EMD Geothermal Committee
Annual Report

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Geothermal Commodity Report

Executive Summary

There are three categories of geothermal energy use, electrical power generation; direct use as heat; and geothermal heat pumps (also known as ground-source or geoexchange heat pumps). At present electrical power generation is primarily restricted to countries close to active tectonic plate boundaries where magmatic activity and/or very young faults give access to water to be heated to temperatures sufficient to generate power. Direct use geothermal heat is available in a much wider range of tectonic settings where hot water or brine at directly useable temperatures and volumes is available at the surface or at economic depths. Geothermal heat pumps can essentially operate at any location: they consume energy rather than produce energy, but are very energy efficient.

Twenty-four countries currently use geothermal resources to generate electricity with fourteen of these countries having generating capacities close to 100 MW or greater. The US has the largest generating capacity at about 3,570 MW, almost twice that of Philippines with about 1,870 MW, the country with the next largest generating capacity. In a few countries, such as Iceland, the Philippines, Indonesia, and Kenya, geothermal power resources are growing rapidly and have the potential to make major, if not majority contributions to the national electrical economies. In the US geothermal electrical generating capacity is growing very slowly because of competition from other renewable resources and low natural gas prices.

The most efficient use of geothermal energy is direct use because there are no losses in converting energy from one form to another. Europe currently leads the world in direct use for heating. Most of this heat is derived from low-temperature geothermal systems (<100°C). There are strong incentives in European nations to develop renewable resources: i) many European nations lack domestic and/or secure supplies of fossil fuels; ii) fossil fuel prices are high; and iii) the nations are committed to reducing carbon emissions. Five countries in Europe had installed direct use capacities of 500 MWt (megawatts thermal) or greater in 2017, Turkey, Iceland, Italy, Hungary and France, with Turkey having the greatest installed capacity of 3,262 MWt.

Geothermal (ground source or geoexchange) heat pumps may be used at most locations as they do not require above normal ground temperatures. They do not need high near-surface temperatures because the ground is used as thermal buffer in which heat is extracted and stored. Heat pump capacity in many European countries is growing steadily with dramatic growth in a few countries. Geothermal heat pumps typically reduce energy consumption relative to conventional heating and cooling systems by 65 to 80%.

Although geothermal electricity has the potential to make a major contribution to the energy budget of a few nations, geothermal direct use and geothermal heat pumps have the potential to make an impact on the energy budgets of most nations by reducing the need for the consumption of other energy resources for heating, cooling and producing hot water.

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Introduction

Geothermal energy use falls into three categories; electrical power generation; direct use as heat; and geothermal heat pumps (also known as ground-source or geoexchange heat pumps). These three uses operate in three different, but overlapping temperature ranges that decrease in the order that the uses are listed in the previous sentence. At present electrical power generation is primarily restricted to countries close to active tectonic plate boundaries where magmatic activity and/or very young faults give access to water to be heated to temperatures sufficient to generate power. Direct use geothermal heat is available in a much wider range of tectonic settings, either where natural hydrologic systems circulate meteoric water to depth, where it is heated by the geothermal gradient, and returned to the surface, often manifested as thermal springs, or in deep aquifers in sedimentary basins where it may rise under artesian pressure and/or be pumped to the surface. Artificial systems in which induced permeability at depth is accessed through two or more boreholes are being tested in a number of countries for both power production and direct use heat (EGS: Enhanced or Engineered Geothermal Systems), but at present these systems are not economic. For geothermal heat pumps the ground is used as thermal buffer in which heat from building cooling systems stored during the summer, and heat is recovered for building heating in winter months. Geothermal heat pumps can essentially operate at any location: they consume energy rather than produce energy, but are very energy efficient. The three uses of geothermal energy as commodities will be discussed separately below.

Geothermal Electricity Production

The US currently leads the world in geothermal electricity production with a current operating capacity of 3567 MWe (megawatts electrical), as shown in Figure 1. Indonesia, however, has 4,013 MWe of capacity under development which, if all were to come on line, would bring Indonesia into first place in geothermal generating capacity. Indonesia's large backlog of capacity under development appears to be associated with projects delayed by prolonged power-purchase agreements, delayed permits associated with use of conservation or protected areas, and/or resistance from local residents. Growth in the US is very slow at present because of competition from gas-turbine power plants with low gas prices since 2015. Gas-turbine plants are cheaper to build than geothermal power plants, with less up-front exploration risk, but because gas turbines continue to require fuel from an external source to operate, geothermal plants produce electricity at a lower cost per kWhr during the operating lifetimes of the power plants.

