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# Barriers and enablers to geothermal district heating system development in the United States

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ABSTRACT

According to the US Energy Information Administration, space and hot water heating represented about 20% of total US energy demand in 2006. Given that most of this demand is met by burning natural gas, propane, and fuel oil, an enormous opportunity exists for directly utilizing indigenous geothermal energy as a cleaner, nearly emissions-free renewable alternative. Although the US is rich in geothermal energy resources, they have been frequently undervalued in America's portfolio of options as a means of offsetting fossil fuel emissions while providing a local, reliable energy source for communities. Currently, there are only 21 operating GDHS in the US with a capacity of about 100 MW thermal. Interviews with current US district heating operators were used to collect data on and analyze the development of these systems. This article presents the current structure of the US regulatory and market environment for GDHS along with a comparative study of district heating in Iceland where geothermal energy is extensively utilized. It goes on to review the barriers and enablers to utilizing geothermal district heating systems (GDHS) in the US for space and hot water heating and provides policy recommendations on how to advance this energy sector in the US.

## 1. Introduction

In early winter of 1890 in Boise, Idaho, Boise Water Works began drilling geothermal wells just outside of town. At a depth of 120 m (400 ft) they encountered hot water (77 °C/170 °F). 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, and within a few years the system was providing hot water to over 200 homes and 40 businesses in the area and still serves about 275 residences today (Rafferty, 1992). However, after a promising start and a century of development in the sector, there are currently only 21 geothermal district heating systems (GDHS) operating in the US with a total capacity of about 100 $MW_t$. This slow growth is in sharp contrast with the situation in Iceland where the first GDHS was built in the 1930s and now about 90% of the country's space and water heating needs are supplied by geothermal energy (Loftsdottir and Thorarinsdottir, 2006). Of course, there were obvious barriers to developing district heating or co-generation systems in the US during that same period, including the availability of low cost natural gas, oil, and coal for most of the 20th century, and the separate supply and distribution systems for electricity, gas, and oil that evolved in a geographically large country.

Today, to combat rising concerns about climate change, increasing fossil energy prices, fuel supply and security concerns, and environmental sustainability in general, nations worldwide are reviewing their energy infrastructure and use patterns to look for ways to conserve energy by being more efficient and to transform their energy supply systems towards increased use of local, more sustainable resources. Geothermal provides a nearly emissions-free, renewable source of heat whose production characteristics are ideal for local district heating applications.

## 2. Opportunity for expansion

About 20% of US energy use is expended for space and hot water heating,[1] mostly provided by natural gas, fuel oil or propane all of which produce varying amounts of GHG emissions and are

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[1] The residential sector represents 21% of the total US energy consumption and combined space and hot water heating attribute 64% of the total residential energy demand with the remainder in electricity use for appliances and air conditioning. The US commercial sector, which consumes about 18% of total US energy production, also uses a significant portion of its energy use for space heating or about 30% (including all district heating for commercial buildings and assuming that all EIA reported fuel oil and half the reported natural gas use in commercial buildings is utilized for space heating).

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being imported from foreign countries at an increasing rate as US supplies are depleted. The other portion of heating is provided by electrical resistance heating or by air-to-air heat pumps, powered electrically in large part by energy from coal and natural gas (Energy Information Administration, 2007). In addition to heating, hot water is used in a number of industrial applications like food processing and paper manufacturing. Thus it seems appropriate and timely to re-evaluate the geothermal option for supplying a portion of these needs given the environmental and energy security benefits.

Currently, no more than a tiny fraction of the estimated US geothermal energy resource potential is being utilized. In 2006 geothermal electricity generation in the US represented a mere 0.5% of the total US energy mix (Energy Information Administration, 2007). The United States Geological Survey (USGS) has estimated that the power generation potential from identified geothermal systems is about 9000 MW and a further 30,000 $MW_e$ from unidentified sources (Williams et al., 2008). Direct use resources have recently been estimated at 60,000 MW of thermal energy potential (Green and Nix, 2006). Besides conventional hydrothermal resources, four other geothermal resource categories provide even more potential for geothermal energy utilization. These include geopressured resources, which exist under high pressures and often have large amounts of methane and geothermally heated water that is co-produced with oil and gas. Combined, geopressured and co-produced geothermal have a resource base of over 100,000 $MW_e$ for providing electricity and at least 6–8 times that much for direct thermal use (Green and Nix, 2006). Furthermore, the resource base for Enhanced Geothermal Systems (EGS) that represent accessible hot rock deposits that lack sufficient natural permeability and/or natural fluids in place to support economic production rates of hot water or steam is enormous. With suitable stimulation EGS reservoirs can be engineered to emulate the production characteristics of today's commercial hydrothermal systems. The recent MIT-led study (Tester et al., 2006) suggests that EGS could provide more than 1,000,000 MW of thermal capacity (that is about 100,000 $MW_e$) over the next 50 years assuming that a successful national development and deployment program is conducted during the next 10–15 years. Moreover, the US EGS resource base is large enough with 14,000,000 EJ of accessible stored thermal energy to meet US thermal energy demand sustainably for thousands of years (see Chapter 2 in Tester et al., 2006). Finally, by utilizing shallow geothermal resources, more than 1,000,000 MWt of US heating and air conditioning demand could be met using efficient ground source heat pumps operating with coefficients of performance in excess of 4 (Green and Nix, 2006).

Although this work focused only on geothermal district heating systems, there are a number of opportunities for expanded geothermal utilization, including base load electricity generation, geothermal heat pumps, and adsorption and absorption cooling that should be evaluated as well. Table 1 summarizes the US installed geothermal capacity in 2005 compared to the potential detailed above.

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 connected to five or more buildings. Geothermal district heating systems mainly utilize direct use technology but are sometimes augmented using ground source heat pumps.

The technology used for GDHS is mature and widely used. For instance in Iceland, about 90% of space heating needs of its over 300,000 citizens is met by GDHS and about 100,000 residences in the Paris Basin are heated by a GDHS (Loftsdottir and Thorarinsdottir, 2006; Ungemach, 2007). Fig. 1 shows the schematic layout of a GDHS.

