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Update on Geothermal Direct-Use Installations in the United States

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ABSTRACT

Direct-use of geothermal energy currently has limited penetration in the United States, with an estimated installed capacity of about 500 MW_{th}, supplying on the order of 0.01% of the total annual U.S. heat demand (about 30 EJ). We see higher penetration levels in other countries such as Iceland (about 90%) and Hungary (2.5%). An updated database of geothermal direct-use systems in the U.S. has been compiled and analyzed, building upon the Oregon Institute of Technology (OIT) Geo-Heat Center direct-use database. Types of direct-use applications examined include hot springs resorts and pools, aquaculture farms, greenhouses, and district heating systems, among others; power-generating facilities and ground-source heat pumps were excluded. Where possible, the current operation status, open and close dates, well data, and other technical data were obtained for each entry. The database contains 545 installations, of which 407 are open, 108 are closed, and 30 have an unknown status. Spas are the most common type of installation, accounting for 50% of installations by number. Aquaculture installations (46 out of 407 open installations) account for the largest percentage (26%) of installed capacity in operation (129 MW_{th} out of 501 MW_{th}). Historical deployment curves show the installed capacity significantly increased in the 1970s and 1980s mainly due to development of geothermal district heating, aquaculture, and greenhouse systems. Since the 2000s, geothermal direct-use development appears to have slowed, and the number of sites in operation decreased due to closures. Case studies reveal multiple barriers to geothermal direct-use implementation and operation, including 1) existence of an information gap among stakeholders, developers, and the general public, 2) competition from cheap natural gas, and 3) the family-owned, small-scale nature of businesses might result in discontinuation among generations.

1. INTRODUCTION

1.1 Direct-Use of Geothermal Energy

Geothermal direct-use (GDU) energy systems exploit low-temperature geothermal resources—here defined as having temperatures below 150°C—to utilize the Earth's thermal energy for a wide range of end-use heating applications. Commercial direct-use of geothermal energy in the U.S. dates back to the 19th century, with the construction of the world's first geothermal district heating system in Boise, Idaho, and the development of spas in places such as Hot Springs, Arkansas, and Pagosa Springs, Colorado (DOE, 2016). Over the last two centuries, hundreds of GDU applications (including resorts, greenhouses, district heating systems, and industrial processes, among others) have been developed nationally, but the largest push for direct-use came during the oil crisis of the 1970s. This event drove government funding for geothermal research and demonstration projects and significantly increased deployment rates for several years, after which research into and development of low-temperature geothermal appears to have leveled off.

The market for low-temperature heat is significant and much of this market could be supplied using low-temperature geothermal resources. Fox et al. (2011) estimates that about 25% of total U.S. primary energy consumption is used for supplying heat of less than 120ºC and appropriate low-temperature geothermal resources are widely available in the U.S. (Blackwell et al., 2013; Mullane et al., 2016). Utilizing these cooler geothermal resources for electricity generation is not economically viable due to low conversion efficiencies, suggesting the development of these resources for direct-use applications as an economic alternative (Beckers, 2016).

1.2 Direct-Use Installations Database

From 1975 until recently, the Oregon Institute of Technology (OIT) Geo-Heat Center (OIT, 2016) maintained a database of the GDU sites in the U.S. to track installations. Data were collected for some entries including application type, installed capacity, well flow rates, production temperatures, and contact information, although this information was missing for many of the entries. Due to funding constraints, database activity halted. Over the past year, analysts at the National Renewable Energy Laboratory (NREL) have worked to bring the database up to date, populating missing data, and adding new data, such as date closed (if applicable). Additional work included adding 77 new sites, removing duplicate sites, verifying status and names of existing sites, adding latitude and longitude coordinates, and, where possible, adding missing data such as technical and contact information. The results are presented in this paper. Ground-source heat pumps are not considered in this study.

No standardized reporting requirements are in place in the U.S., which hinders maintenance of this database and increases the chance of overlooking existing sites. In Europe for example, more strict reporting requirements exist. Under Renewable Energy Directive 2009/28/EC (EU, 2009), the European Union member countries are required to submit progress reports on installed renewable energy capacity, including GDU and heat pumps, every two years to the European Commission.