There is a wide range of temperatures and depths at which potential geothermal resources exist, as shown in Figure 2 (Allis and Moore, 2014). As with all resources, economics and local conditions determine the viability of a resource. For example, Figure 2 shows the low-temperature cut-off for moderate-temperature resources at about 120°C. However, at Chena Hot Springs, Alaska, 400

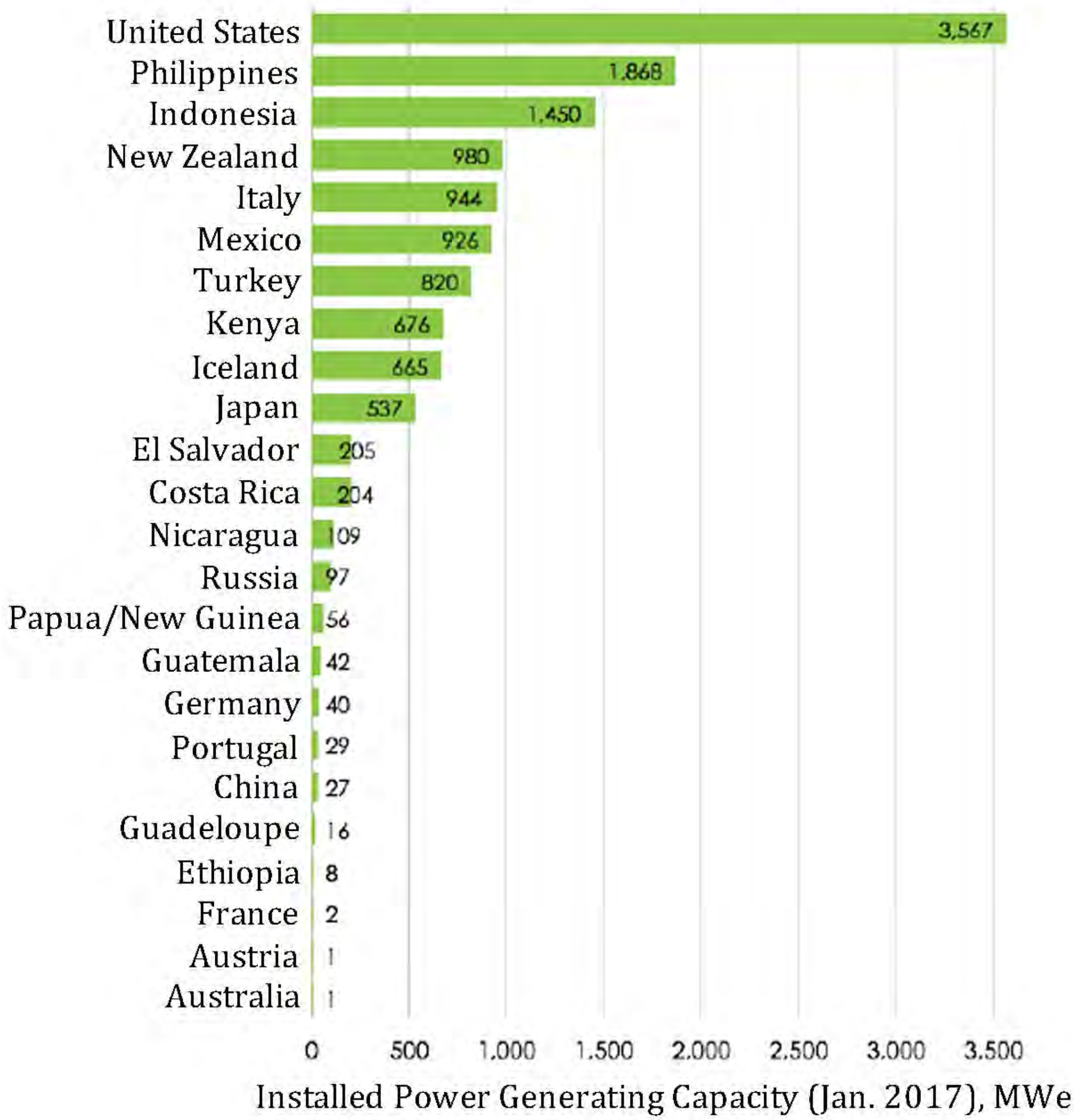

Figure 1. Countries with installed geothermal electricity generating capacity (January 2017). Modified from http://thinkgeoenergy.com/category/technology/.

kWe (kilowatt electrical) of electricity is generated from water at a temperature of about 75°C, with cooling water at about 4.5°C (Benoit et al., 2007). The alternative to this geothermal electricity generation is diesel-powered generators, with very high-priced diesel fuel in the very remote location of Chena Hot Springs.