**Table 1**
US Geothermal capacity in 2005 and estimated developable resource in 2050 (data from Green and Nix, 2006; Tester et al., 2006; Williams et al., 2008).

| **Electrical generating capacity** | **2005** | **Potential** |
|---|---|---|
| Electricity from high grade hydrothermal ($MW_e$) | 2800 | 30,000 |
| Electricity for enhanced Geothermal systems ($MW_e$) | 0 | > 100,000 |
| Electricity from co-produced and geopressured (MWe) | 2 | > 100,000 |
| **Direct thermal capacity** | | |
| Direct use hydrothermal ($MW_t$) | 620 | 60,000 |
| Direct use from enhanced geothermal systems | 0 | > 1,000,000 |
| Geothermal heat pumps ($MW_t$) | 7385[a] | > 1,000,000 |

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

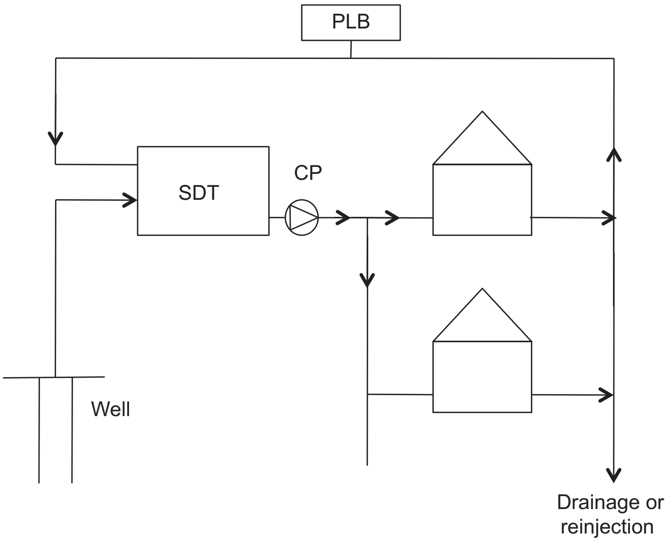

**Fig. 1.** Schematic layout of a geothermal district heating system that uses a geothermal resource directly. SDT=storage and degassing tank, CP=circulation pump, PLB=peak load boiler (Marcel, 2007).

GDHS can provide multiple environmental and economic benefits to communities that utilize them. For example, carbon dioxide emissions from the US space and hot water heating and cooking in the residential and commercial sectors in 2006 amounted about 470 million metric tons of annual $CO_2$ emissions. That is five million tons more than the total $CO_2$ emissions of South Korea in 2004 (Watkins et al., 2008). Thus within this sector lies a huge opportunity to decrease emissions. GDHS provide a clean, essentially emission free form of space heating that could help offset US $CO_2$ emissions, if deployed at a large scale. Fossil fuel supply limitations and price fluctuations also give GDHS a distinct advantage over their fossil-fired counterparts. GDHS use an indigenous energy source that is insulated from changes in fuel price or supply. This feature leads to long-term, stable space heating rates for GDHS which fossil fuel-fired facilities cannot guarantee.

## 3. Barriers to deployment

There are systemic barriers to implementing district heating in the US whether using direct or co-generation approaches of any type. These include relatively affordable gas and oil supplies and separate, well-developed electricity and fuel delivery infrastructures. There are also several barriers specific to geothermal applications and they were the focus of this study.

In 1996, a US DOE Low-Temperature Resource Assessment (Boyd, 1996) reported state by state regional estimates of low temperature geothermal resources collocated with potential users. The assessment identified 271 collocated communities. Later, Bloomquist and Lund (2000) emphasized the need for a balanced approach to encourage district heating development. They reported that of the 271 communities, contacted as part of the collocation study, only one community responded with interest in geothermal development. Their analysis cited several potential barriers to GDHS development that had been identified by previous studies. For example local authorities are frequently unaware of geothermal energy system benefits and GDHS are perceived to be complex, high risk undertakings. Also, local leaders lack the necessary knowledge to develop GDHS and consequently are often not interested in utilizing geothermal energy (Congressional Research Service, 1983; Gleason, 1993).

Despite these barriers to development, 21 GDHS have been constructed in the US. This study examined what sets these communities apart from others and analyzes the lessons learned. It extends 30+ years of excellent work of the Geo Heat Center at the Oregon Institute of Technology which is currently led by John Lund and Tonya Boyd (Geo Heat Center, 2008).

## 4. Approach

Current operating GDHS systems and their market conditions were analyzed to identify major barriers and enablers for increasing deployment in the US. The US Geological Survey (USGS) estimates that the ultimate potential for direct use applications in the United States is about 60,000 $MW_t$. As a base case estimate, we selected a 10,000 $MW_t$ target for future conventional GDHS capacity, representing a hundred fold increase from current capacity and equivalent to supplying the heating needs for about 2,000,000 people.[2]

To answer whether 10,000 $MW_t$ capacity of geothermal district heating systems in the US is a feasible deployment goal in the next few decades we focused on identifying possible technical, economic, political and social barriers and enablers. With no comprehensive database available to describe the current status of GDHS in the US, information was collected by telephone interviews and follow-up emails with GDHS operators. Interviews were conducted between December 2007 and April 2008 for all 21 operating systems and information gathered on one system no longer in operation. Data were analyzed and compared with development experience from Iceland to identify potential barriers and enablers of large-scale GDHS deployment in the US. To assess public understanding of potential benefits and barriers to development cited in the literature, 104 communities previously identified as being collocated with a low temperature geothermal resource were sent a short survey and the results analyzed. The results of the study were combined to produce a list of recommendations to encourage geothermal district heating system development in the US.

## 5. US geothermal district heating systems

Specific characteristics of the 22 US GDHS studied are tabulated in Table 2. Annual energy use for the US GDHS studied ranged from 0.2 to 22 GWh per year (see Fig. 2) with an average number of connections of about 30 and an average resource temperature of about 73 °C (163 °F). Most of the systems were developed during the early 1980s when US federal support for geothermal development was strong and natural gas prices were high. During the 1990s there was no further GDHS development in the US, but recently, as conventional space heating fuel prices have risen, interest has increased because GDHS provide a sustainable energy source immune to fuel price fluctuations (see Fig. 3).

Analysis shows that GDHS can be highly economically competitive with other heating systems. The three most recently developed GDHS, I'SOT in Canby, California (2003), Lakeview, Oregon (2005) and Bluffdale, Utah (2003), provide the best indication of current development costs for developing new US systems. Using standard economic methods, estimated capital costs per kW and operating costs were used to calculate levelized energy costs for all three systems as summarized in Table 3. As with most renewable energy projects, upfront capital costs are offset by lower operating costs as fuel does not have to be purchased. The variation in system costs can be attributed to different resource quality and the ratio of thermal load to connections. Table 4 compares representative GDHS levelized energy costs to residential fuel prices for 2007 in the US. The table clearly illustrates that GDHS can be highly competitive with other space heating fuel sources and geothermal resources can represent the lowest cost alternative in today's energy market. Using the median initial capital cost per kW ($500/$kW_t$) for GDHS calculated as part of this study and multiplying that by the net increase in capacity of about 9900 $MW_t$ the total investment needed to increase US GDHS capacity to the base case of 10,000 $MW_t$ was found to be under $5 billion dollars. Although this is a rough estimate, it shows the potential for large scale up of GDHS in the US.

