simple payback to the customer in a few years. Currently the system rate is \$0.60 per therm or \$0.60 per 100,000 btus (Kent Johnson, personal communication, 12/04/2008).

When the system came online it had 23 customers which was not enough to cover operating expenses. After a rate change in 1987, the system began to slowly add new users at a rate of one to two every other year. Recently with rising energy prices, interest to hook up to the system has soared and in 2007, five new customers were added to the system. Today the system manages to cover its operational costs and turn a profit and the town is starting to pay back the \$2-2.5 million deficit that had developed in their replacement fund. Once the replacement fund is back on track the system operators envision going back to a price rate based on operational costs of the system instead of natural gas prices (Kent Johnson, personal communication, 12/04/2008).

3.3.1.2 Fort Boise Veterans' Hospital

Thirty-three of the forty buildings that make up the Fort Boise Veteran's Hospital complex are heated by a geothermal district heating system. The total hospital complex occupies 450,000 sq feet (42,000 m^2) and the geothermal distribution network is about a mile and a half long (2.5 km). The system was developed in 1988 making it the youngest of the four GDHS in Boise. As the hospital was already in place when the system was constructed, all buildings had to be retrofitted to accommodate geothermal heating. Mr. Doug Lamb, who oversees the system believes the initial construction costs including retrofits were in the range of seven to eight million dollars (Doug Lamb, personal communication, 02/27/08).

The system is served by one production (1,660 feet/506 m) and one injection well (2,300 feet/701 m). The geothermal water comes out of the well at about 161°F (72°C) and is reinjected at about 135-140°F (57-60°C). The system is equipped with a central natural gas fired back up boiler and is run year round as it supplies domestic hot water as well as space heating (Doug Lamb, personal communication, 02/27/08).

Since the system was developed in the late 80s, three buildings have been added totaling about 53-55,000 square feet (4,900-5,100 m^2) of heated space. Savings for the system have not been calculated for long time. Mr. Lamb, the systems operator, estimates that the annual savings are about \$300,000 while operating costs were estimated as part of this study at about $60,000. The system uses an average of about 22,000,000 cubic feet (800,000 liters) of hot water annually and four employees maintain the complex's heating system (Doug Lamb, personal communication, 02/27/08).

3.3.1.3 Idaho Capital Mall

The Idaho Capital Mall system serves the state buildings in Boise. It was developed in 1982 and began by servicing ten buildings. Initial capital costs were $1,800,000 with a $250,000 contribution from the DOE. The system is served by one production well that produces hot water at 150°F (66°C) which is reinjected into a reinjection well after passing through the system. Today there are fifteen buildings on the system totaling about a million square feet of heating space (Ric Johnston, personal communication, 02/06/08).

Savings for the system have not been calculated since 1981. Back then they were about $150,000. Ric Johnston, the system's supervisor, estimates that the savings have doubled since that time. The system uses about 128 million gallons (480 million liters) of hot water a year and has a ΔT of about 20-30°F (11-17°C) (Idaho Office of Energy Resources, 2008). Operational costs for the system consist of a $5,000 annual fee paid to the Idaho Department of Lands for the geothermal water, as geothermal fluid is considered a mineral in the state of Idaho, electric costs which are less than $50,000 annually and about 25 man-hours of regular maintenance per year. Total estimated operating costs are about $56,000. All buildings but one have a hot water or steam boiler as back up but the State GDHS is now in the process of setting up an arrangement the Boise City District Heating System to use that system as a back up in order to be able to stop running the natural gas boilers. The system is run from October through May (Ric Johnston, personal communication, 02/06/08).

3.3.1.4 Warm Springs Water District

The Warm Springs Water District system is the oldest GDHS in the U.S. The first wells were drilled in 1890 and the system officially came online in 1892. It now serves about 275 customers. Most of the customers are residential and annual system flow is about 220 million gallons (830 million liters). The system's distribution network is 4 miles long (6.5 km). The system is served by two production wells, both of which are around 400 feet (120

m) deep and supply about 172-178°F (78-81°C) water. The system runs all year round but at a much lower flow rate during the summer (Rod Baldwin, personal communication, 02/22/08).

The system does not have a central reinjection system like the other geothermal systems in Boise. Instead individual customers dispose of their consumed water either into drainage ditches or small, shallow injection wells. The system's operators have considered drilling an injection well but price estimates for the project are high and the capital needed is not available. The drilling costs estimates for a new well are about $750,000 and the return distribution system to turn the system into a closed loop system would cost about $4 million (Rod Baldwin, personal communication, 02/22/08).

The system is run as a district, a subdivision of the State of Idaho Water and Sewer department. All users are members and they elect a five person board to run the system. In the 1980s the district was cut back from about 300 to 250-260 customers. In recent years they have been adding a few new customers every year and there are plans to expand the distribution network by 600 ft (180 m) in 2008. Annual revenues for the Warm Springs System are about $225,000 and annual operating costs vary from about $180,000-$380,000[14]. Thirty-five customers of the 275 use water meters and pay $0.00118 per 1000 gallons of water. The rest pay for use of the geothermal resource using an orifice rate system where the rates depend on the diameter of their distribution line. The orifice rates vary from $380-$1200 a year (Rod Baldwin, personal communication, 02/22/08).

Having a back-up heating system is not required of customers. New customers pay for all construction and for the costs of annexing the property into the district (advertising and legal fees). If existing customers want to replace old pipe with insulated pipes the system gives them the pipe and the customers pay for installation (Rod Baldwin, personal communication, 02/22/08).

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[14] Recent variance in annual operation cost is dependent on the amount of pipe replacement done in the distribution system each year.

3.3.2 College of Southern Idaho

98-99% of the College of Southern Idaho (CSI) campus is heated by a geothermal district heating system run by the College. The system was started up in 1980 when the campus was retrofitted for geothermal space heating. It runs 365 days a year and is served by two wells, one drilled in 1979 to 2,220 feet (670 m) and the other drilled in 1981 to 1,480 feet (450 m) (K. W. Neely, 1996). The wells are used alternatively to provide the campus with heat. The campus area heated by geothermal is 533,658 sq feet (50,000 m^2) and the system does not operate a back up boiler (Randy Dill and Allen Scherbinske, personal communication, 02/07/08).

The geothermal water comes out of the wells at about 100°F (38°C) and the College has water rights for about 2,700 gpm (170 kg/s). The system pumps anywhere from 10-2,400 gpm (1-150 liters) depending on demand (Randy Dill and Allen Scherbinske, personal communication, 02/07/08). Once the fluid has been utilized it is discharged into canals that flow into the Snake River (K. W. Neely, 1996). The initial capital costs for the system are unavailable but drilling costs for the 1979 well were $105,000 and $100,000 for the well drilled in 1981 (Randy Dill and Allen Scherbinske, personal communication, 02/07/08).

As the campus has expanded over the years, buildings have been added on to the system gradually. Currently, the system reaches capacity at peak load but the CSI has put in hybrid water-to-water heat pump system which has led to a reduced water use rate. The CSI furthermore intends to use the return water at 90°F (32°C) in another water-to-water heat pump system to heat a new building that construction will start on in the summer of 2008. Only one building on campus, the Expo Center, is not heated by the geothermal system but instead uses natural gas (Randy Dill and Allen Scherbinske, personal communication, 02/07/08).

Although the geothermal heating system has not been used for green energy promotion for the campus in the past Mr. Dill, director of maintenance at CSI, believes the campus's first LEED certified building that is intended to break ground this summer will change that and subsequently more focus will be put on using the geothermal system for promotional purposes for the campus (Randy Dill and Allen Scherbinske, personal communication, 02/07/08).

3.3.3 Kanaka Rapids Ranch

Kanaka Rapids Ranch is a subdivision housing community north of Buhl in southern Idaho. Because the construction of the geothermal district heating system was part of the community development project back in 1989, no retrofitting was needed to install the system. Two wells, both about 900 feet deep (275 m), serve the system and after use the water is disposed of by individual users into a creek or a lake (Mary Rosen, personal communication, 02/22/08). The distribution lines are about 4.7 miles (7.4 km) long and distribute 750 gpm (47 kg/s) of 98°F (37°C) water to 42 homes while the system has the potential to serve up to 120 users (Patti Belden, personal communication, 04/30/08). Individual water source heat pumps are used to augment the system which is run all year round and used for cooling in the summer (Mary Rosen, personal communication, 02/22/08).

In 1994 the homeowners in the subdivision formed a water company, Homeowners' Water System, Inc., to own and operate the geothermal system. Each home pays $120 annual fee for the use of the system. The subdivision is still growing and so is the geothermal system. The current average growth rate is about four to five new users each year. New users pay a $500 connection fee and all costs associated with connecting their house to the system. Substitute fuels in the area include natural gas and electricity (Mary Rosen, personal communication, 02/22/08).

Mrs. Rosen, the former president of the Kanaka Rapids Ranch Water Board, stated that the current revenues for the system are not high enough to cover the maintenance needed. However, raising the rates has proved difficult. An ideal rate for the system would be $52 per month per user. That would cover a new well, which they need, a maintenance fund and a reserve fund. However, all efforts to increase the user rates to $52/month have been thwarted by the community (Mary Rosen, personal communication, 02/22/08).

3.4 New Mexico

There is one geothermal district heating system running in New Mexico at Gila Hot Springs and another GDHS was recently taken offline at the New Mexico State University in Las Cruces.

3.4.1 Gila Hot Springs

Gila Hot Springs is a very small community in southwestern New Mexico with only about 30 year round residents. Geothermal resources have been used in the area for a very long time starting with the Apache Indians using the springs as steam baths and geothermal energy has been used for space heating in the area since the 1950s. In the early 80s, wells were drilled and a geothermal district heating system developed. At the time of construction some buildings had to be retrofitted to accommodate the new heating system. The system gets its water from a well that produces up to 100 gpm (6 kg/s) of 140°F (60°C) and has a ΔT of about 45°F (25°C). There are about 15 buildings on the geothermal system totaling about 100,000 square feet (9,000 m^2) and they are served by ca six mile (10 km) long distribution line (Allen Campbell, personal communication, 02/29/08).

The users own the geothermal system. The community founded an S-Corporation[15] and shares were sold to users. There are no user fees but everyone chips in with maintenance and retrofits. The system is run all year round and for back up purposes they operate a propane generator that takes over pumping when the power goes out, which happens frequently in this small isolated community. Also for back up purposes, the system is designed to have pump redundancy and most houses on the system have some sort of private back up system (Allen Campbell, personal communication, 02/29/08).

The geothermal resource at Gila Hot Springs is very clean and free of minerals and consequently, it is also the communities' source for potable water. Apart from using the

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[15] S-Corporations are generally exempt from federal income tax other than tax on certain capital gains and passive income (Internal Revenue Service, 2008)

geothermal fluid for heating, the community also cools the geothermal water down and uses it as drinking water (Allen Campbell, personal communication, 02/29/08).

3.4.2 New Mexico State University

The New Mexico State University (NMSU) system was started in 1982 when buildings were retrofitted and a distribution network built with funding from the State of New Mexico and the DOE (Witcher et al., 2002). Three wells were used to serve the system, one injection well and two production wells although five geothermal wells were drilled in total on campus. The two production wells were used sequentially, i.e. one was used for a few years and then the other and provided 250 gpm (16 kg/s) of 140-147°F (60-64°C) water. The geothermal system provided domestic hot water and/or space heating for 30 buildings on the NMSU campus that are now heated with natural gas (Witcher et al., 2002).

The system was shut down in 2003. The injection well is located in the in the middle of the campus golf course. During work on the golf course dirt was dumped down the injection well, which along with corrosion and scaling caused a system shut down and it has not been reinstated (Jim Witcher, personal communication, 01/08/08). A forensic study was done on the system in 2007 that concluded that the system was not very well engineered. A rush to construct the system probably contributed to the bad engineering decisions made. As a result the system had inadequate flow of hot water along with excessive sand in the pumped water which caused problems in the distribution network and led to unreliable service (Millennium Energy LLC, 2006).

3.5 Nevada

There are four geothermal district heating systems in two cities operating in Nevada. Both cities, Reno and Elko, are located in the western part of the state.

3.5.1 Reno

Although the two geothermal systems in Reno, Nevada are operated by the same company they are classified as two systems because they were developed at different times and are served by separate distribution systems.

3.5.1.1 Warren and Manzanita Estates

The Warren and Manzanita Estates geothermal systems were constructed as part of a new housing development in 1983 and 1986 respectively by Mr. Frank Warren, a developer. A geothermal connection in a box in the front yard was provided for every house in the lot. Buyers could then decide if they wanted to connect to the system. Both systems are operated by the Nevada Geothermal Utility Company (Dennis Trexler, personal communication, 11/09/07).

When the system was started up, only ten houses were connected to the systems but the number of users has grown and the systems now serve about 110 homes (Trexler, 2008). GDHS rates are tied to natural gas prices. The system has not grown since 2003 even though as an incentive to new customers, the Nevada Geothermal Utility Company will give the first year of heat and hot water for free. This is probably due to the fact that all lots in the area are now landscaped making connection to the system expensive. Also, the system's old heat exchanger cannot adequately handle much growth so not much effort is put into attracting new customers (Dennis Trexler, personal communication, 11/09/07).

The system is served by two production wells drilled in 1982 (833 ft/254 m) and 1985 (685 ft/209 m) and one injection well drilled in 1985 (1,250/381 m). Another well drilled to 1,625 ft (495 m) in 1995 as an injection well is not capable of producing or accepting fluids. The wells provide up to 400 gpm (25 kg/s) of 203-205°F (95-96°C) water and are reinjected at a temperature of 155-172°F (68-78°C) depending on system load (Trexler, 2008). The initial capital costs for the systems were about $1.4 million (Bruce Harvey, personal communication, 04/04/08).

New owners bought the system in 2006 and at that time the system had not been maintained for 22 years. The system has now been put through a complete revamp. The system revenue in 2007 was $164,000 and there was a 7.5% rate in 2008. Furthermore, new Nevada State legislation enacted in 2007 will grant the system energy credits which will be another source of revenue for the system. (Dennis Trexler, personal communication, 11/09/07).

Operating expenses were about $114,000 in 2007 but they were unusually high because of extensive maintenance and construction needed to make up for the 22 years when there was next to none maintenance. Mr. Harvey, one of the system owners expects maintenance and operation costs of the system to be about $90,000 once rework is completed. Although the system is currently turning a profit, if major retrofits of the system's three mile (4.8 km) distribution system were needed, it would not be cost effective to continue operation of the system (personal communication, Bruce Harvey, 04/04/08).

3.5.2 Elko

Two geothermal district heating systems are operated in Elko, Nevada. One system is run by the County School District and the other by a private company.