The ideal geothermal reservoir for power production is one that produces dry steam, but these are very rare. Most reservoirs produce superheated (>100°C at 1 atmosphere pressure) water or brine. The geothermal fluid is flashed to steam at the surface with residual water being returned to the

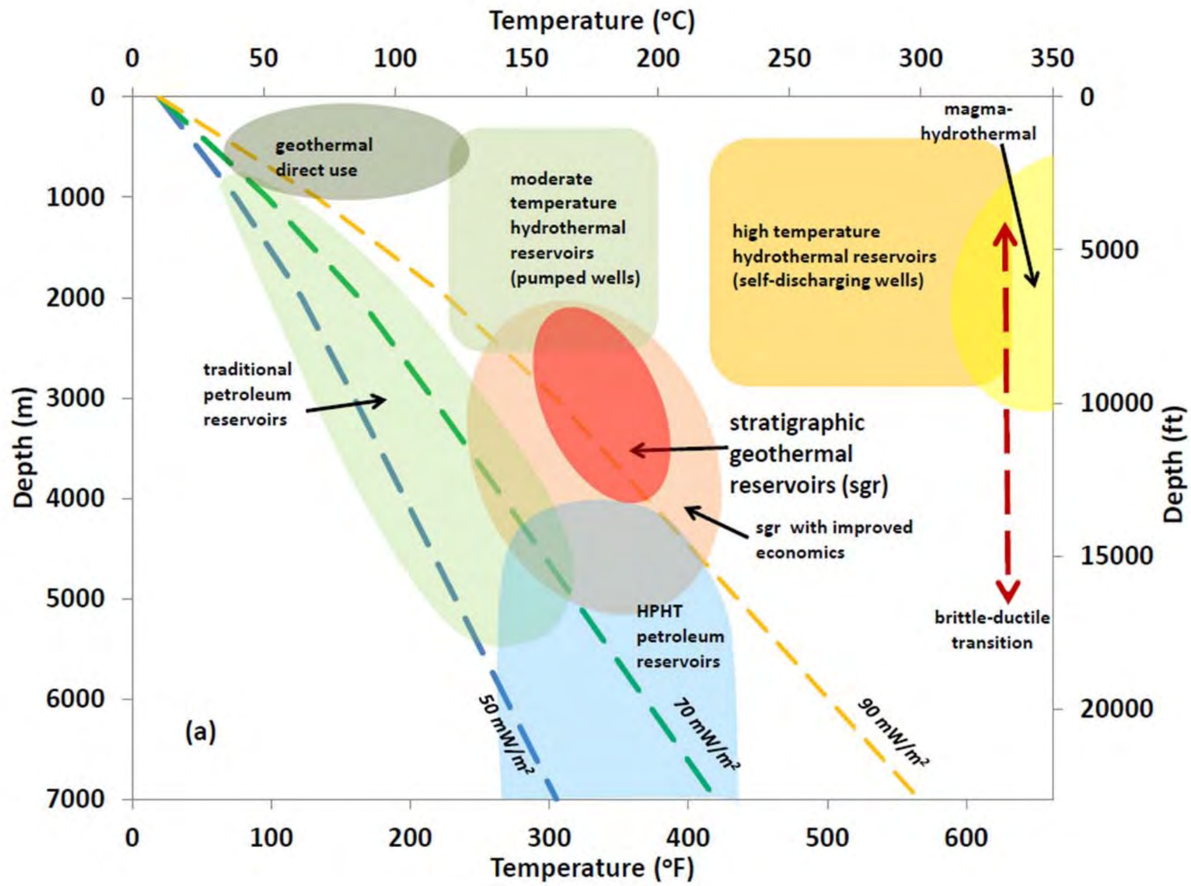

Figure 2. Plot of temperature as a function of depth showing temperature-depth fields for petroleum reservoirs and for different types of traditional geothermal reservoirs. Reproduced from Allis and Moore (2014), with permission.