1.3 GeoVision Study

Updating the U.S. GDU database and understanding the current status and trends of GDU development in the country supports the ongoing low-temperature geothermal energy research at NREL as part of the U.S. Department of Energy (DOE) Geothermal Vision

(GeoVision) Study (DOE, 2016a). This study is a major undertaking by the DOE across several national laboratories, with the overall goal to assess potential growth scenarios for geothermal electricity and direct-use for 2020, 2030, and 2050. Other related efforts at NREL supporting the GeoVision study include a low-temperature geothermal resource assessment for the U.S. by Mullane et al. (2016); a low-temperature thermal-demand assessment for the residential, commercial, manufacturing, and agricultural sectors in the U.S. by McCabe et al. (2016); and an analysis by Beckers and Young (2017) on performance, cost, and financial parameters for market-penetration modeling of geothermal district heating GDH systems.

2. METHODOLOGY

Internet search engines (e.g., Google) and online business records were used to find recent information on existing and new facilities. In some cases, this material was either insufficient or unavailable, so the owner or business was contacted via phone, email, or social media for more information. Technical data are populated whenever possible, but was limited by time constraints, contact ability, and willingness to share information. For all installations, latitude and longitude coordinates were obtained, with the exception of 17 sites where neither business address nor photos were disclosed.

3. UPDATE OF U.S. GEOTHERMAL DIRECT-USE INSTALLATIONS

3.1 Current Status

Data and statistics on application type, installed capacity, resource temperature, and operation status of all installations in the updated database are shown in Figures 1 to 4. For counting purposes in these charts, individual installations/applications were used as the unit of measurement, not site locations. For example, if the same site location used geothermal resources for both space heating and a greenhouse, that would count as two applications toward the final total. If the site had gone through a change of ownership, where the application remained the same but different data had been collected in multiple entries, the most recent end use was counted; the historical use was not. In the current database, there are 545 individual installations and 444 unique site locations. Of the 545 installations, 407 were verified as open, 108 were found to be closed, and 30 remain unknown due to time and information constraints. Of the total 545 installations, 88 have been added by NREL. Of these 88 added installations, only 6 were recently built (since 2010), while the other 82 were missing in the original OIT database.

As of 2016, the total installed capacity is estimated at 501 MW_{th} for installations confirmed in operation, 163 MW_{th} for installations that have been closed, and 30 MW_{th} for installations with unknown status. In calculating these capacity numbers, average capacity values were assigned to those installations with unknown capacity (87 out of 545): 0.47 MW_{th} for spas/resorts, 2.7 MW_{th} for aquaculture, 0.82 MW_{th} for space heating, and 3.1 MW_{th} for greenhouses. The corresponding standard deviations when calculating these averages for spas/resorts, aquaculture, space heating, and greenhouses are 1.2 MW_{th}, 2.9 MW_{th}, 1.6 MW_{th}, and 6.2 MW_{th}, respectively. The estimated installed capacity of sites in operation (501 MW_{th}) is a significant drop in capacity compared to 615 MW_{th} reported by Lund and Boyd (2016).

Figure 1 shows the number of open, closed, and unknown installations by application type. This graph gives insight into what types of facilities have been closed and where the unknowns lie. Greenhouses saw the highest closure rate as a percentage of the total, whereas resorts/pools had the largest absolute number of closed sites. District heating systems have the smallest percentage of closure, most likely due to the large-scale, utility-type nature of the application, as well as the amount of planning and financial investment that precedes construction.