3.5.2.1 County School District

As the name suggest, the Elko County School District system is run by the County School District in Elko, Nevada. In 1985 a well was drilled to 1876 feet (572 m) with plans to construct a geothermal heat pump system to heat the local junior high school. However, what was encountered was a geothermal resource with artesian flow of 300 gpm (19 kg/s) of 190°F (88°C) water. Consequently it was decided to use the resource to heat all the school district buildings and several other buildings in town (Bloomquist, 2004a). The system was started up in 1986 and now serves 16 buildings run by four entities, most of which had to be retrofitted. All buildings but one have a hot water or steam boiler as back up (Steve Bowers, personal communication, 02/05/08).

At the time of construction in 1985, the project received $250,000 from the DOE to help with the $1,500,000 total capital costs of the system. Annual operation cost for the system is $75,000 which is split between the users by respective use. The entities that use the system have furthermore agreed to pay for additional maintenance if the need arises. In 2002 the savings realized by the system users were calculated as exceeding $285,000 and as natural gas prices have risen in recent years those savings have increased (Steve Bowers, personal communication, 02/05/08 & 03/13/08).

3.5.2.2 Elko District Heat

The Elko District Heat system is a private GDHS that was started up in 1982. Originally the system served three big commercial customers but the number of users has grown and currently the system serves 18 customers. One production well, 860 feet (262 m) deep, drilled in 1981 supplies 176°F (80°C) hot water to the system. Total annual water use is about 160 million gallons (600 million liters) a year. The distribution system lies from the outskirts of town into the central commercial district. It is about a mile and a half (2.5 km) long and all the customers except two are industrial or commercial (Mike Lattin, personal communication, 02/11/08).

Elko is located at an elevation of 5,000 feet (1,500 m) and has a short summer; only about three months. Therefore, heating is required for about six to eight months a year. There is also a linens laundry on the system that uses the water directly for washing year round and consequently the system is 365 days a year (Mike Lattin, personal communication, 02/11/08).

Primary users get the water at 176°F (80°C) and the water leaves their systems at about 140-135°F (57-60°C). The water is then led to secondary users who return it at about 100°F (38°C). After use the water is dumped into two evaporation ponds. Primary users pay $1.65 per 100 gallons and cascaded or secondary users pay one third of that price. All customers are required to have and maintain a back up system. New users have been incentivized to come online in the past either by the utility paying the connection costs or by offering reduced geothermal water rates for a specified time (Mike Lattin, personal communication, 02/11/08).

Revenue from the system is about $150,000-$200,000 annually and average operational costs are about $60,000. In 2007 and most likely in 2008 operational costs will be higher or around $100,000 due to major renovations being done on the system. The total capital cost of the system was $1.2 million. At the time of construction the system received $827,000 from the federal Program Opportunity Notice (PON) as a demonstration grant to show geothermal district heating system viability. The system operators calculated the payback period as being about 10-15 years without the DOE funding and about 3-5 years with the DOE funding (Mike Lattin, personal communication, 02/11/08).

3.6 Oregon

Oregon State has three operating geothermal systems, one of which is the youngest geothermal district heating system in the country, started up in 2005.

3.6.1 Klamath Falls

The area around Klamath Falls has a rich history of geothermal utilization. Native Americans used the hot springs for various purposes and the first geothermal wells were drilled in the 1930s. There are currently about 600 geothermal wells in the area, most of which are utilized for individual heating needs using downhole heat exchangers[16]. Klamath Falls has had an operating geothermal district heating system since 1964 and is also the home of the Geo-Heat Center. There are currently two GDHS operating in the city. (John Lund, personal communication, 11/29/07).

3.6.1.1 City of Klamath Falls

The City of Klamath Falls District Heating System was developed in the early 80s and started up in 1984. The project was started with a $2,000,000 dollar federal grant from the PON program. The funds were intended to stimulate growth. Without the grant, upfront costs would have been too high for the city to embark on the project (John Lund, personal communication, 11/29/07). The system also received a $300,000 Community Development Block Grant. Total project costs were about $2.58 million (Lienau, 1984). About five years ago the system received a grant from NREL to pay for the capital costs of a needed upgrade to the system (Jeff Ball, personal communication, 01/30/08).

The system is served by two production wells and one injection well. Drilling of the production wells began in 1979 with a 334 ft (102 m) well and a second well was drilled to

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[16] Downhole heat exchangers use a geothermal resource to heat secondary water for space and domestic hot water heating by circulating it through a loop of pipes or tubes in a geothermal well (Lund, 2004).

a depth of 367 ft (112 m) (Lienau & Rafferty, 1991). Combined they have a pumping capacity of 1,200 gpm (76 kg/s) (Brown, 2007) and provide 210°F (99°C) water. After use the geothermal fluid is reinjected into a well that was drilled in 1975 to 1,235 feet (Lienau & Rafferty, 1991). The system is currently run all year long except for two to three weeks every year when it is shut off for maintenance. All users are required to maintain a back up system (Jeff Ball, personal communication, 01/30/08).

Cost of retrofitting has been the major barrier to adding new customers for the Klamath Falls system. To encourage users to use renewable energy Oregon State operates incentive programs that among other things help people retrofit their buildings for geothermal. One, the Business Energy Tax Credit, is a 35% tax credit available to taxable entities that connect to the system and the other is the Small Energy Loan Program that will loan the cost of connection to the potential geothermal customer (Rafferty, 1993). As a further incentive to new customers, Klamath Falls has offered them one year of free heating, and several years of discounted heat. The number of discounted years is usually a negotiation. New construction in the area typically comes online if it is designed by local architects but it has proved hard to convince out of town architects that geothermal heating is preferable and they tend to go with more traditional heating equipment (Jeff Ball, personal communication, 03/13/08).

Initially, opposition from local, private geothermal well owners due to concerns about how the City's system would affect the geothermal aquifer, delayed start up of the system by three years (Lienau, 1984). Then, during the systems first season of operation, major failures in joints caused system shut down and caused litigation. The case was settled and the system was put back online. However, the shut down translated into a lack of trust from their customers. Regaining lost trust has taken time. In the 1990s a marketing campaign helped the geothermal system grow and increased confidence in the system. In the last five years more customers have been added and the system now serves just over 20 customers, mostly government and commercial buildings. The system's largest customer is a greenhouse nursery that grows seedlings (Jeff Ball, personal communication, 01/30/08).

The geothermal system rates were set at 80% of natural gas prices are now about 70% of gas prices because of rising natural gas prices. Mr. Ball, Klamath Falls City Manager furthermore maintains that because geothermal heating is more efficient than gas heating the net effective cost of geothermal heating is about half of what gas heating costs are (Jeff Ball, personal communication, 01/30/08).

The system has been breaking even for the last couple of years. Before that, it was subsidized by the city that provided maintenance manpower from the City's sewer and water divisions. Even though the system is no longer run at a loss, the current revenue is not enough to cover projected capital needs. Nevertheless, the City believes that the resource is valuable enough to keep using it. The GDHS is considered a service to the City just like the sewage or water system. All users save on their heating costs and that includes the city and county buildings that use the system. Furthermore, return heat from the system is used to heat streets in the city center and thus saves money on snow removal. The geothermal system is also used as part of the city's sustainability package and their green image (Jeff Ball, personal communication, 01/30/08).

3.6.1.2 Oregon Institute of Technology

The Oregon Institute of Technology (OIT) geothermal system, started up in 1964, is the second oldest GDHS in the U.S. The campus, located in Klamath Falls, was developed with the utilization of the nearby geothermal resource in mind. Also located at the OIT is the Geo Heat Center which researches and promotes the use of geothermal direct use applications (John Lund, personal communication, 11/29/2007).

The system is served by three production wells; two are 1800 feet (549 m) and one 1300 feet (396 m) deep that have a combined pumping capacity of 980 gpm (62 kg/s) of 192°F (89°C) water (Lienau, 1996). Two injection wells were drilled in the 1990 after a City ordinance ordering that water had to be reinjected back into the system. The injection wells are 2005 feet (611 m) and 1675 feet (511 m) deep. The University does not operate a back up system. They used to run a backup boiler but it has been removed and they now solely rely on redundancy in the system (John Lund, personal communication, 11/29/2007).

The system has grown slowly over the years and at least four new university buildings have been added on since startup, plus an adjacent retirement home is now served by the system. The total space heated is now about 750,000 square feet (70,000 m^2) and estimated annual savings are about $1,300,000. Estimated annual operating costs are about $50,000 (John Lund, personal communication, 11/29/2007).

Apart from space heating, the geothermal system also provides cooling to about 280,000 square feet (25,000 m^2) on campus. This is done by using an absorption chiller that was installed in 1980 (Lienau, 1996). The University also has plans to drill a new 6000 foot (1,829 m) well and use the geothermal fluid from that well to produce 1.2 MW of electricity (John Lund, personal communication, 11/29/2007).

3.6.2 Lakeview

The GDHS in Lakeview, Oregon is the newest addition to the U.S. GDHS sector. It was developed in 2005 in conjunction with the construction of the Warner Creek Correctional Facility. Lakeview has a population of 2,500 and is located close to the California border. It is a "depressed" timber community and the construction of the correctional facility was part of an effort to boost employment in the town. The geothermal system serves the 400 bed, 117,000 square feet minimum security facility with hot water for space heating and domestic hot water (Ray Simms, personal communication, 02/04/08).

One production well produces 206°F (97°C) fluid which is used in the system, cooled to 140°F (60°C) and then reinjected back into the system through a second injection well. Both wells are about 600 feet (183 m). The city has water rights to produce 300 gpm (19 kg/s) from the well but they are currently only using about 140 gpm (9 kg/s). The correctional facility has a backup propane boiler in case the geothermal system goes offline (Ray Simms, personal communication, 02/04/08).

The town of Lakeview runs the system but the State of Oregon paid most of the geothermal system development costs as an economic development project for Lakeview. In return the correctional facility pays reduced heating rates. The town supplemented the capital costs to oversize the system's capacity to enable expansion of the system in the future (Ray Simms, personal communication, 02/04/08).

The town also received a Business Energy Tax Credit from the State of Oregon which amounted to about 35% of the investment. Even though the town is a municipality and therefore does not pay taxes, the credits are resalable on the market and were sold to COSTCO for $409,000. The total cost of the project was $1.2 million (Ray Simms, personal communication, 02/04/08).

The correctional facility staff has estimated that the geothermal system saves them about $180,000 annually. Mr. Simms, Lakeview's town manager, believes that the savings might be even greater because when the system broke down in the spring of 2007 the prison was paying about a $1,000 per day for the propane to heat the facility whereas they pay $3,500 a month for the geothermal water. The income from the correctional facility covers operational costs for the system (Ray Simms, personal communication, 02/04/08).

The town has received an Oregon Energy Trust Grant to do a feasibility study of producing electricity from the geothermal well used for the district heating system. If the project goes ahead they would use an existing, nearby cold water well for cooling purposes. The town has furthermore applied and is optimistic that it will receive a grant from the Oregon Economic and Community Development Department to do a feasibility of another GDHS in town. That system would utilize an existing geothermal well located on the opposite side of town to the prison well. Heat analysis and pumping tests performed in 2007 showed that the well probably has enough capacity and heat (about 190°F/88°C) to heat the school, hospital and some industrial buildings in the area. (Ray Simms, personal communication, 02/04/08).

3.7 South Dakota

There are two operating geothermal district heating systems in South Dakota, located in the southern part of the state in Midland and Philip.

3.7.1 Midland

The Midland District Heating System in South Dakota was developed in 1969. It is a small system owned by the town. The town's original geothermal well was drilled in about 1959 as a water supply for the town. In 1964 a school was built and geothermal water used to as a heating source. Then in 1969, the well broke down and could not be repaired. Subsequently another geothermal well was drilled and that well is currently used to serve the town's district heating system (Reuben Vollmer, personal communication, 02/11/08).

The production well is 3,300 feet (1,006 m) deep and produces 180 gpm (11 kg/s) of 152°F (67°C) water. The system has a maximum ΔT of about 25°F (14°C) (Lund et al., 1998). Once the water has been passed through the system it is dumped into the Bad River. The system is run all year round but at a very low flow rate (1-2 gallons/min or less than 1 kg/s) in the summer. Midland received federal assistance including a Farm Home Administration grant to construct their system (Reuben Vollmer, personal communication, 02/11/08). Initial capital costs are unavailable but annual operational costs have been estimated at about $1,800 and annual savings at about $17,000.

There are about a dozen buildings on the Midland district system. Most of the buildings are either commercial or governmental with only one home on the system. The system has developed incrementally and most buildings have had to be retrofitted at the time of connection. Substitute fuels in the area are mainly propane and fuel oil. For the first three years customers pay $150 per year for their water and after that the rate goes up to $300 pre year. If a building owner operates more than one building on the system, he/she pays half price for the second building, i.e. $75 and $150 per year. Each customer is allowed a maximum flow of five gpm (0.3 kg/s) and is not required to have a back up system, although many do (Reuben Vollmer, personal communication, 02/11/08).

3.7.2 Philip

The Philip District Heating system in South Dakota was developed in 1980 and is run by a heating district owned by its users. The system uses excess hot water from the town's school heating system which comes from a single 1,300 ft (396 m) production well with a maximum flow of about 340 gpm (21 kg/s) (F. W. Childs et al., 1983). After the water has been run through the system it is treated at a barium treatment plant before being discharged into the Bad River. The water comes out of the well at 151°F (66°C) and leaves the system at about 100–105°F (38-41°C). District heating users are not required to have a back up system although some do. The system is shut off at spring and turned back on in the fall by the school janitor (Ray Smith, personal communication, 02/01/08).

Initial capital costs were $1,209,185 and of that, 77% was paid by the U.S. DOE as a cost share project (F. W. Childs et al., 1983). The system serves seven businesses with hot water which all had to be retrofitted to use geothermal heat. The monthly rate paid to the school for the hot water is $6,500 which is split among the district members according to use. Maintenance is handled as it comes up by the members. The system has not grown since it was developed, but recently because of rising propane prices there has been some interest to hook up to the system from other entities in town (Ray Smith, personal communication, 02/01/08).

3.8 Utah

There is one operating geothermal district heating system in Utah located close to Bluffdale on the outskirts of Salt Lake City.

3.8.1 Bluffdale

Like the Lakeview system in Oregon, the Bluffdale geothermal district heating system serves a correctional facility. The facility consists of six buildings with an area of about 400,000 square feet (37,000 m^2). The system was started up in 2003 and is the third attempt at heating this Utah State Prison with geothermal energy. According to the current system operator, the first two attempts failed because of scaling and lack of maintenance. Scaling accrued because the geothermal fluid is rich in minerals and particulates and prior systems were operated at too large a ΔT which resulted in precipitation of the minerals (Matt Bruce, personal communication, 04/30/08).

The geothermal fluid is provided by a 1,203 ft (367 m) deep well drilled in 1981. The water comes out of the well at about 170-180°F (77-82°C) at a rate of about 500 gpm (32 kg/s). The ΔT of the system is about 15°F (8°C). After use in the prison, the water is sent to a fish hatchery at no cost, where the temperature is dropped a further 25°F (14°C). After use the water is sent for disposal to a wetlands development project (Matt Bruce, personal communication, 04/30/08).