reservoir. Steam is used to drive a turbine that turns a generator to produce electricity. Below about 220°C the thermal energy in the geothermal water flashed to steam starts to decline and binary power plants are used. In a binary power plant geothermal fluid passes through a heat exchanger and its heat is transferred to a fluid with a lower boiling temperature than water; vapor from this secondary fluid is used to drive the turbine. The secondary fluid is then cooled, condensed and returned to the heat exchanger to be reheated and repeat the cycle. After passing through the heat exchanger the geothermal fluid is returned to the reservoir. At present (2018), typical minimum operating temperature for these systems is about 120°C, although lower temperature systems, such as Chena Hot Springs, are in operation. The secondary fluid is organic, similar to a refrigerant (Organic Rankine Cycle) or a mixture of ammonia and water (Kalina System). Some power plants use multiple stages of flashing or combinations of flash and binary systems.

The center of the temperature-depth diagram in Figure 2, labelled stratigraphic geothermal reservoirs, is perhaps that least exploited field in terms of potentially productive geothermal reservoirs. Lithologies, temperatures, and depths in this field are familiar to hydrocarbon drillers.

A project in the northern Alps in southern Germany (Unterhaching) has demonstrated the potential of this field for both power production and district heating. Two wells tap the extreme low-temperature end of this region. The production well, with a depth of 3,446 m, produces up to 150 l/s of water from a fractured, karst limestone aquifer at a temperature of 122°C; the water is returned to the aquifer under gravity in an injection well 3.864 m deep, and 3.5 km from the production well. An average of 3.4 MWe of electricity was generated with a binary power plant from this system before the decision was made to use all the heat for district heating. Hot fluid is cascaded through approximately 28 km of pipe in a district heating system. A schematic diagram of the combined power plant and district heating system is shown in Figure 3. A second combined geothermal power/district heating plant was built in Germany in the Upper Rhine graben, but is currently not in operation because of problems with triggered seismicity.

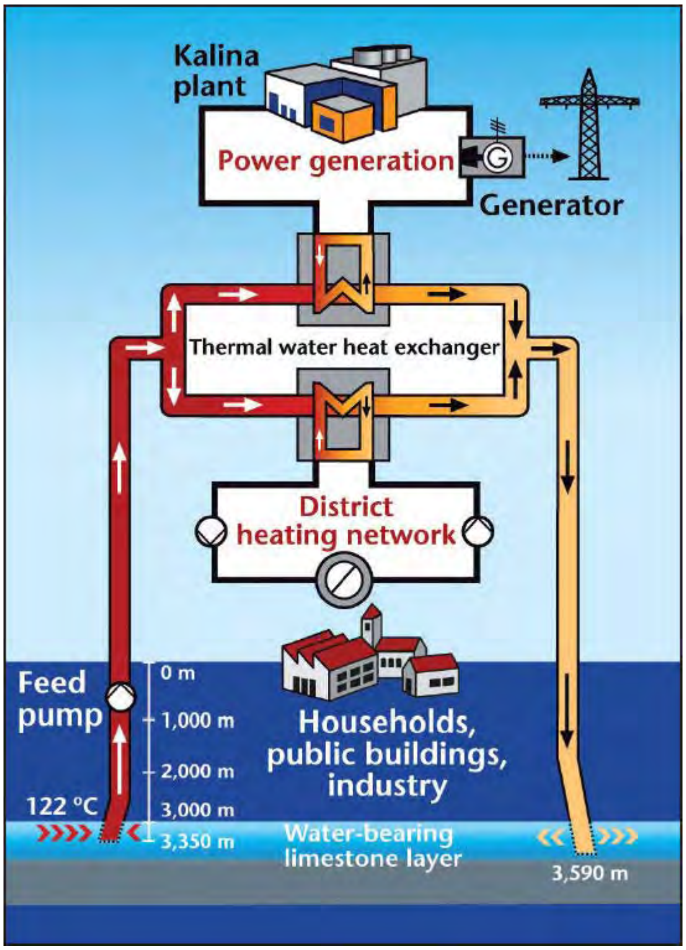

Figure 3. Schematic diagram showing the Unterhaching Geothermal Power Plant and District Heating System. Hot water is pumped from a deep limestone aquifer through a 3,350 production well (left) and divided to heat exchangers to provide heat for a binary (Kalina) power plant (upper) and a district heating system (lower). The cooled water is returned to the aquifer through an injection well about 3.5 km from the production well. The power plant portion of the system is currently not in operation. Reproduced from Bine Informationsdienst (2009), with permission.