The ratio of thermal load to connections can play a big role in the economic feasibility of a GDHS. Two of the country's most recent geothermal district heating systems, Bluffdale and Lakeview, were developed for large facilities, consisting of a few large buildings and thus had a good ratio of thermal load to connections. Prior literature has shown that larger buildings improve the economics of a GDHS because of savings in distribution network costs (Rafferty, 2003). Larger commercial customers provide more revenue for a single connection whereas service to many, smaller energy consumers requires additional capital expenditure in distribution lines and other connection equipment which lowers net revenue. Connection costs can also be a significant barrier to small customer buy in and expansion. Some states, like Oregon, offer incentives for users to connect through programs like the Small Energy Loan Program (Rafferty, 1993).

Another important cost factor is the cost of drilling wells to access the geothermal reservoir. An updated version of the MIT drilling index (Augustine et al., 2006) shows that drilling costs have been rising dramatically in recent years driven in large part by increasing oil prices. The index shows oil and gas well drilling cost trends in the US over a 30-year period and can be used to approximate geothermal well costs up to the year 2005 (see Fig. 4). The index clearly illustrates that drilling costs have risen dramatically since 2000 and the effect is most prominent for the shallowest wells (0–1249 and 1250–2499 ft), which are the two most common depth intervals for GDHS wells. In the past year, as oil and gas prices have dropped so have drilling costs. However, even with somewhat lower drilling prices, this remains a significant part of geothermal development costs.

Besides cost, design and operating problems can also affect the likely success of a GDHS. Six of the 22 systems analyzed experienced problems that can be classified into three categories: (1) problems based on initial engineering design decisions, (2)

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[2] The 2004 capacity of the Reykjavik, Iceland GDHS was about a 1000 $MW_t$ serving about 200,000 people. Consequently, increasing the US GDHS capacity to 10,000 $MW_t$ would translate into serving about 2,000,000 people.

**Table 2**
US geothermal district heating systems, 2007 (data from Geo Heat Center and interviews conducted with US GDHS operators).

| System | State | Start up year | Number of Connections | Capacity, MW$_t$ | Annual energy, GWh/yr | System temp. (°C) |
|---|---|---|---|---|---|---|
| Susanville District Heating | CA | 1982 | 7 | 5.60 | 3.4 | 76 |
| San Bernardino District Heating | CA | 1984 | 77 | 12.80 | 22 | 53 |
| I'SOT District Heating System (Canby) | CA | 2003 | 1 | 0.50 | 1.2 | 85 |
| Pagosa Springs District Heating | CO | 1982 | 22 | 5.10 | 4.8 | 63 |
| Boise City Geothermal District Heating | ID | 1983 | 58 | 31.20 | 19.4 | 77 |
| Fort Boise Veteran's Hospital (Boise) | ID | 1988 | 1 | 1.80 | 3.5 | 72 |
| Idaho Capital Mall (Boise) | ID | 1982 | 1 | 3.30 | 18.7 | 66 |
| Warm Springs Water District (Boise) | ID | 1892 | 275 | 3.60 | 8.8 | 79 |
| College of Southern Idaho (Twin Falls) | ID | 1980 | 1 | 6.34[c] | 14 | 38 |
| Kanaka Rapids Ranch (north of Buhl) | ID | 1989 | 42 | 1.10[c,d] | 2.4 | 37 |
| Gila Hot Springs | NM | 1987 | < 15[a] | 0.30 | 0.9 | 60 |
| New Mexico State University (Las Cruces) | NM | 1982 | 1 | 2.70 | 10.5 | 62 |
| Warren Estates (Reno) | NV | 1983 | 110[b] | 1.10 | 2.3 | 96 |
| Manzanita Estates (Reno) | NV | 1986 | See Warren | 3.60 | 21.2 | 96 |
| Elko County School District | NV | 1986 | 4 | 4.30 | 4.6 | 88 |
| Elko District Heat | NV | 1982 | 18 | 3.80 | 6.5 | 80 |
| City of Klamath Falls District Heating | OR | 1984 | 20 | 4.7 | 10.3 | 99 |
| Oregon Institute of Technology (Klamath Falls) | OR | 1964 | 1 | 6.20 | 13.7 | 89 |
| Lakeview | OR | 2005 | 1 | 2.44 | 3.8 | 97 |
| Midland District Heating | SD | 1969 | 12 | 0.09 | 0.2 | 67 |
| Philip District Heating | SD | 1980 | 7 | 2.50 | 5.2 | 66 |
| Bluffdale | UT | 2003 | 1 | 1.98 | 4.3 | 79 |

[a] There are 15 buildings on the system, the number of connections is probably a little smaller.
[b] The combined number of connections for the Warren and Manzanita Estates.
[c] Only includes geothermal capacity of the system and ignores capacity added by heat pumps.
[d] Assumes a $\Delta T$ of 5.6 °C (10°F).

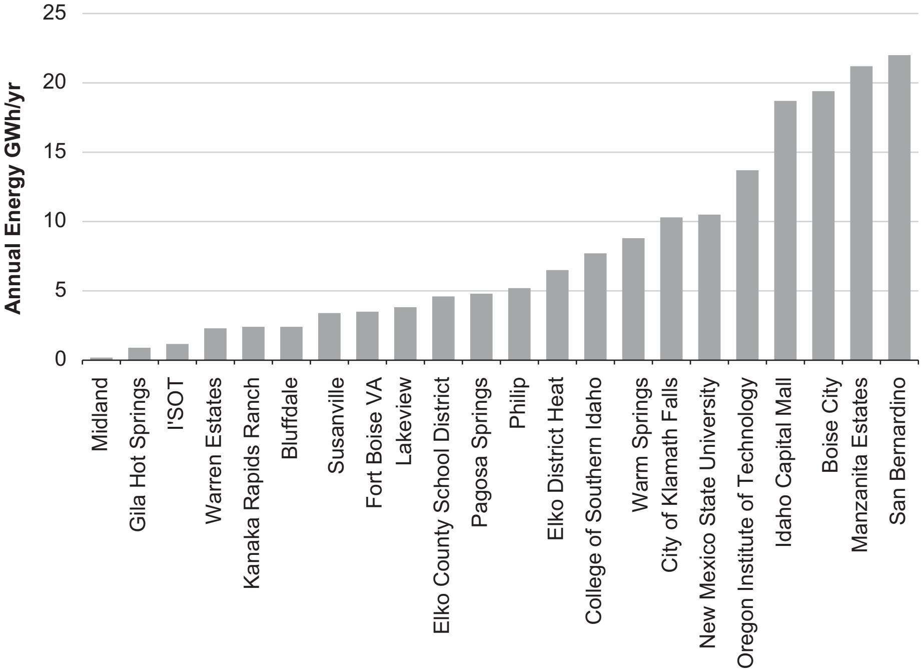

**Fig. 2.** Annual energy use for GDHS—(Data from Geo Heat Center, Oregon Institute of Technology (2007) and interviews conducted with GDHS operators (this study)).

legal difficulties due to reservoir water level concerns and (3) inadequate market assessments.