The system is run through a service contract with Johnsons Controls Inc. (JCI) and keeps a natural gas boiler from the prior heating system as back up. The system provides both heating and domestic hot water and is therefore run year round. Initial capital costs for the geothermal system, which required retrofitting the facility from a natural gas steam system, were $900,000 while annual savings have been estimated at $400,000. (Matt Bruce, personal communication, 04/30/08). Using data provided by JCI, the annual operating costs have been estimated at about $9,000.

3.9 U.S. Geothermal District Heating Systems Cost Data

Cost information collected includes data on annual operation costs, annual revenue or savings whichever are applicable, initial capital costs and drilling costs. When cost figures were not available they were estimated using methods detailed in Section 2.2. The available actual initial capital costs, and actual and estimated operating costs, revenues or savings and drilling costs are tabulated in Table 5.

Table 5 - U.S. geothermal district heating systems costs. Estimated Costs are represented by parenthesis.

System	Annual Operating Costs	Annual Savings or Revenue	Actual Initial Capital Costs	Drilling Costs
Susanville District Heating	($60,000)	$70,000	Not available	($217,000)
San Bernardino District Heating	($144,000)	$141,000	$6,000,000	($133,000)
I'SOT District Heating System (Canby)	$9,500	$46,000	$1,200,000	$450,000
Pagosa Springs District Heating	$26,500	$47,500	$1,400,000	($68,000)
Boise City Geothermal District Heating	$1,767,746[2]	$1,859,896[2]	Not available	($809,000)
Fort Boise Veteran's Hospital (Boise)	($60,000)	($300,000)	$7,500,000	($418,000)
Idaho Capital Mall (Boise)	($56,000)	($300,000)	$1,800,000	($546,000)
Warm Springs Water District (Boise)	$280,000[3]	$225,000	Not available	Not available
College of Southern Idaho (Twin Falls)	($170,000)	($298,000)	Not available	$205,700
Kanaka Rapids Ranch (north of Buhl)	($26,000)	$5,040	Not available	($221,000)
Gila Hot Springs	($7,000)	$15,000[3]	Not available	($24,000)
New Mexico State University (Las Cruces)	($81,000)	($195,000)	Not available	($337,000)
Warren Estates (Reno)	$90,000	$176,300	$1,400,000	($533,000)
Manzanita Estates (Reno)	See Warren Estates	See Warren Estates	See Warren Estates	See Warren Estates
Elko County School District	$75,000	($340,000)[4]	$1,500,000	($206,000)
Elko District Heat	$60,000	$175,000[3]	$1,101,346	$166,314
City of Klamath Falls District Heating	$223,965[2]	$239,667[2]	$2,580,000	($187,000)
Oregon Institute of Technology (Klamath Falls)	($48,000)	($1,280,000)	Not available	$150,000
Lakeview	($42,000)	($320,000)	$1,200,000	($723,000)
Midland District Heating	($1,800)	($17,000)	Not available	$75,000
Philip District Heating	$6,500	($80,000)	$1,218,884	$311,516
Bluffdale	($9,200)	$400,000	$900,000	($143,000)

[1] Average for 2007 and 2008.
[2] Average for 2006, 2007 and 2008.
[3] Average from numbers given in interview.
[4] Estimated savings from 2002 inflated to 2008 using 3% inflation rate.

There are two main components to GDHS capital costs, the geothermal well costs and the distribution system costs. The wells include the drilling and completion of one or more production wells and injection wells if needed and the distribution costs include the cost of pumps, piping, control systems, metering system and heat exchangers. The cost of each component varies by site and size of system. Apart from these, capital costs, exploration, permitting and financing costs are also important cost factors.

The three most recently developed GDHS in the U.S., I'SOT (2003), Lakeview (2005) and Bluffdale (2003), provide indication of what the current costs for developing a geothermal district heating system in the U.S. are. A payback period analysis along with calculation of estimated capital costs per kW and estimated levelized energy costs were performed for all three systems using methods described in Section 2.3.

The I'SOT system services a small community in northern California. Because many of the town's streets are not yet paved, laying distribution pipes into the streets proved less expensive than it otherwise would have been. The total capital costs for the development of the system were $1,200,000. A present value analysis of those costs using a 3% inflation rate puts the present value of I'SOT's capital costs at about $1,400,000 in 2008 or about $2,800/kW. A simple payback analysis shows that the payback time for the system, assuming no increases in operational costs or savings, is 33 years. Levelized energy costs for the ISOT system are $36 per mmBtu.

The Bluffdale system was developed in 2003 and serves a correctional facility that was retrofitted from a natural gas steam system. The capital costs for the project were about $900,000 and did not include drilling costs as the correctional facility already owned a geothermal well from previous geothermal projects. A present value analysis to the year 2008 gives a present value of initial capital costs of about $1,000,000 or about $500 per kW and a payback analysis shows that the system breaks even after 3 years. Levelized energy costs were estimated as $8 per mmBtu.

The Lakeview system was developed in 2005 and serves a correctional facility built at time of system development. The total capital costs for the project were $1,200,000 and inflated by 3% up to 2008 the total capital costs amount to about $1,300,000 or about $500 per kW. A payback analysis with the conservative assumption that there are no increases in operational costs or savings, shows that the payback for the system is nine years. Levelized energy costs were estimated as $15 per mmBtu. The cost analysis for the three systems is summarized in Table 6.

Table 6 - Cost analysis for I'SOT, Bluffdale, Lakeview

System	Total Capital Costs 2008$	$ per kW	$ per mmBtu
I'SOT	$1,400,000	$2,800	$36
Bluffdale	$1,000,000	$500	$8
Lakeview	$1,300,000	$500	$15

3.9.1 Drilling Costs

Drilling cost data for the 22 systems were collected or estimated using methods detailed in Section 2.2.1.4. Using actual drilling cost data, cost per foot for six geothermal GDHS wells were calculated. These calculations are presented in Figure 22 by the drilling year of the well. The data show an apparent trend of rising drilling costs per foot over the years.

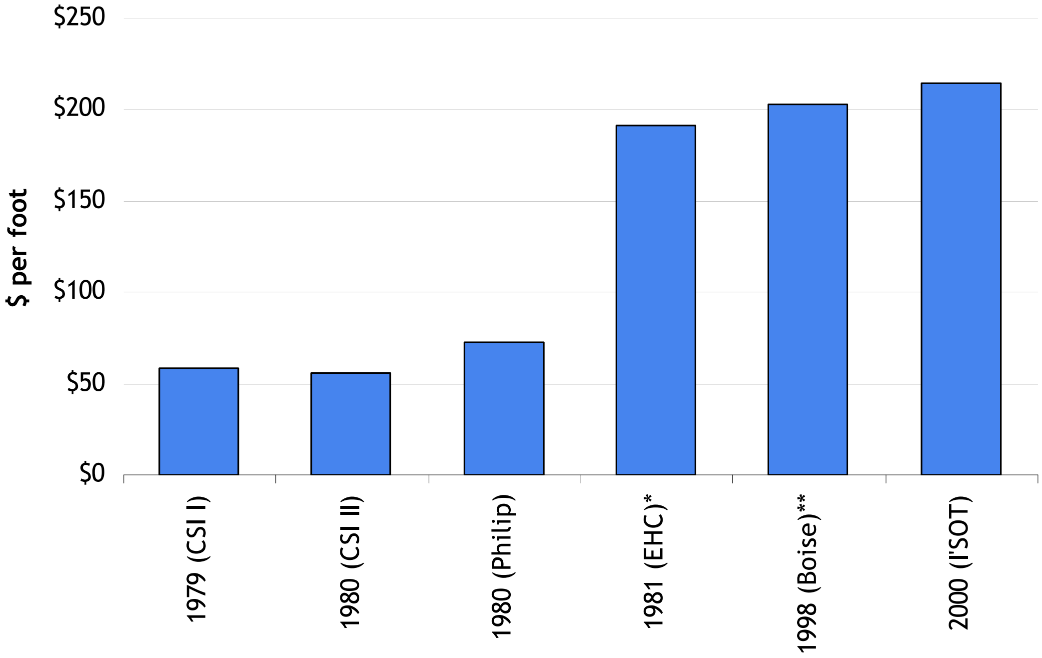

Figure 22 - Actual drilling costs per foot by drilling year. *Elko Heat Company, **Boise City System.

3.10 Geothermal District Heating Systems Design Data

Data on the systems' design conditions and design success can be found in Table 7. The information includes data on space heating substitutes available in the area, whether a market assessment was performed before construction, whether retrofitting of buildings was required at the time of system development, whether the system is run all year round or seasonally and whether the system has encountered any substantial engineering or other design problems. Figure 23 shows part of the data from Table 7 graphically.

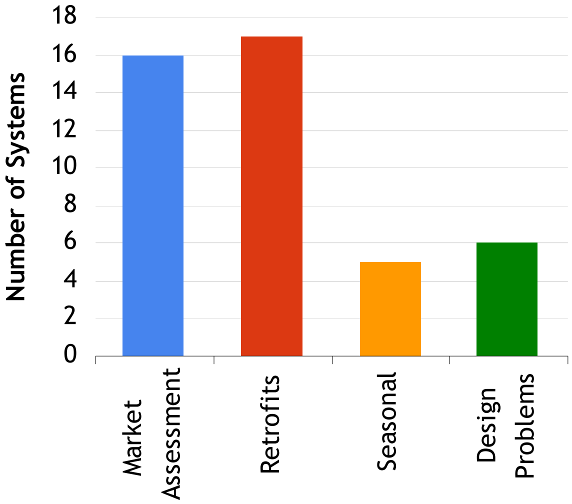

Figure 23 - GDHS systems studied that performed a market assessment, had to retrofit buildings, have seasonal variation in operation and have experienced significant design problems. Total number of systems studied is 22.

Table 7 - Substitute fuels, design conditions and design success of U.S. GDHS.

System	Substitutes	Market Assessment	Retrofits	Seasonal	Design Problems
Susanville District Heating	W, P, FO	No	Yes	Yes	Yes
San Bernardino District Heating	NG	No	Yes	No	No
I'SOT District Heating System (Canby)	P	Yes	Yes	No	No
Pagosa Springs District Heating	NG, E	Yes	Yes	Yes	Yes
Boise City Geothermal District Heating	NG, GSHP	Yes	Yes	No	Yes
Fort Boise Veteran's Hospital (Boise)	NG, FO	Yes	Yes	No	No
Idaho Capital Mall (Boise)	NG	Yes	Yes	Yes	No
Warm Springs Water District (Boise)	NG, FO	No	Yes	No	No
College of Southern Idaho (Twin Falls)	NG	Yes	Yes	No	No
Kanaka Rapids Ranch (north of Buhl)	NG, E	Yes	No	No	No
Gila Hot Springs	P, W	Yes	Yes	No	No
New Mexico State University (Las Cruces)	NG	Yes	Yes	No	Yes
Warren Estates (Reno)	NG	Yes	No	No	No
Manzanita Estates (Reno)	NG	Yes	No	No	No
Elko County School District	NG	No	Yes	No	No
Elko District Heat	NG	Yes	Yes	No	No
City of Klamath Falls District Heating	NG, FO, E	No	Yes	No	Yes
Oregon Institute of Technology (Klamath Falls)	NG, FO, E, W	Yes	No	No	Yes
Lakeview	P	Yes	No	No	No
Midland District Heating	FO, P, W	No	Yes	Yes	No
Philip District Heating	P, E	Yes	Yes	Yes	No
Bluffdale	NG	Yes	Yes	No	No

NG = Natural Gas, FO = Fuel oil, E = Electricity, P = Propane, W = Wood

3.11 GDHS Policy Data

Policy data were gathered for the GDHS and can be found in Table 8. Factors researched include whether the system received substantial federal or state funding at the time of development, whether users are required to operate their own backup heating system, whether any incentives are available for new users to hook up to the system and whether the system reinjects the geothermal fluid. Figure 24 shows data from Table 8 graphically.

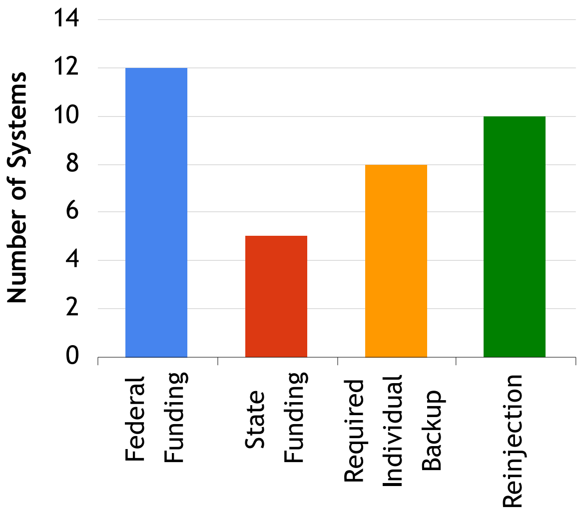

Figure 24 - GDHS systems studied that received federal and state funding at time of construction, that require users to have individual backup systems and that reinject their geothermal fluid. Total number of systems studied is 22.

Table 8 - U.S. GDHS policy data.

System	Federal funding	State Funding	Required Individual back up	Incentives for New Users	Reinjection
Susanville District Heating	Yes	Yes	Yes	No incentives	Yes
San Bernardino District Heating	Yes	Yes	Yes	Rates tied to NG rates	No
I'SOT District Heating System (Canby)	Yes	Yes	No	Not applicable	No
Pagosa Springs District Heating	Yes	No	No	System pays all connection costs. Customers only need to expose service lines.	No
Boise City Geothermal District Heating	Yes	No	No	Rates tied to NG rates	Yes
Fort Boise Veteran's Hospital	No	No	No	Not applicable	Yes
Idaho Capital Mall (Boise)	Yes	No	Yes	Not applicable	Yes
Warm Springs Water District (Boise)	No	No	No	No incentives	No
College of Southern Idaho (Twin Falls)	No	No	No	Not applicable	No
Kanaka Rapids Ranch (north of Buhl)	No	No	No	No incentives	No
Gila Hot Springs	No	No	No	Not applicable	No
New Mexico State University (Las Cruces)	Yes	Yes	No	Not applicable	Yes
Warren Estates (Reno)	No	No	Yes	First yr free and rates tied to NG rates	Yes
Manzanita Estates (Reno)	No	No	Yes	First yr free and rates tied to NG rates	Yes
Elko County School District	Yes	No	Yes	No incentives	No
Elko District Heat	Yes	No	Yes	Pay construction costs or discount hot water	No
City of Klamath Falls District Heating	Yes	No	Yes	First season free & reimbursement if other customers hook onto extension. Rates tied to NG rates.	Yes
Oregon Institute of Technology (Klamath Falls)	No	No	No	Not applicable	Yes
Lakeview	No	Yes	No	Not applicable	Yes
Midland District Heating	Yes	No	No	Discounted rates	No
Philip District Heating	Yes	No	No	No incentives	No
Bluffdale	No	No	No	Not applicable	No

4 Logistic Regression Results

A logistic regression analysis was performed on the GDHS data set. Each variable's correlation with the success of a system was analyzed and a logistic model was developed to predict the success of a system using the likelihood test statistic. The following independent variables were tested to try to assess their influence on U.S. GDHS success:

1. federal funding at the time of construction,
2. state funding at the time of construction,
3. whether a market assessment was performed before the project was developed,
4. whether retrofits were needed,
5. whether that system is run all year round,
6. whether it has encountered any significant design problems,
7. whether individual back up is required,
8. whether the system offers incentives to new users,
9. whether system rates are tied to natural gas prices, and
10. whether the system reinjects its geothermal fluid.