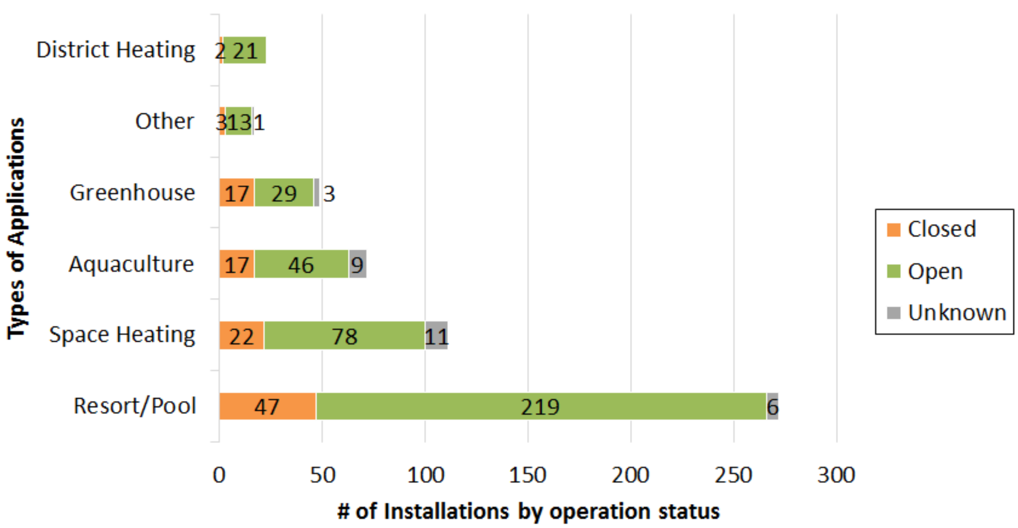

Figure 1. Number of open, closed, and unknown installations according to type of application. "Other" comprises irrigation, snow melting, dehydration, laundry, industrial, algae production, and alligator farming. District heating systems have the fewest closures whereas resorts/pools have the largest.

Figure 2 illustrates the number of open sites as they correspond with installed capacity. Again, average values by application type are assigned to open installations with missing capacity data. District heating systems, aquaculture facilities, and greenhouses are less common than resorts/pools or space heating facilities, but tend to be larger in capacity. Aquaculture, for example, comprises only 11% (46) of the total number of sites but accounts for 26% (129 MW_{th}) of the nation's installed capacity, whereas resorts/pools make up 54% (219) of the sites yet account for only 20% (97 MW_{th}) of the installed capacity.

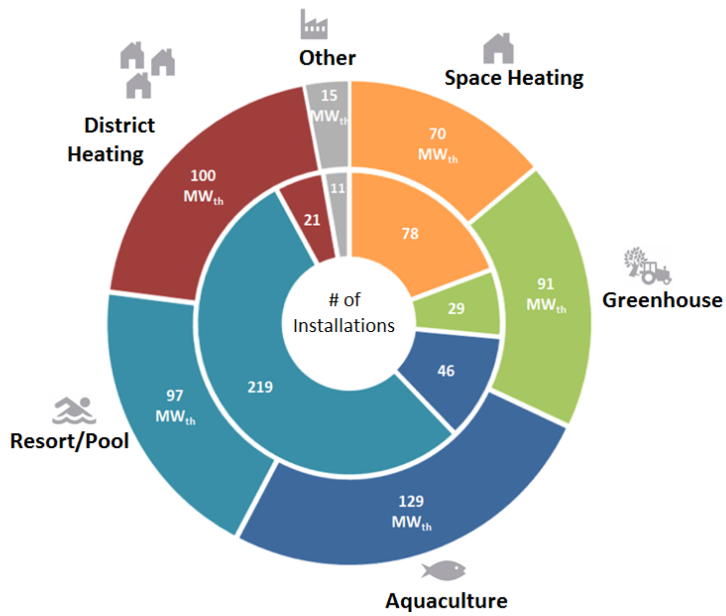

Figure 2. Comparison of the type and number of open installations with their respective installed capacity. Aquaculture systems tend to be larger, representing 11% of the installations but 26% of total installed capacity, and resorts/pools show the opposite, comprising 54% of the installations yet only 19% of the installed capacity.