Both the Klamath Falls, Oregon 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 the system to be shut down during its first operating season (the system was subsequently rebuilt and has been in operation ever since). The NMSU system suffered from poor well design and construction and was shut down permanently in 2003 (Millennium Energy LLC, 2006).

Three of the systems researched experienced legal difficulties caused by aquifer water level concerns. When Boise City, Idaho 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 geothermal fluids 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). Similar problems arose in Pagosa Springs, Colorado and the City of Klamath Falls, Oregon.

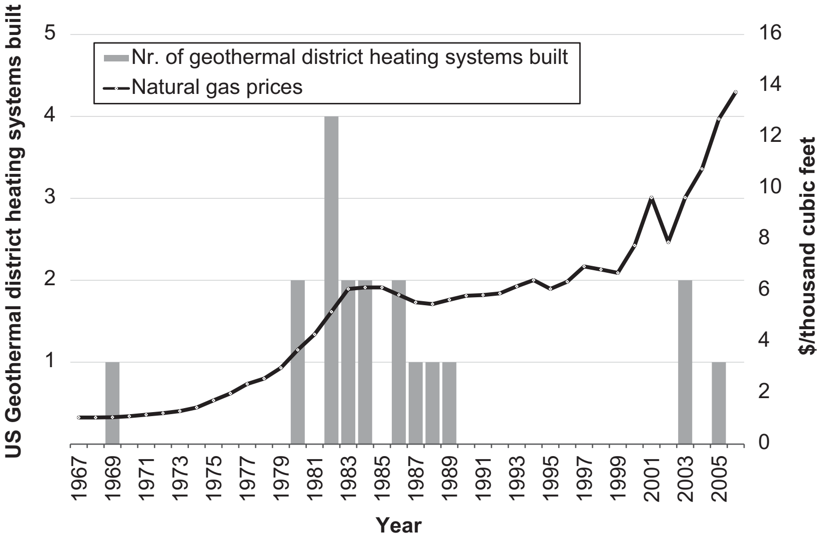

**Fig. 3.** Development of GDHS compared to the residential price of natural gas. Natural gas price data from (Energy Information Administration, 2008).

**Table 3**
Cost analysis for I'SOT, Bluffdale and Lakeview.

| System | State | Total capital costs 2008$ | $ per kW | $ per kWh | $ per mmBtu |
|---|---|---|---|---|---|
| I'SOT | California | $1,400,000 | $2,800 | $0.12 | $36 |
| Bluffdale | Utah | $1,000,000 | $500 | $0.03 | $8 |
| Lakeview | Oregon | $1,300,000 | $500 | $0.05 | $15 |

**Table 4**
Representative 2007 average unit costs of energy for residential energy sources (fossil fuel data from US Department of Energy, 2007).

| Fuel source | Price 2007 $/kWh | Price 2007 $/mmBtu |
|---|---|---|
| Electricity | 0.11 | 31.21 |
| Propane | 0.07 | 20.47 |
| Kerosene | 0.07 | 19.48 |
| No. 2 heating oil | 0.05 | 16.01 |
| Natural gas | 0.04 | 12.18 |
| Geothermal district heating | 0.03 to 0.12 | 8.00 to 36.00 |

In Susanville, California an inadequate market assessment at the start of the project caused problems. The system was connected to a low-income residential neighborhood as well as to part of the commercial district. In order to serve both these areas the city operated two wells. However, the revenue from the residential part of the system, where the houses were small and family incomes tight, was not sufficient to cover the added expense of operating a second well. Consequently, the City of Susanville has recently switched the residential customers to natural gas heating and now only operates a single well to serve its commercial customers.

These cases show the importance of investigating possible geothermal aquifer and water level effects of a geothermal system before developing a GDHS to avoid litigation problems later on. Engineering design and materials selection lessons learned in prior systems help to mitigate risks in subsequent developments. Of equal importance to developers is performing an adequate market survey to ensure sufficient revenue streams to cover capital and operational costs.

Directed policies and incentives are other important aspects of GDHS development. A majority of the systems studied received either federal (12) or state (5) funding at the time of development emphasizing the importance of government support for small renewable energy industries. Eight of the systems require their customers to maintain a separate back up heating system. This requirement presents an added cost to the customers, can decrease the perceived reliability of the system and thus be a barrier to expansion. Ten systems use a closed-loop configuration where the geothermal fluid is reinjected into the reservoir after utilization (see Fig. 5). Reinjection is usually preferred as it minimizes environmental impacts and helps to maintain and manage the reservoir. It does however increase the total cost of the project because it entails drilling reinjection wells. As drilling costs are a large component this can have a significant impact on the economic feasibility of a GDHS.

Some US operators provide incentives for new users to connect to the GDHS. Incentives are important because of the general lack of public understanding of geothermal energy. Fundamentally, people resist change, and changing over to an unknown, "uncalibrated" system or a not very well understood energy source requires even more incentives than switching to an alternative conventional heating systems based on oil, gas, or electricity. Consequently, educational programs to increase public awareness of geothermal energy are important for GDHS development and help to accelerate public acceptance of this energy source.

A common incentive used by GDHS operators, 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 is reassuring to new customers but 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 proposed by some groups would be to offer customers low, fixed rates for an extended period of time.