4.1 Successful Systems

The information collected from the interviews was analyzed to identify systems that did not meet the criteria for a successful system. Five systems were categorized as having experienced substantial operational problems. These problems were identified by comparing operational costs with revenue or savings of the system. Of the five identified systems, one is no longer running and four systems currently or recently have been unable to meet their operational and maintenance costs with revenue or savings.

The New Mexico State University system is no longer running and was therefore categorized as unsuccessful. The geothermal district heating system run by the City of Klamath Falls was categorized as having encountered serious trouble because of its history of being unable to meet its operation and maintenance costs with revenue. Although Klamath Falls City has recently with hard work turned the system around, the system operated at a loss for several years and it still cannot cover projected capital needs. Similarly, the Susanville District Heating System was categorized as having experienced substantial problems. Like Klamath Falls, Susanville has recently made changes to its system and customer base and has managed to turn the economics around and is now making a profit. Nevertheless, because of its history of financial losses it was categorized as a troubled system for analysis purposes. The Boise City Geothermal System and San Bernardino systems were also categorized as troubled because of their history of being unable to meet operational costs. Finally, the Kanaka Rapids Ranch geothermal district heating system is experiencing significant operational problems because its current users' fees are not high enough to cover maintenance needed and thus was classified as unsuccessful. The other 17 systems were categorized as successful.

4.2 Influential Variables

The logistic regression suggests the success of a GDHS in the U.S. can be best predicted using only two independent variables: (1) whether the system has encountered significant design problems and (2) whether the system received state funding. The regression suggests that coefficients for both these independent variables are negative (see Table 9).

Table 9 - Logistic regression model results.

Coefficient	Value	Standard Error	Wald Statistic z	P> |z|
Constant = β_0	2.6065	1.0639	2.4499	1.9857
Design prob. = β_1	-2.1667	1.4030	-1.5443	0.1225
State fund. = β_2	-2.7823	1.3320	-2.0888	0.0367

The final model is as follows:

$$P(Y = 1) = \frac{e^{(2.6065x_0 - 2.1667x_1 - 2.7823x_2)}}{1 + e^{(2.6065 - 2.1667x_1 - 2.7823x_2)}}$$

Where P(Y = 1) is the odds of a GDHS being successful. The *G* value for the model is 8.3996 which corresponds to a *p*-value of $P[\chi^2(2) > 8.3996] = 0.015$ which is significant at the $\alpha = 0.05$ level. Thus the null hypothesis, that the model's coefficients are zero, was rejected at a 5% significance level or in other words, there is only a 5% chance that a right hypothesis is being rejected. A Wald test furthermore indicates that the design problems are significant at 5% level and state funding is significant at a 15% level. The model correctly predicts 80.95% of the observations and therefore indicates that substantial design problems and state funding at the time of development are good indicators of significant operational problems for a U.S. GDHS.

As the model is comprised of only 21 observations its conclusions provide an indication, not quantitative validation, of a relationship between variables. It is important to analyze the identified influential variables further to reach any conclusions. In Section 6, these identified influential variables are analyzed in more detail to try to assess why they are important to GDHS success.

5 Survey Results

As noted in Section 1.4, the literature cites three main potential barriers to GDHS development in the United States. These are: local authorities' unawareness of geothermal energy system benefits, the fact that GDHS are complex, high risk undertakings and that local leaders lack the necessary knowledge to develop GDHS. To assess the validity of these barriers a survey was sent out to 104 communities of the 271 communities identified in the low temperature geothermal resource collocation study done in 1996. As mentioned before, all 271 communities were sent letters shortly after the completion of the study, as a follow-up, informing the communities of the geothermal potential located close to their community and as a result only one town contacted the Geo Heat Center interested in exploring the geothermal opportunity further.

Of the 104 communities that received the survey, 34 responded, giving a response ratio of 33%. Responses were received from small towns up to big cities. Almost everyone answered all the questions, only one community leader did not identify which town/city they represented, one respondent did not answer what he thought the environmental impacts of a GDHS would be and one respondent did not identify main barriers to GDHS development. The responses represented communities in at least eleven states of the fourteen that surveys were sent to. The states represented include Arizona, California, Colorado, Idaho, Montana, New Mexico, Oregon, Utah, Texas, Alaska and Nebraska while communities in Nevada, Wisconsin and South Dakota did not respond to the survey.

Notably, half of the communities that responded to the survey stated that there is not a geothermal resource located close to their town/city even though all communities that were sent the survey have been identified as being collocated with a geothermal resource suitable for direct use (see Figure 25). The lack of knowledge of nearby geothermal potential is an important barrier to geothermal development in these communities.

Furthermore, over 59% of respondents say that the do not have access to or know of any resources to assess the feasibility of, advise on or design a geothermal district heating system (see Figure 26). This confirms the barrier stated in literature, that community leaders lack the necessary knowledge to develop GDHS and moreover says that they do not know where to turn if I want to acquire that knowledge.

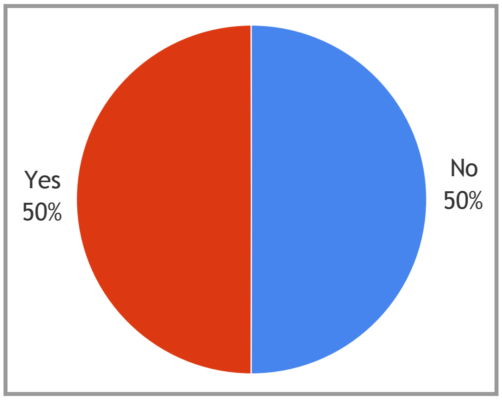

Figure 25 - Is there a geothermal resource located near your town/city?

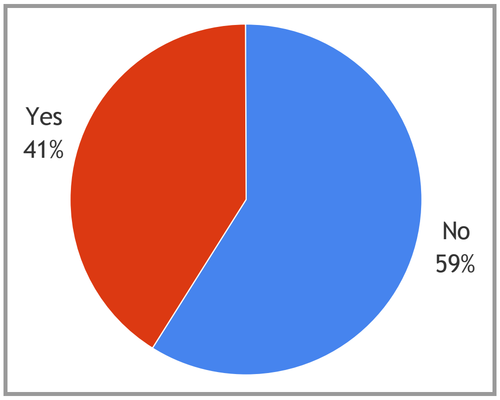

Figure 26 - Do you have access to or know of resources to assess the feasibility of, advise on or design a geothermal district heating system in your town/city?

However, the survey does indicate that local leaders are aware of the benefits of geothermal district heating. When asked about social/political, economic and environmental effects of developing a geothermal district heating system in their community, 79% of community leaders responded that it would have a somewhat to very beneficial effects on social and political aspects, 82% stated that they believed it would have somewhat beneficial to very beneficial effects on economic aspects and 79% think that it would have somewhat to very beneficial environmental effects. Also, only 6% of community leaders believed that a GDHS would have a somewhat negative effect on social/political aspects, only 3% believed it would have a negative impact on the economic status in their community and no respondent thought that a GDHS would have a negative impact on environmental aspects in the town/city (see Figure 27 - Figure 29).

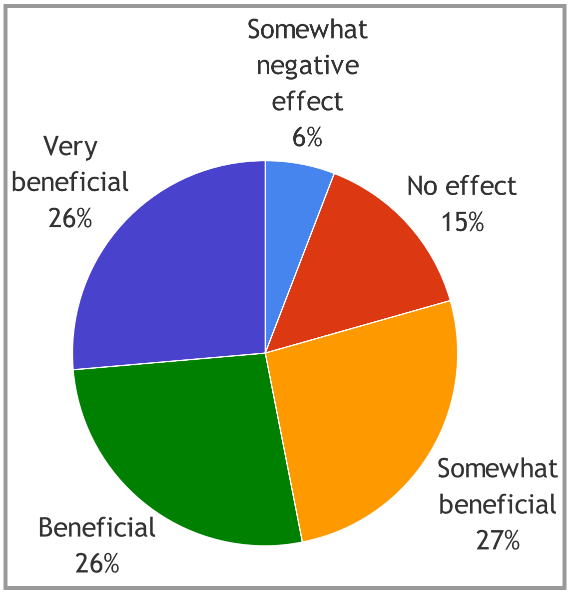

Figure 27 - What effect do you think a geothermal district heating system would have on social/political aspects in your town/city?

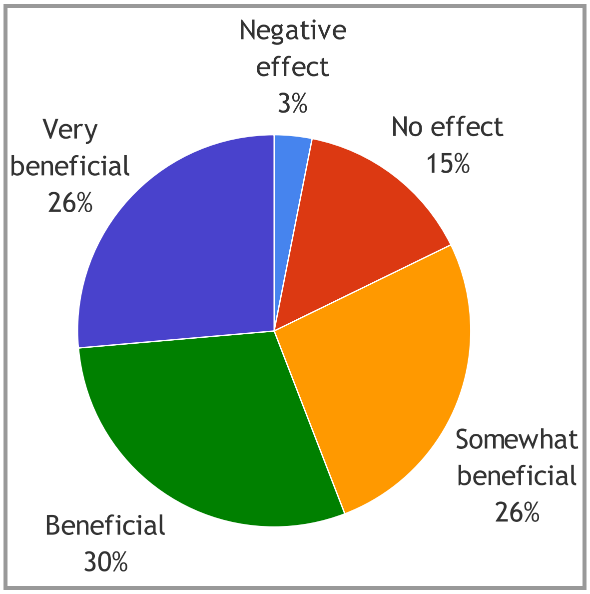

Figure 28 - What effect do you think a geothermal district heating system would have on the economic status in your town/city?

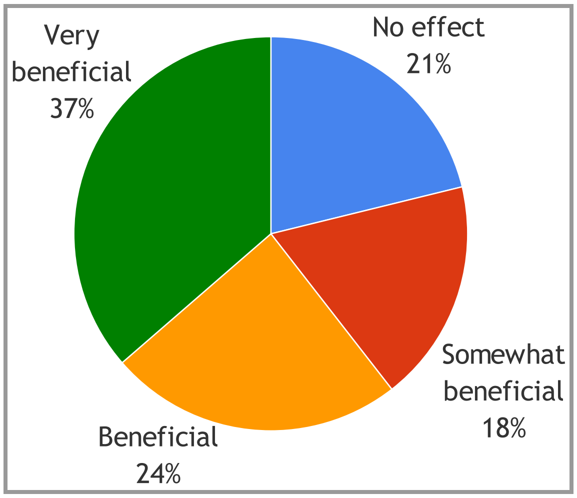

Figure 29 - What effect do you think a geothermal district heating system would have on environmental aspects in your town/city?

Consequently, it seems that community leaders are aware that a GDHS could provide their town/city with various benefits. The survey did not ask the leaders to specify the benefits the believed would stem from a GDHS and perhaps they would not be able to specify the exact benefits but the survey nevertheless shows that most community leaders would consider the development of a GDHS beneficial to their community.

Finally, respondents were asked to identify what they believed were the main barriers to geothermal district heating system development in their community (see Figure 30). Economic feasibility was the most popular barrier cited among community leaders with lack of resource coming in as a close second. Thirteen respondents also identified the complexity of the project as a barrier and nine responses identified lack of expertise within local government and the community as a barrier. This confirms that the fact that GDHS are perceived to be complex, high risk undertakings. This perceived complexity is a significant barrier to GDHS development.

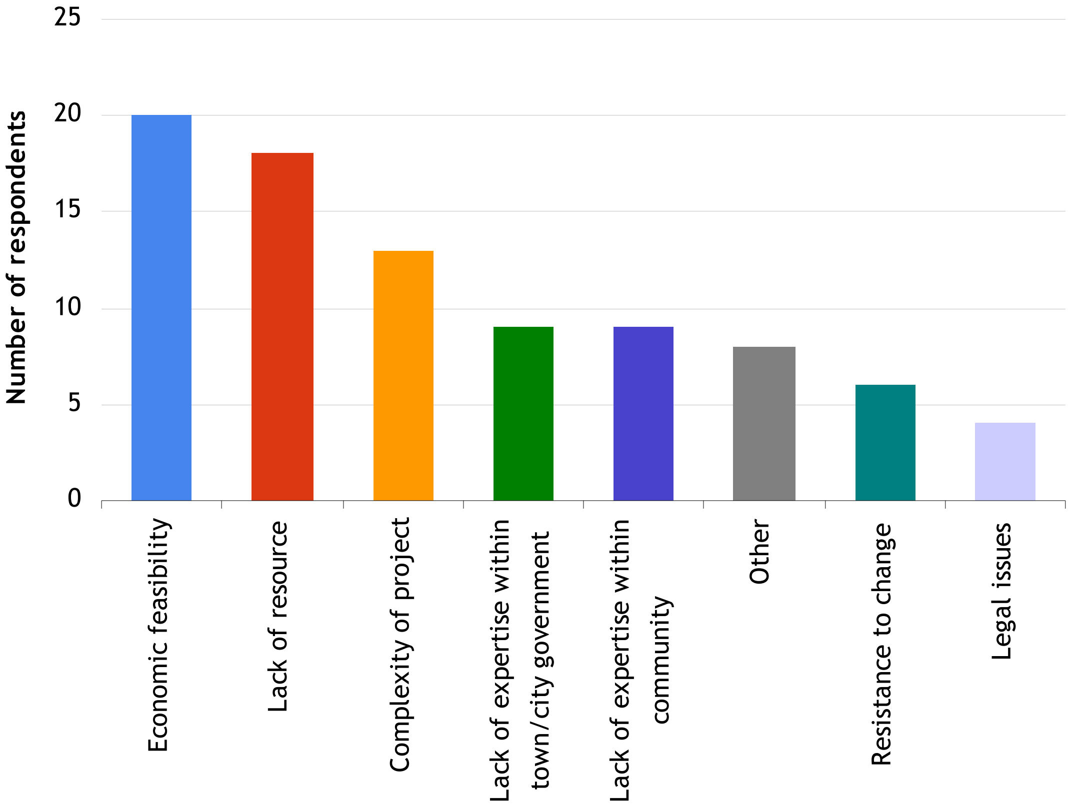

Figure 30 - What do you see as the main barriers to geothermal district heating development in your community?