Figure 3 groups the open sites by application type and the resource temperature utilized. Temperature data were available for 341 out of 407 open installations. About 45% of the open installations with known resource temperature fall into a temperature range of 25°C–50°C, dominated by resorts and spas. Most greenhouses and the vast majority of district heating systems utilize temperatures between 50°C and 90°C. Resource temperatures higher than these are uncommon for direct-use applications in the U.S.

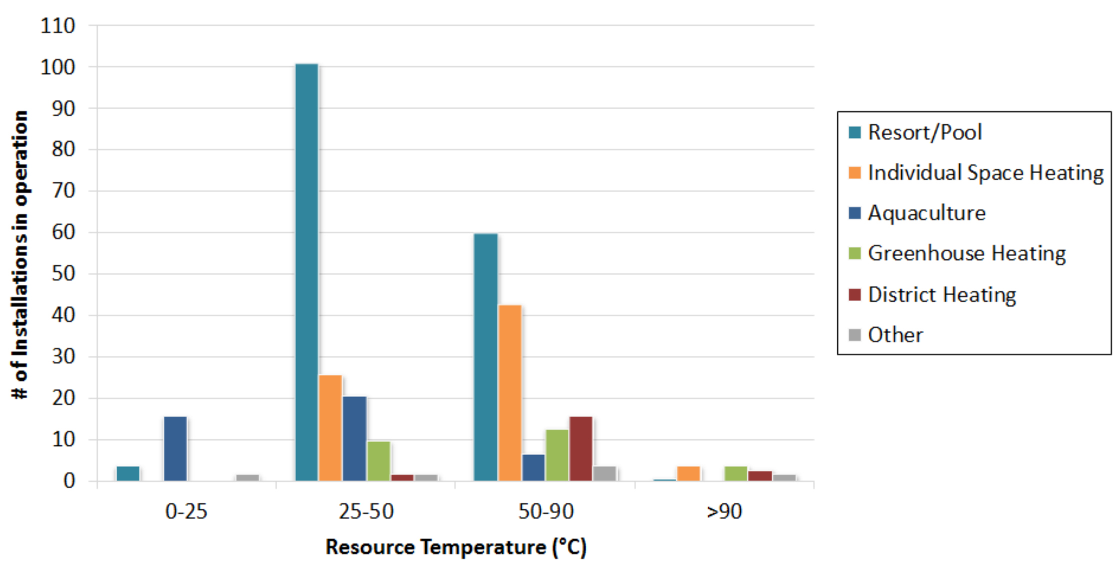

Figure 3. Distribution of open sites according to the resource temperature utilized. About **48% of the sites fall into the 25°C–50°C range, and temperatures above 90°C are uncommon for direct-use applications in the U.S.**

3.2 Historical Installation Curves

One addition to the database was populating open and closed dates of GDU installations; these have now been catalogued for nearly all sites. Historical installation curves (or penetration curves) show, by application type in Figures 4 and 5, the cumulative number of installations and installed capacity from 1850 until 2015. The year 1900 was selected as opening date when no opening year was found for natural pools, but documents show bathing has been occurring at the site for a long time (e.g., by Native Americans). As before, missing capacity for 87 installations is estimated using the average capacity for the respective application.

Figure 4 shows the number of sites in operation by application type. Resorts and pools were the earliest GDU application in operation and still constitute about 50% of applications in operation today. Despite their large number, they have limited contribution to cumulative installed capacity, especially over the last several decades, as shown in Figure 5. District heating, aquaculture, and greenhouses have been more popular since the 1970s. Figure 5 also shows that cumulative installed capacity accelerated in the 1970s and 1980s, then leveled off, and has eventually decreased since the 2000s due to installation closures.