For more than a decade the possibility of producing power from hot water brought to the surface in association with oil and gas production (produced water) has been discussed (e.g., Tester et al., 2006, Section 2.6.2). For a few years 150 to 250 kWe were generated from produced water in the Rocky Mountain Oilfield Testing Center in Wyoming (e.g., Reinhardt et al., 2011) from water at about 91.5°C. This field produced an unusual quantity of water, however. Quick analyses suggest that there should be a good supply of water in many basins at a temperature of about 120°C for binary power production. However, when production from individual wells were examined, few wells have sustained water production and to keep a binary power plant supplied, many wells would need to be connected together and the configurations of wells would need to be continually changed as water production changed among wells. With the low value of water relative to the prices of oil and gas, most producers are not interested in complicating field operations with piping produced water to low capacity binary power plants.

One instance has arisen in which producers have an incentive to consider power production from produced water. Some wells produce water at such a high temperature that regulations require that the water be cooled before it is reinjected or otherwise disposed. Cooling is generally by air-cooled heat exchangers powered by diesel generators. A binary power plant is a cooling heat exchanger that generates power rather than consumes power. Professor Will Gosnold at the University of North Dakota was hoping to extract heat for power production from hydraulically fractured horizontal wells but for various reasons this was not possible: however, a supply of hot produced water that needed to be cooled came available. A picture of the binary power plant that was put in place to cool this water is shown in Figure 4. These units are self-contained and have cooling fans to cool the secondary fluid after passing through the turbines on top of the units. About 250 kWe are generated by the units which is used for the pumps in the oil field. The project was funded by the US Department of Energy and is a green solution to cooling the water. Portable binary units with a similar capacity are commercially available and that could be delivered to wells with hot produced water with less permanent structures. However, the economics of using such systems are not yet available.

Direct Use

The most efficient use of geothermal energy is direct use: thermal energy from the earth is used directly as heat without conversion to another form of energy. Approximately 50% of the energy used domestically in the US is used for heating or for hot water, and a similar percentage is used in many other nations and in many commercial and industrial operations. Thus, where this heat may be economically and sustainably supplied locally from geothermal reservoirs, geothermal direct use is a viable option. Direct use has many other applications in addition to space heating, including greenhouse heating, spas, process drying, and aquaculture.

Direct use may be combined with geothermal power production, either by diverting some of the primary geothermal fluid from the reservoir to direct use, or by cascading the heat from the outlet of a geothermal turbine. At Unterhaching fluid for both power and direct use are taken from a single production well generating 3.4 MWe electrical and with a thermal output of 30.4 MWt,

Figure 4. Pair of binary geothermal electricity generating units producing electricity form hot produced water from a North Dakota Oil Field. Image from: https://www.energy.gov/eere/success-stories/articles/eere-success-story-doe-funded-project-first-permanent-facility-co.

(megawatts thermal), representing the heating requirements of approximately 3,000 households (Figure 3; Bine Informationsdienst, 2009). Europe currently leads the world in direct use for heating. Most of this heat is derived from low-temperature geothermal systems (<100°C). There are strong incentives in European nations to develop renewable resources: i) many European nations lack domestic and/or secure supplies of fossil fuels; ii) fossil fuel prices are high; and iii) the nations are committed to reducing carbon emissions.

An EGS for direct use was recently developed in Northern Alsace (France), designed to produce water at 170°C to deliver 24 MWt to a biorefinery in order to cover about 25% of their industrial heat needs. Two deep wells were drilled to target the same fault zone in the crystalline basement, as shown in Figure 5 (Baujard et al., 2017). Temperature logs from the wells indicate a conductive thermal regime down to a depth of about 1650 m, overlying a natural convection system with a temperature of 160°C. Permeability stimulation has included low-rate cold fluid injection, targeted chemical stimulation, and hydraulic stimulation. Flows between the wells exceeding 40 l/s were established during production tests. Heat is delivered to the biorefinery through a 14 km transport pipe loop, and the thermal system was placed into operation in mid-2016 (Baujard et al., 2017).