## 6. Need for education

To assess the extent of public geothermal energy awareness and the validity of barriers cited in literature about local leaders' lack of knowledge about GDHS, a survey was sent out to 104

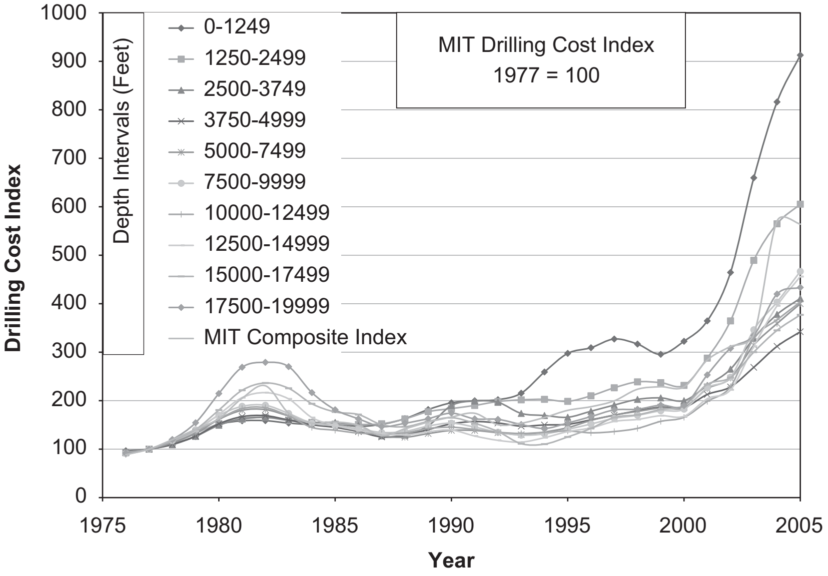

**Fig. 4.** MIT Drilling Costs Index—Three year moving average 1975–2005 (updated from (Augustine et al., 2006)).

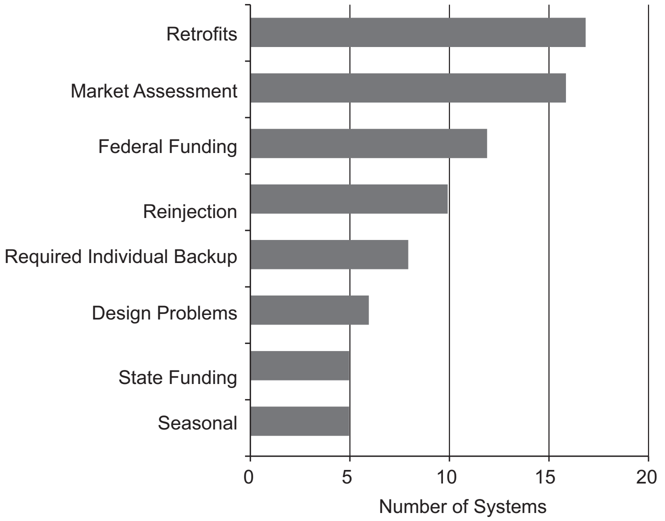

**Fig. 5.** The number of GDHS studied that received government funding, require individual backup, reinject their fluids, performed a market assessment, had to retrofit, are run seasonally and experienced design problems. Total number of systems studied is 22.

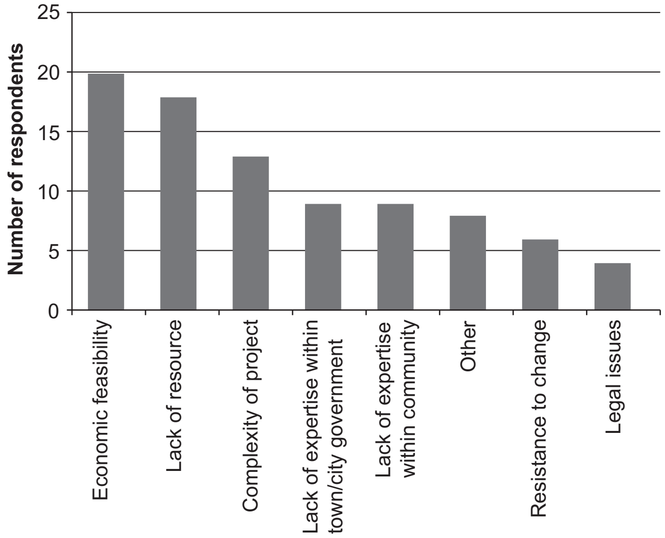

**Fig. 6.** What do you see as the main barriers to geothermal district heating development in your community?

communities[3] of the 271 communities identified in the low temperature geothermal resource collocation study done in 1996. Of the 104 communities that received the survey, 34 responded. Responses were received from small towns and big cities alike, in eleven out of the 14 states that survey was sent to.[4]

Ironically, half of the communities that responded were not aware that a geothermal resource was located close to their town/city even though all communities surveyed were identified as being collocated with a geothermal resource. Furthermore, almost 60% of respondents said that they are unsure of how to assess the feasibility of, get advice on, or design a geothermal district heating system. Nevertheless, despite the lack of awareness of nearby resources and access to geothermal expertise, the survey did 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, about 80% of community leaders responded that it would have beneficial effects on social/political, economic and environmental aspects.

Finally, respondents were asked to identify what they believed were the main barriers to geothermal district heating system development in their community (see Fig. 6). As with most renewable energy sources, the upfront capital costs of geothermal energy projects are high, so that loans or equity must be secured with measurable investment and debt equity rates. Although these costs are offset later in the project by having no fuel costs,

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[3] The 104 communities were selected from the 271 collocated communities because an email address of the mayor, a council member, 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. Communities that did not have accessible email addresses were not contacted.

[4] 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.

initial capital investments are cited as a significant barrier by community leaders. An investment has to be made in exploration, drilling, construction, permits and leases before any revenue starts to flow. 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.[5] These results suggest that GDHS are often perceived to be complex, high risk undertakings and confirms the barriers cited in prior literature.

Responding to these barriers, the federal government started the *GeoPowering the West* program in 2001 to improve geothermal awareness in the US and to broaden and better coordinate outreach, partnering, and education programs (US Department of Energy, 2006). Although this program is no longer being funded, it is crucial that efforts like it are supported continually for several years to accelerate the deployment of GDHS and other geothermal projects.

## 7. Resource risk

Apart from upfront capital costs there is also substantial risk involved in finding an economically viable resource underground for a greenfield geothermal development. Unlike wind and solar where the resource quality can be measured relatively easily, in geothermal development nothing is 100% certain about the resource until a well has been drilled and an economical flow of water or steam has been proven. Identified ‘‘Known Geothermal Resource Areas’’ (KGRA) as defined by the USGS provide some of the best opportunities for successful geothermal development within the United States. Nevertheless, even when working in a KGRA, the initial drilling risk is significant.

Furthermore, the KGRA classification is based on the last extensive US geothermal survey, reported by the USGS in 1979. For almost thirty years there has been no substantive geothermal evaluation program on a national scale. It was not until the US Energy Policy Act of 2005 (EPACT) that an update of the assessment was ordered and starting in fiscal year 2006 the USGS received modest funding for geothermal resource assessment (Energy Policy Act of 2005, 2005). The 2007 USGS assessment re-examined mostly older, ‘‘legacy’’ data, and did not re-evaluate the US low temperature geothermal resource, appropriate for direct use. It instead focused solely on moderate- (90–150 °C) to high-temperature ($>150\,^\circ$C) resources that can be most effectively utilized for electricity production in 13 western states (Williams et al., 2007). The USGS published its updated geothermal assessment in October, 2008.