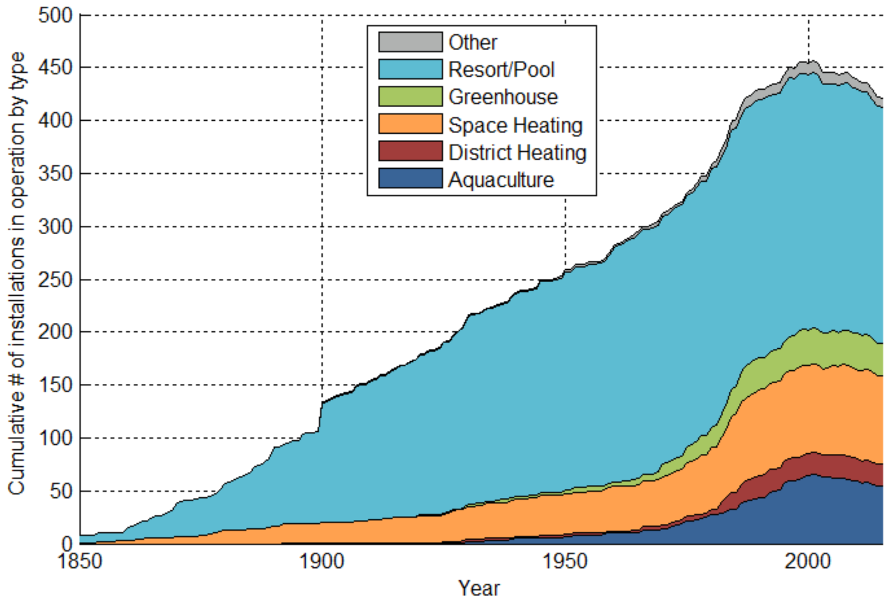

Figure 4. Cumulative number of installations in operation by type. Resort/pools have historically represented a large fraction of direct-use, and this trend continues today. The figure also shows that district heating, greenhouses, and aquaculture started growing in popularity in the 1970s.

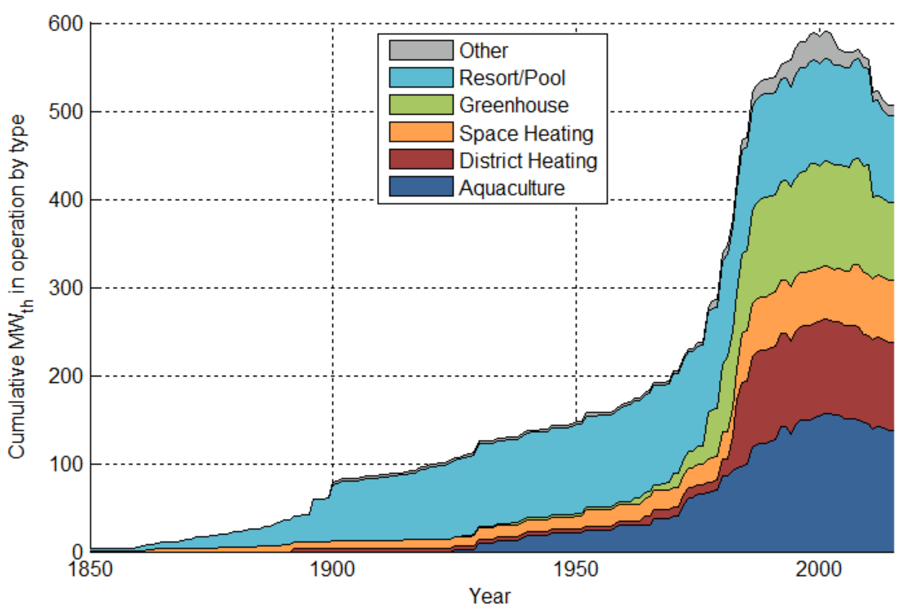

Figure 5. Cumulative installed capacity in operation [MW$_{th}$]. Direct-use system construction spiked in the 1970s and 1980s, after which it leveled off and decreased due to installation closures.