Respondents were also given the option of checking an "other" box and write a short comment indicating a barrier not recognized by the survey. Comments showed that some of the towns have looked into utilizing their geothermal resources but have been unable to do so because of local issues or restrictions, like that the resource does not lie within city limits and is on private land, or the water rights are owned by an Indian tribe. One respondent indicated that the geothermal resources were already being used beneficially and another that the town has just received a grant to clean, test and do a feasibility study of using a City Well to heat the local school.

6 Barriers and Enablers

In this chapter potential influential variables are analyzed in more depth to identify root causes as to why the logistic regression identified state funding and design problems as the most influential variables. Furthermore, other variables analyzed will be discussed including geothermal policy issues, the impact of substitute prices, economic analysis of recent systems, and the results of the survey of collocated communities.

6.1 U.S. Geothermal Policy

Two legislative acts form the basis for geothermal regulation in the United States, the California Geothermal Resource Act of 1967 and the Federal Geothermal Steam Act of 1970. Recently, the Energy Policy Act of 2005 and the Energy Independence Security Act of 2007 included changes to geothermal regulations and appropriated funding to the DOE geothermal program.

6.1.1 Federal Funding

Since the 1960s, the U.S. federal government has initiated several funding programs to support the development of geothermal energy. Early programs focused on minimizing or reducing financial risks involved with exploration and development of geothermal resources (Bloomquist, 2005b).

A number of federal geothermal loan programs were started between 1974 and 1980. The most successful of these was the Geothermal Loan Guarantee Program (GLGP) which was implemented in 1974. Its objectives were threefold. Firstly to encourage accelerated development of geothermal energy by private and public entities in an environmental acceptable manner by minimizing financial risk. Secondly, the program’s aim was to develop normal borrower-lender relationships for the geothermal sector and thirdly, to enhance competition and encourage new entry into the geothermal market (Bloomquist, 2005b). The program provided a loan guarantee of up to 75% of the project costs and up to 100% of the amount borrowed. In 1980, the amount that could be borrowed rose to 90% of the project costs if the applicant was an electric, housing or other cooperative or municipality but limited to at most a $100 million dollar loan per project and $200 million per applicant. The GLGP was successful and a number of geothermal projects were funded by the program. However, the severe requirements for loan approval have spouted criticisms that the program funded projects that could have received financing in the open market and that even though the loans were federally guaranteed the risk of default was too great to utilities' credit ratings for them to take a chance on geothermal development projects. The program was stopped in the 1980s due to lack of appropriations (Bloomquist, 2005b).

Other federal loan programs include the User Coupled Confirmation Drilling Program initiated in 1980 and designed to encourage geothermal direct use development by industry and federal cost share for confirmation of geothermal resources. Along with hedging resource confirmation risk the program was supposed to help build geothermal industry infrastructure. In the program, the federal government would agree to fund 20%-90% of the project, paying a bigger share for unsuccessful projects. The 1980 Energy Security Act passed more programs supporting geothermal development including the Feasibility Study Loans, Reservoir Confirmation Loans and System Construction Loans. However, none of these programs were implemented because of lack of appropriations (Bloomquist, 2005b).

Three other federal geothermal financial assistance programs are worth mentioning. The first is the U.S. Department of Energy (DOE) Technical Assistance Grant Program. It was designed with the intent to encourage development of direct use of geothermal applications to developers with little or no experience in geothermal energy. It provided up to 100 hours of technical assistance to geothermal developers. Later that assistance was scaled back to eight hours per geothermal project to promote growth in the private geothermal development consulting sector. The other two programs are the Program Research and Development Announcement program (PRDA) and the Program Opportunities Notice (PON). PRDA provided grants from \$100,000 - \$125,000 for detailed engineering and feasibility studies of direct applications of geothermal energy and PON provided cost share assistance on a competitive basis to geothermal direct application and cogeneration of electricity and direct use (Bloomquist, 2005b). Among the projects that received PON funding were the geothermal district heating systems (GDHS) in Boise City, City of

Klamath Falls, Pagosa Springs, Philip and the Elko Heat Company (Frank W. Childs & Sanders, 1983).

Of the 22 systems analyzed in this study, 12 received federal funding at the time of their development. Construction of many of these systems would not have been possible without federal aid. Clearly, federal funding programs have contributed significantly to the current installed geothermal district heating capacity in the U.S. Nevertheless, the question still remains, could the government have done more or done something differently to encourage more sustainable GDHS development and what role should the federal government play today.

In FY 2007 and 2008 the presidential budget proposal cut out funding for the DOE's geothermal research program citing that the technology was mature and did not need further funding support. As might have been expected, cutting the geothermal program raised objections from the geothermal community and from within the geothermal program at the DOE. As a result of protests and continuing appropriations resolutions in the federal government, funding for both FY07 and FY08 ended up being restored. Nevertheless the original plan to cut the program two consecutive years shows that within the DOE, geothermal energy was not considered to justify federally funded research effort. The Energy Independence and Security Act of 2007 included a strong geothermal section calling for continued support for geothermal energy but it is mostly focused on engineered geothermal system technology and does not call for support of low temperature utilization of geothermal resources. Consequently, it is currently unlikely that federal funding assistance will be available for GDHS in the near future. However, political climates can shift quickly and it is impossible to say conclusively that federal funding will not be available.

6.1.2 State Funding

Only limited documentation is available on geothermal state funding programs. Data collected show that California, New Mexico and Oregon have all supported geothermal district heating projects. The California Energy Commission (CEC) has provided financial support for three GDHS: Susanville, San Bernardino and I'SOT. New Mexico supported the GDHS at New Mexico State University and Oregon supported the development of the Lakeview system.

The Susanville District Heating system was a cost share between the CEC and the City of Susanville. The CEC put forth $1,075,014 or 80% of the total project cost while match funds from the City of Susanville amounted to $273,092 (California Energy Commission, 2003a). The San Bernardino system received both grants and loans from the CEC. In total the system received $281,265 in grants from the state of California and $4,324,145 in loans while putting up $1,324,562 of its own money (California Energy Commission, 2003b). The system also received federal funding. The I'SOT geothermal system has also received grants of at least $304,525 from the CEC along with federal assistance to drill an exploratory geothermal well. The funding for the New Mexico State University project came through a special appropriation from the New Mexico State Legislature and Oregon State funded most of the Lakeview geothermal district heating system capital costs as an economic development project for the town of Lakeview.

These projects would not have been developed without the state funding they received. Each of the five projects got a significant portion of the funding needed from state governments. It is hard to say why state funding, unlike federal funding, is correlated negatively with project success. Perhaps it is because the systems funded by state programs were more marginal to start with, which also explains why they needed state funding to materialize. Perhaps the difference between the success of the federal and state programs lies in the fact that the state funding provided to these geothermal projects, unlike the federal funding, was more often in the form of grants instead loans or loan guarantees and thus lower risks were carried by the geothermal developer.

Although state funding was found to be somewhat correlated with system trouble, it is not a guarantee of a definite relationship. Two of the most recent geothermal district heating systems in the U.S. received state funding (I'SOT and Lakeview) and they have not experienced trouble so far. Furthermore, it is evident that state support for GDHS development is important, as the federal government has provided little funding or financial incentives for GDHS in the U.S. since the 1980s and without state support only one GDHS (Bluffdale, UT) would have been developed in the U.S. since 1989.

6.1.3 Geothermal Leasing

A geothermal lease on federal or state land allows the lease holder to develop the geothermal resource located on the lease in exchange for rent or royalty payments to the federal or state government.

6.1.3.1 Federal Leases

About half of the identified hydrothermal resources in the United States are on federal land (Office of the Secretary of the Interior, 2006). The federal Energy Policy Act of 2005 contained provisions that aimed to simplify and streamline the leasing process of federal lands with geothermal potential. The measures were intended to reduce the backlog of geothermal lease applications on federal land and to unplug a system bottleneck. The Department of Interior which includes the BLM and the Department of Agriculture which includes the U.S. Forest Service were directed to enter into a memorandum of understanding designed to create a geothermal leasing process with time limits and reduce the geothermal lease application backlog by 90% within a five-year period. New geothermal lease regulations developed by the BLM to increase the efficiency of the federal geothermal leasing process were issued the summer of 2007, two years after the enactment of the Energy Policy Act (Bureau of Land Management, 2007).

With the recent increase in interest in geothermal energy, a bottleneck within the federal system, that had been low on the radar for over 20 years, now found itself in the spotlight. The bottleneck was the inability of the Bureau of Land Management (BLM) to process federal geothermal lease applications efficiently because of lack of committed staff to geothermal lease processing, lack of geothermal funding and expectation of litigation (National Geothermal Collaborative, 2004). In California, the state with the most geothermal energy production in the U.S., no geothermal leases had been issued for 20 years in 2006. The Geothermal Energy Association even went so far as to say in congressional testimony in July 2006 that “People applying for geothermal leases in California have been more likely to die while waiting in line than receive a lease”

(*Geothermal Energy and Other Renewables*, 2006). This bottleneck was not isolated to the California BLM office and caused a backlog of federal geothermal lease applications to pile up in many of the western states.

Since 1999 the increase in new geothermal lease applications to the BLM has been sharp. In 2003 BLM had received twice as many new geothermal leasing applications in four years than it had in the ten years previous to that. The agency was not prepared. Due to the little geothermal development in the U.S. before the sharp increase in interest, expertise and funding for this part of BLM operations was insufficient and the agency was ill equipped to deal with the increased load of geothermal lease applications. By the end of 2003 a backlog of 230 unprocessed geothermal lease applications had built up (*Geothermal Energy and Other Renewables*, 2006).

The Energy Policy Act of 2005 changed the leasing process with the aim of simplifying and streamlining it. All leasing for electrical generation was directed to be competitive, i.e. acreage should be leased in open auctions instead of on a first come, first serve basis and the royalty structure, calculation and payment distribution were changed. The royalty structure and calculation was simplified with the aim of a more transparent process and whereas before royalty payments were divided 50/50 between the state where the geothermal project was located and the federal government, now the 25% of the funds were allocated to the county were the project was situated, 50% to the state and 25% to the federal government ("Energy Policy Act of 2005," 2005). The new allocation increased the benefits that local communities get from geothermal development in their back yard and were aimed to increase local support for geothermal projects.

Separate changes were also made to geothermal leases for direct use. This was done with the aim of increasing direct use on federal land. The prior leasing and royalty structure was not favorable for direct use projects and as a result in 2006 less than 1% of 1300 plus direct use facilities in the U.S. were on federal land (Fleischmann, 2006). First, the Secretary of the Interior can now identify lands that can be leased exclusively for direct use utilization and those lands can be leased non-competitively, thereby reducing the cost to developers of acquiring land for geothermal direct use development. Moreover, direct use fee regulations were simplified in order to make the process more straightforward and state, local or tribal governments that intend to use geothermal fluid without sale and for public purposes apart from electricity generation will only have to pay a nominal fee for use of the resource on federal land (Haggerty, 2007).

6.1.3.2 State Leases

Most U.S. states, that have hydrothermal resources, used either the California Geothermal Resource Act of 1967 or the Federal Geothermal Steam Act of 1970 as a model for their own geothermal legislature. However, the statues are not uniform and each state has a separate characterization and definition of a geothermal resource (Bloomquist, 1986).

Depending on how the hydrothermal resource has been classified, ownership lies either with the owner of the mineral, groundwater or the surface rights of the estate. On federal land ownership lies with the mineral rights, whereas state rights vary by state. In most eastern states along with California, Arizona and Hawaii, groundwater rights come with the surface rights of the land. In most western states however, groundwater rights belong to the public (Bloomquist, 1986). Like ownership regulations, state leasing processes vary from state to state.

6.1.4 Statutory Authority and Utility Regulations

Whether or not a public sector entity can develop and operate a geothermal district heating system depends on the authority granted to it by the state. U.S. state regulations on municipality authority vary from state to state. In general, towns and cities may not develop geothermal district heating systems unless state legislature has specifically authorized them to do so. However, if “home rule” regulations apply, the municipality might be authorized to construct and operate a utility system. This is for instance the case in Colorado. In some cases it might be best to establish by law a special district or a unit of local government that can engage in the geothermal development proposed. Whatever the options are within a state it is very important for municipalities to investigate what their statutory authority is before engaging in geothermal development. Information on the specific rules in each state can be found in state constitutions or specific legislations (Bloomquist, 2004c, 2005a).

In many states a geothermal district heating project will be subject to regulations regarding public utilities. For small GDHS meeting regulations can be a big administrative barrier because of the extra paper work involved. Several states require that utilities obtain "a certificate of public convenience and necessity" or the equivalent. To acquire the certificate developers must usually prove that there is adequate demand for the proposed utility, that financing is in place, the system will provide the service proposed and will not duplicate existing service in the area. Furthermore, the systems rates will be set by a commission which will base their rate decision not on the current market rate of return but on a "fair rate of return" which is usually less than 12% (Bloomquist, 2004c).

6.1.5 USGS Geothermal Survey

For a greenfield development there is substantial risk involved in finding an economically viable geothermal resource underground. Unlike wind and solar where the resource can be measured relatively easily, in geothermal developments nothing is 100% certain about the resource until a well has been drilled and an economical flow of fluid/steam has been found.

To minimize the risk of hitting a "dry" well it is important to do careful surface exploration before embarking on drilling a well. Surface exploration entails seismic observations, review of surface manifestations, etc. Identified "Known Geothermal Resource Areas" (KGRA) as identified by the United State Geological Survey (USGS) provide some of the best opportunities for success within the United States. Nevertheless, even when working in a KGRA, the initial drilling risk is significant. Geologic layers that might present problems or not hitting a fracture directly are both substantial risks that geothermal developers face.

Furthermore, the assessment that the KGRA classification is built upon is based on the last United States Geothermal survey, performed by the USGS in 1978. For almost thirty years there was no geothermal evaluation program at the USGS. It was not until the Energy Policy Act of 2005 that an update of the assessment was ordered and starting in Fiscal Year 2006 the USGS again had the funding and motivation to reevaluate the 1978 assessment. The assessment will use significantly improved models for geothermal energy recovery factors and estimates of reservoir volumes. However, the assessment will not be as comprehensive as the 1978 survey and will not reevaluate the U.S. low temperature geothermal resource, appropriate for direct use, but instead is solely focusing on moderate- (90°-150° C) to high-temperature (>150°C) resources that can be utilized for electricity production (Williams et al., 2007). The USGS is due to publish its updated geothermal assessment in 2008 ("Energy Policy Act of 2005," 2005).

This is in stark contrast with the ongoing evaluation and survey efforts maintained within the USGS for oil and gas which has been continually updated over the past 30 years (U.S. Geological Survey, 2008) and with the Icelandic government policy that has maintained strong geothermal geological survey activities since the 1970s. Because of this, geothermal developers in the United States have had to rely on old data, oil and gas exploration data and their own exploration and funding to find and utilize geothermal resources. This is a significant barrier to U.S. geothermal development. In fact a survey by the Geothermal Energy Association (GEA) in 2006 showed that much of U.S. geothermal growth was limited to areas already well explored and that about half of geothermal projects under development in the U.S. in 2006, were expansions of existing well fields or power facilities (Fleischmann, 2006).