The very modest US geothermal resource assessment effort is in stark contrast with the ongoing evaluation and survey efforts maintained for oil and gas in the US which has been continually updated over the past 30 years (US Geological Survey, 2008). Also, looking outside the US, Iceland has maintained strong geothermal geological survey activities since the 1970s. Because of these shortcomings, US geothermal developers have had to rely on either old, often inadequate geothermal data, on oil and gas exploration data, or have to fund exploration and drilling activities on their own. This is a significant barrier to US geothermal development. In fact a survey by the Geothermal Energy Association (GEA) in 2006 showed that geothermal developers are not taking on this exploration risk and that much of US geothermal growth is limited to areas already well explored. In fact, about half of geothermal projects under development in the US in 2006 were expansions of existing well fields or power facilities (Fleischmann, 2006).

## 8. Enhanced geothermal systems

Enhanced Geothermal Systems (EGS) could expand opportunities for GDHS to a much larger customer base. If EGS becomes economically feasible, it will not only have an impact on US electricity production but it may eventually have a larger impact on direct use opportunities. EGS technology opens up a much larger resource base for geothermal. If successfully developed, it would make GDHS feasible throughout the United States instead of being limited to areas where hydrothermal resources exist. As discussed earlier, in principle, the size of the US EGS resource is large enough to sustainably supply a significant fraction of the US energy needs for electricity and heat supply indefinitely if it is effectively captured and utilized.

With EGS technology in place, the earlier goal of 10,000 $\mathrm{MW_t}$ for GDHS could be expanded to at least 100,000 $\mathrm{MW_t}$. Costs per $\mathrm{kW_t}$ and levelized energy costs for an EGS GDHS were estimated by assuming that the same surface technology would be used for EGS GDHS as for a hydrothermal GDHS. Consequently, the only cost difference between EGS GDHS and a hydrothermal system was assumed to be increased drilling costs for EGS systems. Although this assumption neglects stimulation and fracturing costs for EGS systems, it was consistent with earlier economic projections for EGS (see Tester et al., 2006) and considered an acceptable approximation for this study at this stage of development of EGS technology.

EGS GDHS costs were estimated using drilling cost data from the JAS database for oil and gas wells (American Petroleum Institute, 1976–2005) with a correction factor to account for cost differences between geothermal and oil and gas wells. Cost numbers from a recently built GDHS in Lakeview were used as a representative case of GDHS surface equipment costs. It should be noted that the Lakeview system has a very favorable thermal load to connection ratio and thus the distribution system costs used in this calculation are relatively low compared to a system that serves a larger number of buildings. Energy production was estimated using the average $\Delta T$ for US GDHS (22 °C/40 °F), the average temperature of US GDHS (73 °C/163 °F) and a capacity factor of 0.25. An average thermal gradient of 30 °C/km was used to estimate depth of wells needed to reach practical GDHS fluid temperatures for GDHS.

Current Lakeview operation costs were used to represent operation costs for an EGS system at a currently achievable production flow rate of 20 kg/s (Tester et al., 2006). To assess the effect of technology advancement on EGS GDHS costs, costs per kW and levelized energy costs were also estimated assuming an 80 kg/s flow rate by approximating twice higher operation costs to account for higher pumping costs and increased energy production.

The calculations show the estimated levelized cost for a US EGS system with current achievable production flow levels as $0.14 per $\mathrm{kWh_t}$ ($41 per mmBtu) and cost per installed $\mathrm{kW_t}$ would be about $1,400. However, if the flow rate is increased to 80 kg/s, the levelized cost for GDHS decreases to $0.04 $\mathrm{kWh_t}$ ($11 per mmBtu) and capital costs per $\mathrm{kW_t}$ decrease to about $400 per $\mathrm{kW_t}$ due to increased energy production (see Table 5). At current field-demonstrated EGS reservoir production flow rates of 20–25 kg/s, increasing US GDHS capacity from 100 to 100,000 $\mathrm{MW_t}$ would require a capital investment of about $135 billion but by

**Table 5**
Estimated levelized costs for US EGS district heating systems.

| Flow rate (kg/s) | Cost per $\mathrm{kW_t}$ | Cost per $\mathrm{kWh_t}$ | Cost per mmBtu |
|---|---|---|---|
| 20 | $1400 | $0.14 | $41 |
| 80 | $400 | $0.04 | $11 |

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[5] 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 or are using the geothermal resource for applications other than GDHS.

increasing the production flow rate to 80 kg/s the total investment costs decrease to about $40 billion.

The promise of EGS is exciting but the technology also has its challenges including achieving sufficient connectivity between wells to allow for economic production flow rates and prevent too much thermal draw down within the reservoir. Also environmental concerns like water use for reservoir creation and induced seismicity effects need to be properly evaluated and managed for each project.

## 9. Iceland-geothermal district heating at large scale

Before we take a closer look at US geothermal energy policy, it is instructive to review Iceland's history of geothermal development. Iceland, a country with a population of about 300,000, is situated on the Atlantic Ridge in the North Atlantic Ocean and is blessed with large hydro and geothermal energy resources. Iceland began utilizing these resources in the early 20th century at the same time as the industrial revolution was starting to take hold in the country. In the 1940s programs emphasizing use of Iceland's renewable resources began to accelerate the decrease of total dependence on imported oil to supply Iceland's primary energy need. By 2005, 71.2% of Iceland's primary energy was supplied by its hydro and geothermal resources providing almost all of the country's heating needs and 99.9% of its electrical power (see Fig. 7) (Loftsdottir and Thorarinsdottir, 2006; National Energy Authority of Iceland, 2007a).

GDHS operation began in Iceland in 1930 and 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 Fig. 7) (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 renewable electricity (10%), and oil (1%).

In 2006, there were 22 regulated GDHS operating in Iceland and about 200 small unregulated systems. Icelandic geothermal district heating utilities usually have close to 100% market penetration in the community that they serve and are owned by one or more local municipalities. The biggest GDHS in Iceland is the Reykjavik system which had an installed capacity of 1070 $MW_t$ and served 193,816 users in 2004.

The Icelandic National Energy Authority, founded in the 1940s, endorsed geothermal energy development from early on by supporting the development of geothermal exploration techniques and utilization methods. The National Energy Authority's mission is to acquire general knowledge about geothermal resources and to make utilization of the nation's geothermal energy resource profitable for Iceland's economy. In 1967, the government established the Icelandic Energy Fund to increase use of geothermal resources. The fund gives out loans for geothermal exploration and drilling. If a resource is not found the loans are turned into grants with no repayment required. Moreover, government backed loans are available to geothermal developers in Iceland. However, as the geothermal energy industry in Iceland has evolved and grown stronger, the government's role in promoting and financing geothermal energy development has decreased with Iceland's utilities now taking the lead in geothermal exploration and development activities (Sturludóttir, 2007).