4. DISCUSSION OF RESULTS

4.1 Comparison to Europe

As discussed in Section 3.1, the U.S. GDU installed capacity confirmed as in operation is estimated at 501 MW_{th}, with district heating systems contributing 100 MW_{th} (~20%). Much larger deployment is seen in Europe with 9,600 MW_{th} of GDU installed capacity (Antics et al., 2016), of which 4,700 MW_{th} is represented by district heating systems (~50%) (EGEC, 2016). Figure 6 shows a comparison of the U.S. with the top nine European countries, which places the U.S. between Hungary and France in terms of installed capacity. The European countries with the highest amount of installed capacity, as estimated by Antics et al. (2016), are 1) Turkey (3,300 MW_{th}, of which 30% is district heating), 2) Iceland (2,100 MW_{th}, of which 90% is district heating), and 3) Italy (1,400 MW_{th}, of which 10% is district heating). The specific distribution among application type for these and other European countries varies widely. Nevertheless, the level of penetration of GDU in several European countries as a percentage of total thermal demand (up to 90% for Iceland) is orders-of-magnitude higher than in the U.S. (only ~0.01%). These higher penetration levels in Europe are likely a result of a combination of reasons including 1) higher cost of natural gas than in the U.S., 2) high-grade hydrothermal resources especially in Iceland, Turkey, and Italy, 3) aggressive government policies and targets for developing renewable resources, and 4), specifically for district heating, more compact cities and mostly hydronic-based heating systems resulting in relatively lower heat-distribution network and retrofit costs. In addition, stricter reporting requirements in Europe likely result in more complete GDU databases. In contrast, the U.S. numbers reported in this paper for number of sites (407) and installed capacity (501 MW_{th}) of GDU in operation may be underestimates.

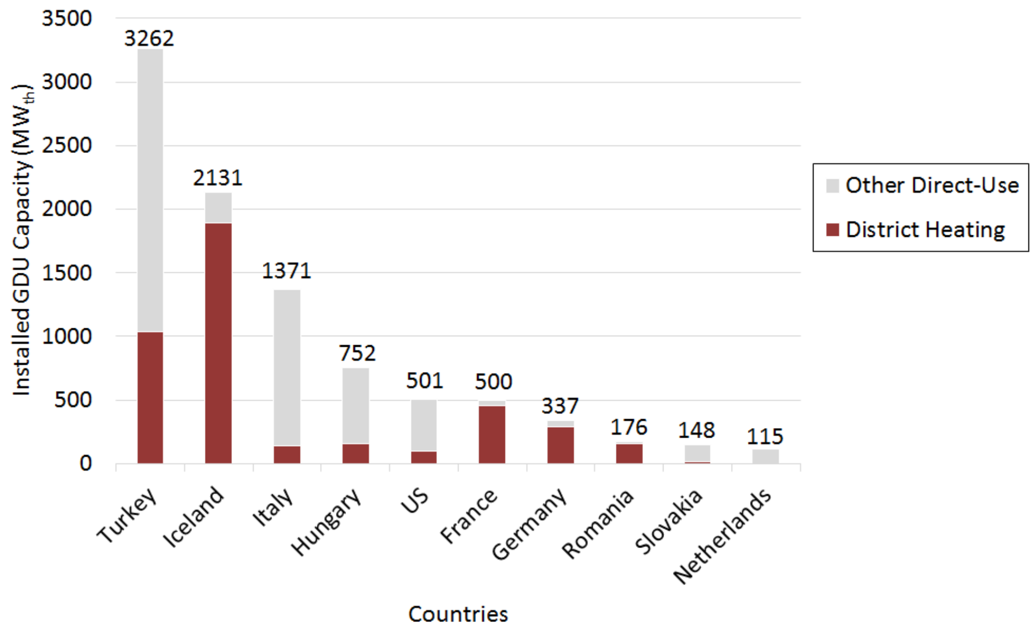

Figure 6. Installed GDU capacity in the U.S. and top nine European countries [MW_{th}]. The U.S. would take the fifth spot after Hungary. Data for Europe are taken from Antics et al. (2016).

4.2 Barriers in U.S.

A handful of reports on GDU barriers including Fleischmann (2007), Thorsteinsson (2008), and Thorsteinsson and Tester (2010) were reviewed. Additionally, we reviewed data from several industrial-scale direct-use sites in Nevada and New Mexico to investigate potential barriers in the U.S. for GDU implementation and operation. They are summarized below and grouped in three categories: policy/market barriers, social acceptance barriers, and technical barriers.