6.2 Design Problems

It is not surprising that significant system design problems have a negative impact on the likelihood of GDHS success. Nonetheless, the correlation between problematic design and odds of an unsuccessful system emphasize the importance of following good engineering practice and adhering to laws and regulation codes along with performing an adequate market assessment. Of the 22 systems analyzed, seven systems were identified has having experienced substantial design problems at some time in their history: Susanville, Pagosa Springs, Boise City, New Mexico State University, City of Klamath Falls and Oregon Institute of Technology.

Both the Klamath Falls and New Mexico State University (NMSU) systems experienced trouble because of initial engineering design decisions. In Klamath Falls major failures in joints in fiberglass piping caused system shut down during its first operating season. The fiberglass pipes were subsequently replaced with pre-insulated ductile iron pipe (Brown, 2007). However, the shutdown led to diminished trust in the system by customers and litigation (Jeff Ball, personal communication, 01/30/08). The NMSU system suffered from poor well design and construction. As a result the system had inadequate flow of hot water along with excessive sand in the pumped water which caused problem in the distribution network and led to unreliable service (Millennium Energy LLC, 2006).

Three of the systems researched experienced legal difficulties caused by aquifer water level concerns. When Boise City started pumping water out of their wells, the water level in the Boise geothermal aquifer fell, causing problems for all geothermal users in the area. Although the issue was finally settled by a state ordinance to reinject and water levels have again risen, the Boise City system is still suffering some backlash from that time (Kent Johnson, personal communication, 04/15/2008). A similar problem arose in Pagosa Springs and Klamath Falls where individual geothermal well owners became worried when they found out about the town’s plans to build a geothermal district heating system.

In Susanville the design problem was caused by inadequate market assessment at the start of the project. The system was laid into a low income part of town as well as part of the commercial district. In order to serve both these areas the city operated two wells. However, the revenue from the system did not cover operational costs. Mainly the revenue from the residential part of the system, where the houses were small and families had a tight income, was not sufficient to cover the added expense of operating a second well. Consequently, the City of Susanville has switched the residential customers to natural gas heating and now only operates a single well to serve its commercial customers.

To assess whether performing a market assessment before developing a GDHS was statistically correlated with successful GDHS, a market assessment variable was regressed against system success for the GDHS dataset. A statistically significant relationship could not be found yet the Susanville example shows that market assessments are a vital part of planning a GDHS and if the market is not sufficient to support a system, operation problems will occur.

These case studies show the importance of investigating possible geothermal aquifer and water level effects of a geothermal system before developing a GDHS in order to avoid litigation problems, to review the engineering design and material selection lessons learned by prior systems to avoid shut down because of poor design and to perform an adequate market survey to ensure sufficient revenue streams to cover operational costs.

6.3 Need for Education

Geothermal energy is not well understood by the general public. The survey results in Section 5 show that most local leaders recognize that a GDHS could bring beneficial environmental, economical and social/political benefits to their community but it was not verified as part of this study whether they understand exactly what those benefits might be. An equally important result from the survey results is that most people are unaware of geothermal resource potential in their local area.

Furthermore the survey shows that there is a lack of geothermal knowledge within local government and communities which clearly acts as a significant barrier. Without knowledge about geothermal and how to develop it is very hard for communities to take initiative and assess the feasibility of a geothermal district heating project. The federal GeoPowering the West program which was started in 2001 focuses on improving geothermal awareness in the U.S. and broadening and better coordinating outreach, partnering, and education programs (U.S. Department of Energy, 2006). It is crucial that this work be continued in order lower knowledge barrier to GDHS development.

6.4 The Relevance of Substitute Fuel Prices

The main substitute fuels for geothermal district heating in the U.S. as a means for space heating, listed in order of relative share of the market are, natural gas, electricity, fuel oil and propane. Figure 31 compares residential natural gas prices over the last thirty years with the development of geothermal district heating systems by plotting annual price data for residential natural gas in the U.S. along with the number of GDHS built each year. During the late 70s and 80s, when the price of natural gas rose, the government was very active in supporting and promoting the development of alternative sources for space heating and many GDHS were built. Then as the price of natural gas leveled out in the late

80s and 90s interest in GDHS development died down. Now with recent spikes in substitute fuel prices, interest in geothermal has risen again and systems are being developed, although regrettably at a slower pace than in the earlier development period.

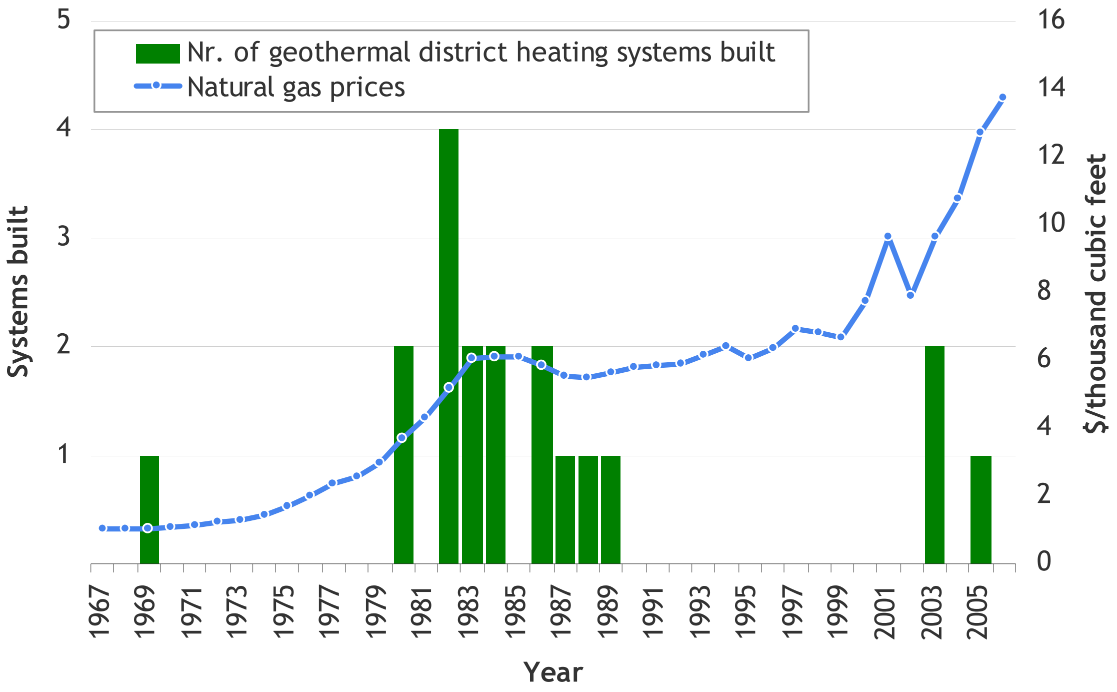

Figure 31 - Development of GDHS compared to the residential price of natural gas. Natural gas price data from (Energy Information Administration, 2008a).

6.5 Incentives for New Users

Several GDHS in the U.S. provide incentives for new users to hook up to their systems (see Table 10). Of course, systems where the operator itself is the system's only user, incentives are not needed. Therefore, as providing incentives is only applicable to some systems, the dataset available for a regression based on this factor was considerably smaller than on the other independent variables analyzed and no significant statistical relationship was found between offering some sort of incentive to hooking up and the success of the system. However, from conversations with GDHS operators, most new customers valued being compensated in some way from switching from their current source of heating to geothermal. For instance in Klamath Falls, offering incentives and advertising state incentives was a very important part of the marketing effort in the 1990s that helped re-establish the revenue base needed for the system (Rafferty, 1993).

Table 10 - GDHS that provide incentives to new customers.

System	Incentives for New Users
San Bernardino District Heating	Rates tied to NG rates
Pagosa Springs District Heating	System pays all connection costs. Customers only need to expose service lines.
Boise City Geothermal District Heating	Rates tied to NG rates
Warren Estates	First yr free and rates tied to NG rates
Manzanita Estates	First yr free and rates tied to NG rates
Elko District Heat	Pay construction costs or discount hot water
City of Klamath Falls District Heating	First season free & if other customers hook onto the extension a reimbursement is given. Rates tied to NG rates.
Midland District Heating	Discounted rates

Furthermore, incentives are important for geothermal systems because of the general lack of public understanding of geothermal. Fundamentally, people resist change, and changing over to an unknown or a not very well understood energy source requires even more incentives than changing to the “norm” like a fossil fueled system. Consequently, education campaigns to increase public acceptance of geothermal energy are an important incentive tool for GDHS developers.

Another common incentive for GDHS, which results from geothermal being the “unconventional” source for heating, is to tie the system rates to common heating fuel prices in the area, e.g. natural gas rates. The GDHS operator promises that the geothermal rates will always be a certain percentage lower than natural gas prices. This approach has been criticized in the past because by making this promise, geothermal developers are separating their revenue stream from their operating costs and are subject to price decreases in natural gas prices. An alternative that has been proposed to natural gas rate tying to offer customers low, fixed rates for an extended period of time. To try to identify whether rate tying affected the success of a GDHS, a logistic regression with natural gas rate tying as an independent variable was performed. However, the regression against the success of a GDHS is subject to the same limitations as the incentive regression was and it did not identify any statistically significant relationship between providing price rates that scale with gas prices and the success of a system.

6.6 Economic Factors

As with most renewable energy sources, the upfront capital costs of geothermal energy projects are high. An investment has to be made in exploration, drilling, construction, permits and leases before any revenue starts to flow. Although these costs are offset later in the project by having no fuel costs it can be hard to come up with large amounts of capital, with measurable investment and debt equity rates, upfront. It was thus not surprising that economic feasibility was the most popular barrier cited among community leaders in the survey performed as part of this study.

6.6.1 System Costs

The economic feasibility of GDHS is a crucial aspect in supporting growth in the sector. This study has not considered specific cost factors for geothermal systems but instead investigated recent cost experience in the sector and found payback times of 3 to 33 years depending on the project with initial capital costs of \$500 to \$2,800 per kW_t. Levelized energy costs were also estimated for the three most recent systems and were found to be \$8 to \$36 per mmBtu. Table 11 shows GDHS levelized energy costs compared to other U.S. residential fuel prices for 2007. From the comparison, it is clear that GDHS can be highly competitive with other fuel sources and even be the least cost alternative.

Table 11 - Representative average unit costs of energy for residential energy sources (fossil fuel data from (U.S. Department of Energy, 2007)).

Fuel Source	Price 2007 $/mmBtu
Electricity	31.21
Propane	20.47
Kerosene	19.48
No. 2 heating oil	16.01
Natural Gas	12.18
Geothermal District Heating	8.00 to 36.00

The total investment needed to increase U.S. GDHS capacity to 10,000 MW_t comes to just under \$5 billion dollars or the equivalence of about five new 1 GW coal plants The investment cost was estimated by using the median initial capital cost per kW (\$500/kW_t) for GDHS calculated as part of this study and multiplying that by the capacity increase of about 9,900 $MW_{t.}$.

6.6.2 Size of Customers

Notably, two of the country's most recent geothermal district heating systems were developed to heat large facilities, consisting of a few large buildings. Prior literature has also shown that larger buildings improve the economics of a GDHS because of savings in distribution network costs (Rafferty, 2003b). Larger commercial customers provide more revenue for a single connection whereas the same revenue from smaller energy consumers would require additional capital expenditure in distribution lines. This proved to be very important in Susanville where it was found uneconomic to continue serving small residential users and the system was downsized to serve only the bigger commercial customers. As a result of the downsizing the Susanville GDHS is now running at a profit (Craig Platt, personal communication, 03/10/08).

Connection costs for small customers can be a significant barrier to customer buy in and expansion. Often, retrofit costs for individual residential users outweigh the benefits of connecting to a geothermal district heating system because they are not big enough energy consumers. Some states, like Oregon, have offered incentives for users to connect like the Small Energy Loan Program and have helped many customers to connect to a GDHS (Rafferty, 1993). Although connection costs can be a barrier, when presented with a choice consumers prefer lower monthly bills to discounted connection costs. In a survey conducted at Mammoth Lakes, California in 2006 as part of an effort to install a geothermal district heating in town, more customers stated they would be willing to connect to a system with lower monthly heating bills and upfront connection costs than to a system with no upfront costs and higher heating bills (Bovitz Research Group, 2006).

6.6.3 Drilling Costs

The GDHS drilling cost data collected for this study show an apparent trend of rising drilling costs. This agrees with trends shown by the MIT drilling index discussed Section 2.2.1.5. The MIT index shows oil and gas well drilling cost trends in the U.S. over a thirty year period and can be used to approximate geothermal well costs (see Figure 32) (Augustine et al., 2006). It clearly illustrates that drilling costs have risen dramatically since 2000 and the effect is most prominent for the shallowest wells (0-1249 feet and 1250-2499 feet). GDHS wells usually fall into these two shallowest drilling depths categories. Thus rising drilling costs are of special concern for GDHS development in the U.S.

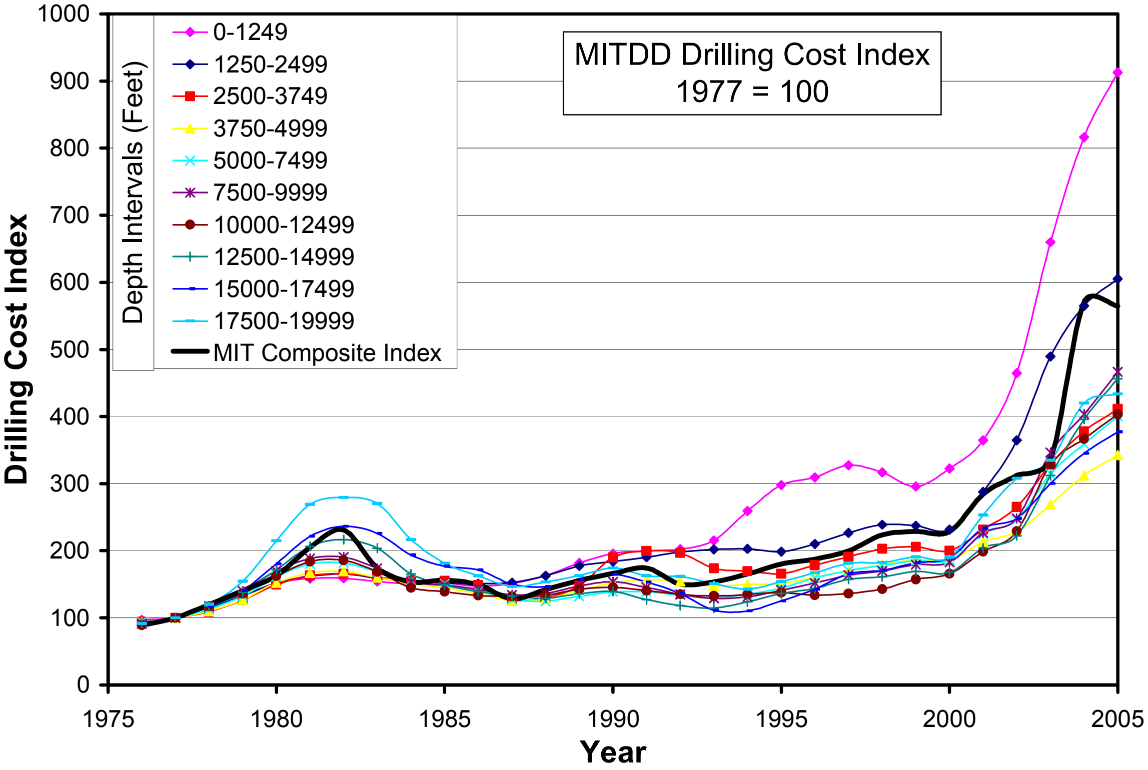

Figure 32 - MIT Drilling Costs Index – Three year moving average. 1975-2005 (updated from (Augustine et al., 2006)).