The Icelandic public is positive towards geothermal energy development. Geothermal is seen as a clean and reliable source of heat and electricity that has improved the population's quality of life. By switching from oil to geothermal energy for space heating, Iceland reduced its $CO_2$ emissions in 2003 by approximately 37% from what they would have otherwise been and from 1970 to 2000 saved the Icelandic economy $8.2 billion in fuel purchases, or three times the Icelandic national budget in 2000 (Bjornsson, 2006). In addition to providing heat and electricity, geothermal energy has also enabled the construction of more than 150 year round, outdoor, heated swimming pools and geothermal spas that are popular with both citizens and visitors. Snow melting using geothermal water has also been gaining ground in Iceland and in 2006 about 430,000 $ft^2$ (40,000 $m^2$) in downtown Reykjavik were installed with a geothermal snow melting system (Bjornsson, 2006).

## 10. US geothermal policy

In contrast to Iceland and other countries, US geothermal policy has not been consistent as evidenced by peaks and valleys in government funding levels. Since the 1970s, the US 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. Two of these programs are the

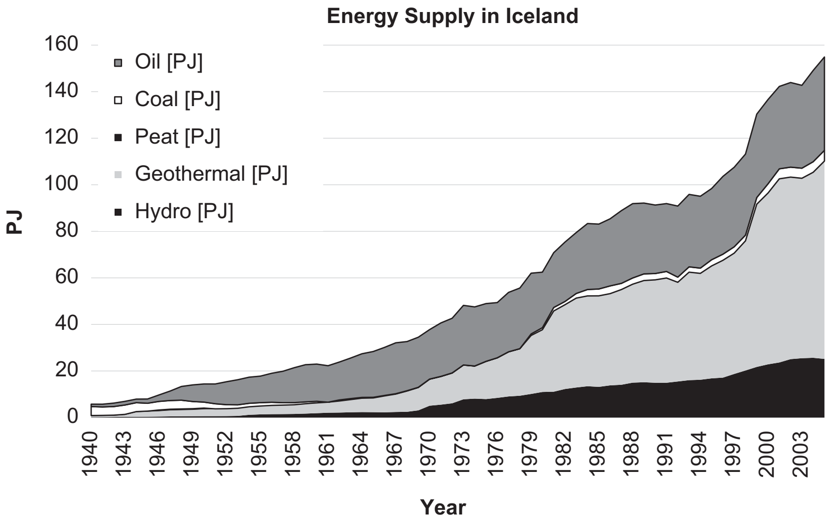

**Fig. 7.** Iceland's primary energy supply 1940–2005. Data from (National Energy Authority of Iceland, 2007b).

Geothermal Loan Guarantee Program (GLGP) which was implemented in 1974 and by many is considered the most successful of these programs, and the User Coupled Confirmation Drilling Program initiated in 1980 (Bloomquist, 2005b). Three other federal geothermal financial assistance programs have been important to GDHS development: (1) The US Department of Energy (DOE) Technical Assistance Grant Program, (2) the Program Research and Development Announcement program (PRDA) and (3) the Program Opportunities Notice (PON) (Bloomquist, 2005b). Several GDHS received funding from PON including Boise City, City of Klamath Falls, Pagosa Springs, Philip and the Elko Heat Company (Childs and Sanders, 1983).

Of the 22 systems we analyzed, 12 received federal funding at the time of development. Construction of many of these systems would not have been possible without federal aid. Yet, in recent years federal support has been very limited. In Fiscal years (FY) 2007 and 2008 the presidential budget proposal cut 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, this raised objections from the geothermal community and from private and public sectors involved in geothermal energy development. As a result of protests and continuing negotiations regarding federal appropriations, funding for FY07 was partly restored and in FY08 the program was reinstated.

Although the Energy Independence and Security Act of 2007 included a strong geothermal section calling for continued support for geothermal energy, it was mostly focused on EGS technology and electricity production and did not call for support of low temperature utilization of geothermal resources in district heating or co-generation applications. Consequently, without a major shift in US renewable energy policy, it is unlikely that federal funding assistance will be available for GDHS in the near future. However, state funding can and should play a role in GDHS development.

The limited data available on state funding programs show that California, New Mexico and Oregon have all supported geothermal district heating projects. In each case, funding was a crucial aspect in the development of the in-state system. State GDHS funding, unlike federal funding, has historically been more often in the form of grants instead of loans or loan guarantees and has thus carried lower risk for the geothermal developer. In the past grant programs have been criticized because they demand less accountability on behalf of the developer than for example loan guarantee programs and thus potentially lead to less sustainable systems.

Geothermal leasing procedures and regulations are also an important factor in GDHS development. A geothermal lease on federal or state land allows the lease holder to develop the geothermal resource in exchange for rent or royalty payments to the federal or state government. About half of the identified hydrothermal resources in the United States are on federal land (Office of the Secretary of the Interior, 2006). The US Energy Policy Act of 2005 (EPACT) contained provisions that aimed to simplify and streamline the leasing process of federal lands with geothermal potential. Measures in EPACT were intended to reduce the backlog of federal geothermal lease applications to remove a critical system bottleneck. New geothermal lease regulations developed by the Bureau of Land Management (BLM) to increase the efficiency of the federal leasing process were issued the summer of 2007, two years after the enactment of the EPACT (Bureau of Land Management, 2007).

For instance, the royalty structure of geothermal lease payments was changed with the aim of a more transparent process and to make division of the proceeds fairer compared to earlier royalty payments which were divided 50/50 between the state where the geothermal project was located and the federal government. Now 25% of the funds are allocated to the county where the project is situated, 50% to the state and 25% to the federal government (Energy Policy Act of 2005, 2005). Increasing the benefits that local communities get from geothermal development incentivizes more local support for new projects.

Changes were also made to geothermal leases to encourage more direct use applications on federal land. The prior leasing and royalty structure was not favorable for direct use projects. This resulted in very few direct use projects being developed on federal lands as evidenced by the fact that in 2006, less than 1% of 1300 plus direct use facilities in the US were on federal land (Fleischmann, 2006). Under the new regulations, the Secretary of the Interior can identify lands to be leased exclusively for direct use and those lands can be leased non-competitively, thereby reducing the cost to developers of acquiring land for direct use development. Also, direct use fee regulations were simplified in order to make the process more straightforward and now, state, local or tribal governments that intend to utilize geothermal energy without sale and for public purposes apart from electricity generation will only have to pay a nominal fee for use of a geothermal resource on federal land (Haggerty, 2007).