4.2.1 Policy/Market Barriers

A major barrier for any GDU application is competition from currently cheap alternative heating sources in the U.S., specifically natural gas (Beckers, 2016). In addition, several GDU facilities produce end-products that compete in a global market (e.g., roses grown in New Mexico greenhouses compete with cheap imports from Ecuador and Colombia (Romo, 2003)). Further, the typical GDU operation is family-owned and small-scale in size, resulting in potential discontinuation across generations (Fleischmann, 2007). Permitting issues and expensive federal well-metering equipment and royalties have been reported as cause for business closures (Witcher and Lund, 2002; Fleischmann, 2007). A lack of federal or state government incentives such as subsidies or tax credits in comparison with other countries or even with other renewable energy technologies has been stated as another reason for limiting GDU development (Fleischmann, 2007). This is augmented by an absence of geothermal professionals, consultants, and businesses as well as aging of the current geothermal workforce (Fleischmann, 2006).

4.2.2 Social-Acceptance Barriers

Wüstenhagen et al. (2007) state that many of the barriers for achieving successful renewable projects at the implementation level can be considered as a manifestation of lack of social acceptance. The Wüstenhagen et al. (2007) study defines social acceptance of renewable energy technologies as a combination of three categories: socio-political acceptance, market acceptance, and community acceptance.

Success in project development depends on the attitude of affected stakeholders including affected members of the public, policymakers, and market actors (Pellizzoni, 2010; Reith et al., 2013). Major social-acceptance barriers for GDU development are a lack of knowledge and perceptions of high cost and risk by local authorities and the general public (Thorsteinsson and Tester, 2010).

4.2.3 Technical Barriers

Major technical barriers for GDU development are limited co-location of high-grade geothermal resources (predominantly occurring in the western U.S.) and high heat demand (mainly in the eastern U.S.), and high upfront project costs due to costly geothermal well drilling. The latter barrier is augmented by relatively high exploration risks. This is different in the U.S. relative to other countries, where the government plays a major role in reducing exploration risk (Fleischmann, 2007). In addition, specifically for district heating systems, a large diversity in heating/cooling systems in the U.S. exists, which complicates and increases the costs of the retrofitting process (Thorsteinsson, 2010).

5. CONCLUSIONS AND FUTURE WORK

The database of GDU installations in the U.S. has been updated and analyzed. The current number of known installations is 545—with 407 open (mainly resorts/pools, space heating, and aquaculture), 107 closed, and 30 unknown. Some 88 new applications have been added to the 2015 OIT database. The total capacity in operation is estimated at 501 MW_{th} (predominantly aquaculture, district heating, and resorts/pools); 163 MW_{th} of sites have been closed and 30 MW_{th} remain unverified. Historical development curves show that resorts and pools are the earliest application (since the 18^{th} century), and they continue to be the dominant application over time in terms of number of installations. Cumulative installed capacity saw a major push in the 1970s and 1980s due to development of district heating, aquaculture, and greenhouse systems, but has declined since the 2000s due to closure of facilities. The historical OIT database did not track operation status, which is the main cause for discrepancy in reported installed capacity relative to published literature. Literature review revealed several major challenges for direct-use installations that could result in potential closure: 1) the family-owned, small-scale nature of direct-use businesses might lead to discontinuation across generations; 2) direct-use businesses often compete in a global market for end products; 3) federal wells require expensive royalties and metering equipment; 4) limited co-location of geothermal resource and thermal demand; and 5) social-acceptance issues and information gaps exist between developers, stakeholders, and the general public.

Recommended future work includes a more in-depth look at market drivers and differences between countries with high deployment (e.g., Europe) and the U.S. For example, comparisons with Europe may include a focus on the following:

- Energy-source decision drivers used by developers (e.g., where do developers get their list of options—from contractors? Are contractors then the target audience for education?),
- Shallow (<3 km) resources,
- Policies for heating,
- Size and compactness of populated areas, and
- Actual energy costs.

Using the results, we can identify potential ways to overcome these barriers in the U.S. for additional GDU deployment.

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