Increased drilling rig demand is a key reason behind the recent rise in drilling costs. As oil and gas prices rose in the U.S., demand for drilling rigs, to explore and drill for oil and gas reserves, increased. Meanwhile, growing interest in geothermal development projects also resulted in increased demand for rigs. This combined with rising cement, steel and fuel prices has caused rapid escalation in U.S. drilling costs. Although it is likely that the high drilling rig rates will spark new entry of drillers into the market, it will be a while before drilling costs re-equilibrate. Also, even with more drilling rig availability, drilling prices will still suffer somewhat from higher steel, cement and fuel costs.

As drilling costs rise, the need to reinject fluid becomes a bigger issue for GDHS development. Whether GDHS needs to reinject the geothermal fluids they extract depends on the chemical composition of the fluid, aquifer level and conditions and an environmental assessment of the area. As drilling an injection well will increase the drilling cost of a project substantially and will require a collection system for the returning geothermal fluid, leading to higher distribution system costs, the independent variable of an injection well was regressed against the GDHS data to assess its correlation with the odds of a successful system. However, no statistically significant relationship was found between the need for an injection well and the success of a system.

6.7 Engineered Geothermal Systems

Engineered Geothermal Systems (EGS) could expand GDHS to a much larger customer base. If EGS becomes economically feasible, it will not only have an impact on electricity production but can also significantly increase the potential for geothermal district heating systems. EGS allows access to a much greater resource base and would make GDHS feasible throughout the United States instead of being limited to areas where hydrothermal resources are in place. As discussed in Section 1.2.1 the U.S. potential for EGS is on the order of millions of EJ or enough to supply all of the U.S. energy needs for thousands of years. However, this will not happen unless money is put into developing the technology and supporting the growth of an EGS industry.

Once EGS is economically feasible, the GDHS earlier capacity goal of 10,000 MW_t can be expanded to at least 100,000 MW_t. Costs per kW and levelized energy costs for an EGS GDHS were estimated using methods described in Sections 2.2.1.5 and 2.3.1. Using current production flow rates demonstrated by EGS projects in Europe and Australia, the estimated levelized cost for a U.S. EGS system would be \$37 per mmBtu and cost per kW installed would be about \$1,300. However, if the flow rate is increased to 80 kg/s as EGS developers expect it will in the next few years, the levelized cost for GDHS decreases to \$10 per mmBtu along with the capital costs per kW, which decrease to about \$400 per kW due to increased energy production.

With current production flow rates, increasing U.S. GDHS capacity from 100 MW_t to 100,000 MW_t would require a capital investment of about \$130 billion but by increasing the production flow rate to 80 kg/s the total investment costs decrease to about \$40 billion. Increasing U.S. GDHS capacity from 100 MW_t to 100,000 MW_t was estimated using the cost per kW numbers reported above.

6.8 Carbon Dioxide Emissions Reduction

By installing 10,000 MW_t of GDHS capacity, about 4,300,000[17] metric tons of CO_2 emissions will be avoided or about 1% of the total U.S. emissions from space and hot water heating. Considering that 10,000 MW_t will provide about two million people, with heat and hot water that is equivalent to displacing all the CO_2 emissions from space and hot water heating for 1% of the U.S. population. Although this emission decrease is not a large fraction of current U.S. greenhouse gas emissions it will contribute to the solution. Also, no single solution will solve the greenhouse gas emission reduction problem and consequently, all cost effective measures to reduce CO_2 emissions should be followed through and supported.

Furthermore, GDHS emissions decreases are scalable to a much larger fraction if EGS technology becomes economically viable. With EGS, GDHS capacity could be increased to 100,000 MW_t and CO_2 emissions from space and hot water heating could be reduced by about 9% which is a significant fraction of the total.

6.9 Other Variables Analyzed

Three other independent variables were regressed against the dataset to see if any relationship could be identified.

6.9.1 Required Back-up Systems

Eleven GDHS in the U.S. require their customers to maintain individual back up systems. This presents an added cost to the customers and can decrease the perceived reliability of the system. However, the model did not show any statistically significant relationship between requiring individual back up systems and the success of a system.

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[17] Emissions decreases were estimated using the conservative assumption that all substitute heating would come from natural gas (methane) which has an enthalpy of combustion of 802.6 kJ/mol. GDHS capacity factor was assumed to be 0.25.

6.9.2 Retrofits

For many of the systems buildings had to be retrofitted in order to be able to utilize the geothermal energy. Even though this increases the cost to the consumer and is often a barrier to new customer hook up it was not found to be statistically significantly correlated with the odds of success of a GDHS.

6.9.3 Seasonal Systems

This study examined whether shutting down the GDHS during the summer was somehow related to the success or failure of a given system. This was not found to be the case. Most likely this is because the systems were designed with this mode of operation in mind. Furthermore, operation costs in the summer decrease along with the revenue and summer downtime provides opportunities for maintenance.

7 Conclusions and Recommendations

The data collected and analyzed in this study have identified several key enablers and barriers to geothermal district heating system (GDHS) development in the United States.

7.1 Technical Feasibility

To determine the technical feasibility of significantly increasing the GDHS capacity in the United States, it first has to be established that a sufficient amount of the natural resource is available to supply the increase in energy production. The geothermal survey performed by the USGS in the late 70s along with further work by the Geo Heat Center have shown conclusively that the U.S. geothermal resource is capable of substantial increases in geothermal direct use.

Second, it is important to analyze whether the technology for geothermal district heating systems is available and ready for large scale deployment. This has also been established for GDHS. The systems have over 100 years of operation history in the U.S. and have been developed successfully worldwide. Furthermore, many design lessons have been learned from the construction and operation of the current U.S. GDHS which will help current developers increase performance, lower costs, and avoid similar mistakes. Making use of the lessons learned and avoiding design problems is key to developing a successful GDHS.

Third, Engineered Geothermal Systems furthermore provide promise for even more capacity increases in the future. However, in order for a GDHS industry to be in place to take advantage of technical advances in EGS technology later on, the industry has to be supported now and growth in the sector encouraged.

7.2 Social/Political Feasibility

The social or political feasibility of large scale deployment of GDHS in the U.S. depends on a range of issues. An important barrier is the lack of knowledge about the resource and how to develop it. As cited in prior work and further emphasized by the survey performed as part of this study, local leaders are not aware of nearby geothermal resources and do not have access to resources that could help them assess the feasibility of and develop a GDHS. In order to build up GDHS capacity in the U.S. there needs to be an ongoing educational effort on geothermal energy and its attributes. Moreover, a geothermal industry that can take on GDHS development projects needs to be established.

The knowledge barrier extends beyond local leaders. There has not been a rigorous geothermal resource assessment program in the U.S. for the past 30 years. Although the Energy Policy Act of 2005 mandated the United States Geological Survey (USGS) to update the resource estimation, low temperature geothermal resources will not be assessed. This is the opposite of Iceland where exploration in low temperature and even previously thought "cold" areas is being supported to look for environmental friendly ways to heat communities. As a result, U.S. GDHS developers must rely on the geothermal resource assessment done in the late 70s, data from oil and gas wells and their own exploration and surveying when assessing the feasibility of utilizing a geothermal resource. The latter of course, demands high investments by the developer before any revenues are realized and acts as a barrier to geothermal projects in unexplored areas.

The U.S. Department of Energy (DOE) Geothermal Program has been through difficult times in the past few years. Moreover, even before the recent budget cuts, the program did not have much money to work with and because GDHS technology is perceived to be mature it has not received much federal funding since the 1980s. Without a shift in federal policy, this trend is likely to continue in the future. In view of that, it is safe to assume that most if not all government funding for GDHS in the near future will come from the states. The logistic regression performed as part of this study found a negative relationship between the odds of success of a system and the state funding at the time of development. This relationship was not very statistically robust but yet emphasizes the need for well structured financial incentives that encourage growth while at the same time support strong, sustainable projects, as for instance loan guarantee programs aim to do.

Another barrier that GDHS developers are faced with is complicated legal and regulatory bureaucracy. If they are a municipality, they must first ascertain that their state constitution allows them to engage in GDHS development. They must then acquire all necessary permits and weave through their state's utility regulations. Moreover, if the developers do not own the land that the geothermal resource lies on or depending on state do not own the mineral rights of the land, they must acquire the land or right by either buying or leasing them from a private party or leasing them from the state or federal government. The federal government leasing regulations have recently been changed to facilitate GDHS development but the new regulations have yet to be tried and tested. Finally, other users of the geothermal aquifer that they intend to tap into must be considered and the effect on the aquifer from the GDHS development must be assessed to avoid litigation from other well owners in the area later on.

Incentives to new users seem to be, from interviews with GDHS operators, an important enabler for geothermal systems. Geothermal is not well recognized by the general public as an energy source and therefore providing incentives to hook up is important to build a customer base. Incentives can also be used to help with capital costs of retrofits which can be a barrier to GDHS expansion when customer retrofit costs outweigh the cost benefits of hooking up to the system. Another customer cost barrier is that many system require their customers to maintain back up heating systems apart from the geothermal system. However, even though incentives, retrofits and required back up all seem to play a part in GDHS viability no statistical relationship was found between these variables and the success of a GDHS.

7.3 Economical Feasibility

Economic feasibility was identified as the main barrier to GDHS development by local leaders in communities recognized as being collocated with low temperature geothermal resources. However, recent cost experience in the U.S. shows that GDHS can be developed economically and provide savings to their users. Furthermore, the cost of developing 10,000 MW_t capacity of GDHS in the U.S. will only require a total investment of about \$5 billion dollars.

Three GDHS have been constructed in the past five years, I'SOT, Bluffdale and Lakeview, and they are all running as planned and providing their owners and or users with considerable savings. The payback period for these systems was calculated as ranging from 3 to 33 years, capital costs from \$500 to \$2,700/kW and levelized energy costs of \$8 to \$36 per mmBtu which is very competitive with other heating costs in the area for all three cases. Notably, all the systems had attributes that lowered their distribution system costs. Lakeview and Bluffdale only serve one large customer and the I'SOT system was laid in a community where most streets were not paved thus reducing the cost of burying the pipes.

An important cost factor for GDHS, drilling costs, has been rising dramatically in the last few years and can be a barrier to GDHS development. Even though drilling prices are likely to re-equilibrate with new entry of drillers into the market in response to high prices, rising well costs are a concern for GDHS developers in the near future. Consequently, success rates of geothermal wells are increasingly important and the only way to increase the odds of a successful well is to increase geothermal resource exploration and develop robust exploration technologies.

7.4 Recommendations

The following specific recommendations are based on the analysis performed in this study:

1. Incorporate design lessons learned (both engineering, legal, and market) from prior GDHS development into current GDHS projects construction.

2. Support development of Engineered Geothermal Systems to increase the potential for GDHS.

3. Continue the geothermal energy awareness efforts of the GeoPowering the West program and to initiate an education program focused on direct use of low temperature resources. The effort should focus on areas where geothermal resources have been identified and inform community leaders about geothermal energy potential in their area. The educational program should include information about the resource, its location, benefits and where to access resources to assess the feasibility of and to develop a GDHS.

4. Support the development of a GDHS industry by supporting geothermal education programs at higher institutions and by promoting industry services available to GDHS developers.

5. Provide legal consulting services to GDHS developers as part of geothermal incentive programs.
6. Enhance U.S.G.S. geothermal assessment efforts to include low temperature geothermal resources with the aim of lowering geothermal developers’ exploration costs.
7. Support research in geothermal resource exploration techniques and equipment to decrease drilling and thus economic risk of GDHS projects.
8. Support research and development of new, cost reducing drilling technologies.
9. Assess the structure of state geothermal funding programs with the aim of developing funding mechanisms that support sustainable projects. Loan guarantee programs and cost shares programs, where the developer takes on part of the development risk, should be favored over direct grant programs.

References

American Petroleum Institute. (1976-2005). Joint Association Survey on Drilling Costs 1976-2005. Washington D.C.

Arkesteijn, K., & Oerlemans, L. (2005). The Early Adoption of Green Power by Dutch Households. An Empirical Exploration of Factors Influencing the Early Adoption of Green Electricity for Domestic Purposes. *Energy Policy*(33), 183-196.

Augustine, C. A., Tester, J. W., Anderson, B., Petty, S., & Livesay, B. J. (2006). *A Comparison of Geothermal with Oil and Gas Well Drilling Costs* Paper presented at the Geothermal Resources Council Annual Meeting.

Baria, R., & Petty, S. (2008, January 28-30). *Economic and Technical Case for Commercial Exploitation of EGS* Paper presented at the Thirty-Third Workshop on Geothermal Reservoir Engineering, Stanford University, California.

Bjornsson, S. (2006). *Geothermal Development and Research in Iceland*. Reykjavik, Iceland: National Energy Authority of Iceland.

Blackwell, D., & Richards, M. (2007). SMU Geothermal.

Bloomquist, R. G. (1986). A Review and Analysis of the Adequacy of the U.S. Legal, Institutional and Financial Framework for Geothermal Development *Geothermics, 15*(1), 87-132.

Bloomquist, R. G. (2003). *United States Geothermal Policy - Provisions of Access and Encouraging Project Development*. Reykjavik: The United Nations University.

Bloomquist, R. G. (2004a). Elko county School District Heating Systems, Elko, Nevada. *GHC Bulletin*(June).

Bloomquist, R. G. (2004b). National Geothermal Policy and Regulation.

Bloomquist, R. G. (2004c). State Regulation of Geothermal District Energy Systems.

Bloomquist, R. G. (2005a). Constitutional or Statutory Authority to Engage in Geothermal District Energy Development and Operation.

Bloomquist, R. G. (2005b, April 24-29). *The Evolution of U.S. Policy Designed to Encourage Geothermal Development Provision of Access and Encouraging Project Development.* Paper presented at the World Geothermal Congress, Antalya, Turkey.

Bloomquist, R. G., & Lund, J. W. (2000). *Resource Development Potential - Revenue Generation Potential: Only a Balanced Approach Can Lead to District Energy Development*. Paper presented at the World Geothermal Congress.