State leasing and geothermal regulations vary from state to state. Most US 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. Each state has its own characterization and definition of a geothermal resource (Bloomquist, 1986). On federal land ownership lies with the mineral rights, whereas state rights lie either with the owner of the mineral, groundwater or the surface rights of the estate.

Even with a geothermal lease or ownership of a resource in hand, 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. US regulations on municipality authority also 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 (Bloomquist, 2004, 2005a). In many states a geothermal district heating project will also be subject to regulations that apply to public utilities. For small GDHS developments, meeting these regulations imposes a large administrative burden, and can reduce revenue because of rate setting regulations (Bloomquist, 2004). This complexity and regulatory inefficiency can be a major barrier to development.

## 11. Conclusions

The data collected and analyzed in this study have identified several key enablers and barriers to district heating development in the United States. They can be divided into three categories; technical, social/political, and economic feasibility. Technically, large scale up of GDHS in the US is feasible. Economic feasibility is also often achievable although some barriers remain in that area. The main barriers to scale up however lie in social and political impediments.

### *11.1. Technical feasibility*

A sufficient amount of the natural geothermal resource is available in the US to supply the increase in energy production needed to expand GDHS to 10,000 $\mathrm{MW_t}$. The geothermal assessment performed by the USGS in the late 1970s along with further work by the Geo Heat Center have shown conclusively that the US geothermal resource is capable of substantial increases in direct use of geothermal for heating applications.

We identified the importance incorporating knowledge gained from existing systems into new developments. With over 100 years of GDHS operation history in the US and successful development at scale worldwide, many lessons have been learned regarding the design, construction and operation of GDHS which will help future US developers increase performance, lower costs and avoid similar mistakes.

In addition, Enhanced Geothermal Systems (EGS) provide promise for even more GDHS capacity increases in the future. However, in order for a GDHS industry to take advantage of forthcoming technical advances in EGS technology, the industry has to be supported and conventional hydrothermal resources developed to encourage growth in the sector and to build up the necessary infrastructure for advancing GDHS on a large national scale.

### *11.2. Economical feasibility*

Reaching economic feasibility remains the main barrier recognized by local leaders to GDHS development. However, recent cost experience in the US shows that GDHS can be developed economically and provide net savings to their users. Furthermore, the cost of developing 10,000 $MW_t$ capacity of GDHS in the US is estimated to only require a total investment of about $5 billion.

Three GDHS have been constructed in the US within the past 5 years, I'SOT, Bluffdale and Lakeview, and they are all running smoothly and provide their owners and/or users with considerable savings. The payback period at 2007 energy prices 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 million Btu 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 risen dramatically in recent years and can be a barrier to GDHS development. Even though drilling prices are now coming down in response to lower oil and gas prices, well costs remain 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 and cheaper drilling methods.

Another economic barrier is the cost of retrofitting existing systems to accommodate geothermal. In the US, there is a diverse array of heating and cooling systems in use. Most use separate supplies of electricity and fuel with combustion furnaces and air chilling units such as gas- or oil-fired hot water or steam heating and electric air conditioning using separate in-house distribution systems or forced hot air and electric air conditioning using the same in-house distribution system. This diversity results in substantial retrofitting challenges to convert heating systems to geothermal. This is not the case for instance in most of Europe where hydronic heating is the norm.

### *11.3. Social/political feasibility*

Thus, the feasibility of large-scale deployment of GDHS in the US depends on a number of social and political issues. An important barrier is 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 generally not aware of nearby geothermal resources and do not have access to organizations that could assess the feasibility of and develop a GDHS. In order to build up GDHS capacity in the US there needs to be an ongoing educational effort on geothermal energy and its attributes and the current lack of infrastructure for geothermal direct use needs to be addressed. Few consultants work in the field and those that work on district heating do not work in geothermal with only a few exceptions. Therefore, a geothermal industry that can take on GDHS development projects needs to be established.

Inadequate knowledge of geothermal opportunities extends beyond local leaders. There has not been a vigorous geothermal resource assessment program in the US for the past 30 years. Although the Energy Policy Act of 2005 mandated the USGS to update the US geothermal resource estimation, federal funding was limited and low temperature geothermal resources were not assessed. The US approach is stark contrast to the situation in Iceland where exploration of low temperature and even previously thought "cold" areas is being supported to look for environmental friendly ways to heat communities.

As a result, US GDHS developers with limited geothermal resource information, typically based on bottomhole temperature data from oil and gas wells or knowledge of known geological features in the area, must undertake their own exploration and surveying to assess the feasibility of utilizing a geothermal resource. This places a large financial burden on the developer before any revenues are realized and acts as a major barrier to considering geothermal projects in unexplored areas.

The US Department of Energy (DOE) Geothermal Program has been severely underfunded in the past few years. Without a shift in federal policy, this trend is likely to continue in the future. The need for well structured financial incentives is apparent given that very few GDHS have been developed in the US without federal, state, or local government support. If the US wants to move towards a more sustainable form of space and hot water heating, government programs that encourage growth while at the same time support strong, sustainable projects, using loan guarantees and similar policy instruments should be established.

Another barrier that GDHS developers are faced with is complicated legal and regulatory bureaucracy. If the developer is a municipality, they must first ascertain that their state constitution allows them to engage in GDHS development and then acquire all necessary permits and weave through their state's utility regulatory organizations. Utility regulations are burdensome for small systems and can be a difficult barrier to overcome. 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.

Policies that provide incentives to new users are an important enabler for geothermal systems. Geothermal is not well recognized by the general public as an energy source and therefore incentives that encourage customers to connect to a GDHS will most likely be needed to build a customer base. Customer retrofit costs frequently outweigh the benefits of hooking up to the system. Thus, incentives can also be used to help lower the capital cost budget of retrofits in existing structures. Another customer barrier is that many GDHS require their customers to maintain back up heating systems which adds to the investment for new buildings.

### *11.3.1. 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. Continue the geothermal energy awareness efforts by supporting educational and awareness programs on a national scale. Efforts for low temperature development 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.
3. Support the development of a GDHS industry by supporting geothermal education programs at higher institutions and by promoting industry services available to GDHS developers.
4. Provide legal consulting services to GDHS developers as part of geothermal incentive programs.
5. Streamline regulations to support the development of renewable heat resources.
6. Reactivate and enhance USGS 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 development of Enhanced Geothermal Systems to increase the potential for GDHS.
9. Support research and development of new, cost reducing drilling technologies to enable competitive deeper heat mining in lower grade regions.
10. Assess the structure of state geothermal funding programs with the aim of developing funding mechanisms to 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.

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