Blue Lagoon. (2008). Images - Blue Lagoon. Retrieved May 8, 2008, from http://www.bluelagoon.com/Images/

Bovitz Research Group. (2006). *Geothermal Heating System Concept Evaluation - Quantitative Report*. Encino: High Sierra Energy Foundation.

Boyd, T. L. (1996). *Collocated Resources*. Paper presented at the Geothermal Resources Council Annual Meeting.

Brookhaven National Laboratory. (1993). *Renewable Energy for America's Cities: Advanced Communties Energy Systems, Proposed Research Development and Demonstration Program*.

Brown, B. (2007). Klamath Falls Geothermal District Heating System at 25 Years. *GHC Bulletin*(June).

Geothermal Resource Leasing and Geothermal Resources Unit Agreements; Final Rule, 43 CFR Parts 3000, 3200, and 3280 C.F.R. (2007).

California Energy Commission. (2002). *Geothermal Energy Project Brief: City of Susanville Geothermal District Heating System*. Sacremento.

California Energy Commission. (2003a). Project Fact Sheet - City of Susanville Geothermal District Heating System. Retrieved April 28, 2008, from http://www.energy.ca.gov/pier/renewable/projects/fact_sheet.html

California Energy Commission. (2003b). Project Fact Sheet - San Bernardino Geothermal District Heating System. Retrieved April 28, 2008, from http://www.energy.ca.gov/pier/renewable/projects/fact_sheet.html

Childs, F. W., Kirol, L. D., Sanders, R. D., & McLatchy, M. J. (1983). Description and Operation of Haakon School Geothermal Heating System. *GRC Transactions, 7*.

Childs, F. W., & Sanders, R. D. (1983). *Direct Use Geothermal PON and PRDA Projects under DOE-ID Administration. Annual Report FY 1982*. Idaho Falls, Idaho: U.S. Department of Energy.

Congressional Research Service. (1983). *Handbook on Alternative Energy Technical Development and Policy*. Washington D.C.

Department of Sports and Leisure in Reykjavík - ÍTR. (2008). Ylströndin Í Nauthólsvík. Retrieved May 8, 2008, from http://www.rvk.is/desktopdefault.aspx/tabid-292

Dickson, M. H., & Fanelli, M. (Eds.). (2003). *Geothermal Energy: Utilization and Technology*. Paris, France: United Nations Educational, Scientific and Cultural Organization.

Energy Information Administration. (2007a). *Annual Energy Review 2006*. Retrieved March 23, 2008. from www.eia.doe.gov.

Energy Information Administration. (2007b). *Emissions of Greenhouse Gases in the United States 2006*. Retrieved March 23, 2008. from www.eia.doe.gov.

Energy Information Administration. (2008a). *U.S. Natural Gas Prices*. Retrieved March 20, 2008. from www.eia.doe.gov.

Energy Information Administration. (2008b). *Weekly Petroleum Status Report*. Retrieved March 19, 2008. from www.eia.doe.gov.

Energy Policy Act of 2005, 119 Stat. 594 (2005).

Fleischmann, D. J. (2006). *What Can We Do? Meeting the Challenges to Developing our Geothermal Resources.* Paper presented at the Geothermal Resources Council Annual Meeting.

Garcia, M. B. (1997). Town of Pagosa Springs Geothermal Heating System. *GHC Bulletin, 18*(3).

Geo Heat Center. (2008). Geothermal Information and Technology Transfer. Fall 2007 and Spring 2008, from http://geoheat.oit.edu/

Geothermal Energy and Other Renewables, U.S. Senate 94 (2006).

Geothermal Energy Association. (2007). Developing Plants in the U.S. Retrieved April 17, 2008, from http://www.geo-energy.org/information/developing.asp

Green, B. D., & Nix, R. G. (2006). *Geothermal - The Energy Under Our Feet* (No. NREL/TP-840-40665): National Renewable Energy Laboratory.

Gunnlaugsson, E., Frimannsson, H., & Sverrisson, G. A. (2000, May 28 - June 10). *District Heating in Reykjavik - 70 Years Experience.* Paper presented at the World Geothermal Congress, Kyushu - Tohoku, Japan.

Gunnlaugsson, E., Ragnarsson, Á., & Stefánsson, V. (2001, 4 - 5 October). *Geothermal Energy in Iceland.* Paper presented at the International Symposium, Izmir, Turkey.

Haggerty, S. (2007, September 28-29). *Geothermal Leasing of Federal Lands under the Energy Policy Act of 2005.* Paper presented at the Geothermal Resources Council Annual Meeting - Pre Meeting Workshop: Geothermal Land, Lease and Unit Legal Issues, Sparks, Nevada.

Hance, C. N. (2005). *Geothermal Industry Employment : Survey Results & Analysis*. Washington D.C. : Geothermal Energy Association.

Harrison, R., Mortimer, N. D., & Smarason, O. B. (1990). *Geothermal Heating: A Handbook for Engineering Economics*. Oxford, U.K.: Pergamon Press.

Hosmer, D. W., & Lemeshow, S. (2000). *Applied Logistic Regression* (2nd ed.). New York: John Wiley & Sons.

Idaho Office of Energy Resources. (2008). District Heating Systems in Idaho. Retrieved May 14, 2008, from http://www.energy.idaho.gov/alternative_fuels/Geothermal/detailed_district.htm

Intergovernmental Panel on Climate Change. (2007a). *Climate Change 2007: Synthesis Report*.

Intergovernmental Panel on Climate Change. (2007b). *Climate Change 2007: The Physical Science Basis - Summary for Policymakers*.

Internal Revenue Service. (2008). S Corporations. Retrieved May 14, 2008, from http://www.irs.gov/businesses/small/article/0,,id=98263,00.html

Johnson, K. (1998). City of Boise Geothermal Injection Well Project June 1998 Update. *GHC Bulletin, 19*(2).

Kagel, A. (2006). *Socioeconomics and Geothermal Energy.* Paper presented at the Geothermal Resources Council Annual Meeting.

Lienau, P. J. (1984). *Geothermal District Heating Institutional Factors: The Klamath Falls Experience*. Klamath Falls, OR: Geo-Heat Center.

Lienau, P. J. (1996). OIT Geothermal System Improvements. *Geo-Heat Center Quarterly Bulletin, 17*.

Lienau, P. J., & Rafferty, K. (1991). Geothermal District Heating System: City of Klamath Falls. *GHC Bulletin*(December).

Loftsdottir, A. S., & Thorarinsdottir, R. I. (2006). *Energy in Iceland*. Reykjavik, Iceland: Ministries of Industry and Commerce.

Lund, J. W. (2004). Examples of Individual Downhole Heat Exchangers in Klamath Falls. *GHC Bulletin, June*.

Lund, J. W., Bloomquist, R. G., Boyd, T. L., & Renner, J. (2005, April 24-29). *The United States of America Country Update.* Paper presented at the World Geothermal Congress 2005, Antalya, Turkey.

Lund, J. W., Nemec, J., & Vollmer, R. (1998). Midland, South Dakota Geothermal District Heating. *GRC Transactions, 22*.

Marcel, R. G. (2007, 30 May - 1 June). *Technology Status of Direct Geothermal Utilization.* Paper presented at the European Geothermal Congress, Unterhaching, Germany.

Menard, S. W. (2001). *Applied Logistic Regression Analysis*. Thousand Oaks, CA: Sage Publications.

Menz, F. C., & Vachon, S. (2006). The Effectiveness of Different Policy Regimes for Promoting Wind Power: Experiences from the States. *Energy Policy, 34*(14), 1786-1796.

Merrick, D. (2002). Adventures in the Life of a Small Geothermal District Heating Project or The Little Project that Could. *GHC Bulletin*(September).

Merrick, D. (2006). Adventures in the Life of a Small Geothermal District Heating Project (The Little Project That Did) Part III. *GRC Transactions, 30*.

Millennium Energy LLC. (2006). *Final Report - New Mexico State University Geothermal System Feasibility Study*. Golden, Colorado.

Montgomery, D. C., & Runger, G. C. (2003). *Applied Statistics and Probability for Engineers*. New York: John Wiley & Sons, Inc.

Muffler, L. J., & Guffanti, M. (Eds.). (1979). *Assessment of Geothermal Resources in the United States - 1978*: U.S. Geological Survey, Circular 790.

National Energy Authority of Iceland. (2007a). *Energy Statistics in Iceland*. Reykjavik, Iceland.

National Energy Authority of Iceland. (2007b). Orkutölur. Retrieved 04/23, 2007, from http://www.orkutolur.is/mm/frumorka/

National Geothermal Collaborative. (2004). *Proceedings - National Geothermal Collaborative Geothermal Leasing Panel*. Sacramento, California.

Neely, K., Galinato, G., & Johnson, K. (2006). City of Boise Geothermal District Heating System. *GRC Transactions, 30*.

Neely, K. W. (1996). Geothermal Heat Keeps Students Warm at the College of Southern Idaho. *GRC Transactions, 20*.

Nordic Adventure Travel. (2008). Nautholsvik, Reykjavik Thermal Beach. Retrieved May 8, 2008, from http://www.nat.is/travelguide/ahugav_st_nautholsvik.htm

Office of the Secretary of the Interior. (2006). Geothermal Rules Encourage Alternative Energy Development on Federal Lands [Electronic Version]. *News - U.S. Department of the Interior*. Retrieved November 9, 2007.

Patel, N. R. (2003). Lecture Notes, 15.062 Data Mining: Logistic Regression. Massachusetts Institute of Technology.

Rafferty, K. (1992, August). A Century of Service: The Boise Warm Springs Water District System. *Geo-Heat Center Quarterly Bulletin, 3*.

Rafferty, K. (1993). *Marketing the Klamath Falls Geothermal District Heating System*. Klamath Falls, OR: Geo-Heat Center for the D.O.E.

Rafferty, K. (2003a). Direct Use : A Reality Check. *GRC Bulletin*(July/August).

Rafferty, K. (2003b). The Economics of Connecting Small Buildings to Geothermal District Heating Systems. *GHC Bulletin*(March).

Richter, A. (2007). *United States - Geothermal Energy Market Report*: Glitnir.

Stone, S. (2006). Reykjavik - Northern Gem. Retrieved May 8, 2008, from http://members.virtualtourist.com/m/658ac/3c82b/

Sturludóttir, L. K. (Ed.). (2007). *Orkumál 2006 - Jarðhiti*. Reykjavik: National Energy Authority (Orkustofnun).

Tester, J. W. (1982). Energy Conversion and Economic Issues for Geothermal Energy. In L. M. Edwards, G. V. Chilingar, H. H. Rieke III & W. H. Fertl (Eds.). Houston, TX: Gulf Publishing.

Tester, J. W., Anderson, B. J., Batchelor, A. S., Blackwell, D. D., Dipippo, R., Drake, E. M., et al. (2006). *"The Future of Geothermal Energy"*. Cambridge: Massachusetts Institute of Technology.

Tester, J. W., Drake, E. M., Driscoll, M. J., Golay, M. W., & Peters, W. A. (2005). *Sustainable Energy, Choosing Among Options*. Cambridge, MA: The MIT Press.

Trexler, D. T. (2008). Nevada Geothermal Utility Company: Nevada's Largest Privately Owned Geothermal Space Heating District. *GHC Bulletin*.

U.S. Department of Energy. (2006). GeoPowering the West. Retrieved May 13, 2008, from http://www1.eere.energy.gov/geothermal/gpw/index.html

U.S. Department of Energy. (2007). *Federal Register: Energy Conservation Program for Consumer Products: Representative Average Unit Costs of Energy*. Retrieved. from.

U.S. Geological Survey. (2008). National Oil and Gas Assessment. Retrieved April 29, 2008, from http://energy.cr.usgs.gov/oilgas/noga/index.html

Watkins, K., Kurukulasuriya, S., Mwangi, M. A., Scott, T., Ugaz, C., Carvajal, L., et al. (2008). *Human Development Report 2007/2008: Fighting climate change: Human solidarity in a divided world*: United Nations Development Programme.

Welsch, R. (2007). Lecture Notes in 15.074/ESD.755J Statistical Reasoning and Data Modeling: Part 10 - Data Mining: Logistic Regression. Massachusetts Institute of Technology.

Williams, C. F., Reed, M. J., Jr., S. P. G., & DeAngelo, J. (2007). *The USGS National Geothermal Resource Assessment: An Update.* Paper presented at the Geothermal Resources Council Annual Meeting, Sparks, Nevada.

Witcher, J. C., Schoenmackers, R., Polka, R., & Cunniff, R. A. (2002). Geothermal Energy at New Mexico State University in Las Cruces. *GHC Bulletin*.

Appendix A – List of Questions

Questions used to collect data from current U.S. geothermal district heating system operators through semi-structured interviews.

1. How much was known about the resource before the project was started?
2. Was any kind of market survey done before embarking on the project?
3. Was there a lot of new construction in the area or were all the buildings retrofitted?
4. Has the project received any kinds of local, state or federal incentives?
5. Do you have any information on the drilling costs? I'm interested in any information you might have on the number of wells, depth and cost.
6. Did the project have a champion – someone who pushed the project forward and without him it wouldn't have come to fruition?
7. Do you have any information on the thermal load density of the service area?
8. What have the rates been for service from the system and do you know how that compares to other heating costs in the area?
9. When was system start up?
10. Has it grown since it was first developed?
11. Has it been profitable? Did it meet the expected returns? Do you know what the payback period was or any information like that?
12. Is it maintained regularly?
13. Does the company own any other district heating systems – have they somehow expanded their district heating operations since the start of this project?
14. Does the system require its customers to have a back up heating system?

15. What’s the temperature of the geothermal resource and at what temperature is the water disposed of?
16. How is the geothermal fluid disposed of after use?
17. Has the system been used for any sort of sustainability public relations purposes?
18. Has the system encountered any litigation problems?
19. Has the system encountered any substantial design problems?
20. Do new users receive any sort of incentives to hook up to the system? What portion of the hook up costs do they have to pay?

Appendix B – Survey

1. Please indicate the name of your community.

2. Is there a geothermal resource located near your town/city?

☐ Yes ☐ No

3. Do you have access to or know of resources to assess the feasibility of, advise on or design a geothermal district heating system in your town/city?

☐ Yes ☐ No

4. What effect do you think a geothermal district heating system would have on the following factors in your town/city?

	Very negative effect	Negative effect	Somewhat negative effect	No effect	Somewhat beneficial	Beneficial	Very beneficial
Economic status	☐	☐	☐	☐	☐	☐	☐
Environmental aspects	☐	☐	☐	☐	☐	☐	☐
Social/political aspects	☐	☐	☐	☐	☐	☐	☐

5. What do you see as the main barriers to geothermal district heating development in your community?

Economic feasibility	☐
Lack of resource	☐
Lack of expertise with in town/city government	☐
Lack of expertise within community	☐
Complexity of project	☐
Legal issues	☐
Resistance to change	☐
Other - please specify	☐