Most direct use systems use natural permeability (aquifers). The example that probably has the highest concentration of well-doublets (a production well and an injection well tapping the same

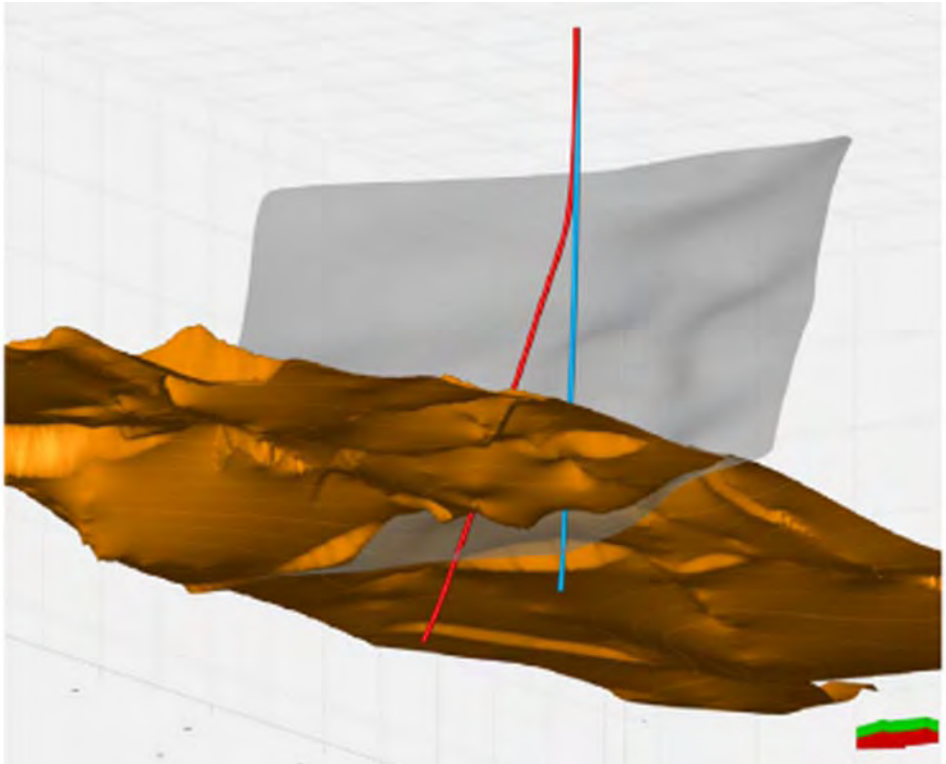

Figure 5. 3D structural model of the Northern Alsace EGS project base on seismic and well data. The Ritterschoffen main fault is shown as the gray surface and the top of the granite surface is shown in orange/brown as viewed from below on a north-east direction. The two wells, GRT-1 (blue) and GRT-2 (red) are shown where they penetrate the surfaces. The green/red arrow points north. Reproduced from Baujard et al. (2017), with permission.

basic aquifer) is the Paris geothermal district heating system, shown schematically in Figure 6. As of 2015, the system had an installed thermal power of about 345 MWt, most used for district heating: a few feeding greenhouses and aquaculture. There are 37 well-doublets or -triplets operating in the system, many of which have been operating since the late 1970s and early 1980s. Water is pumped at a temperature to 60-80°C, and depths of 1,600 to 1,900 m from the Dogger Aquifer and reinjected in the same aquifer (Vernier et al., 2015).

Five countries in Europe had installed direct use capacities of 500 MWt or greater in 2017, Turkey, Iceland, Italy, Hungary and France, with Turkey having the greatest installed capacity of 3,262 MWt, In all, 30 countries had an installed capacity of 1 MWt of more, for a total installed capacity of 9,678 MWt, as shown in Figure 7 (Sanner, 2017). Much of this direct use was for space heating, but a significant portion was used for greenhouses. Although in terms of the total energy budget for Europe, just over 3 GW is fairly small, this energy is used directly with no conversion losses. All energy is used as heat, and most used at close to its source temperature. Thus, in terms of a green energy source, and a domestic energy source, direct geothermal heat has a high intrinsic value.

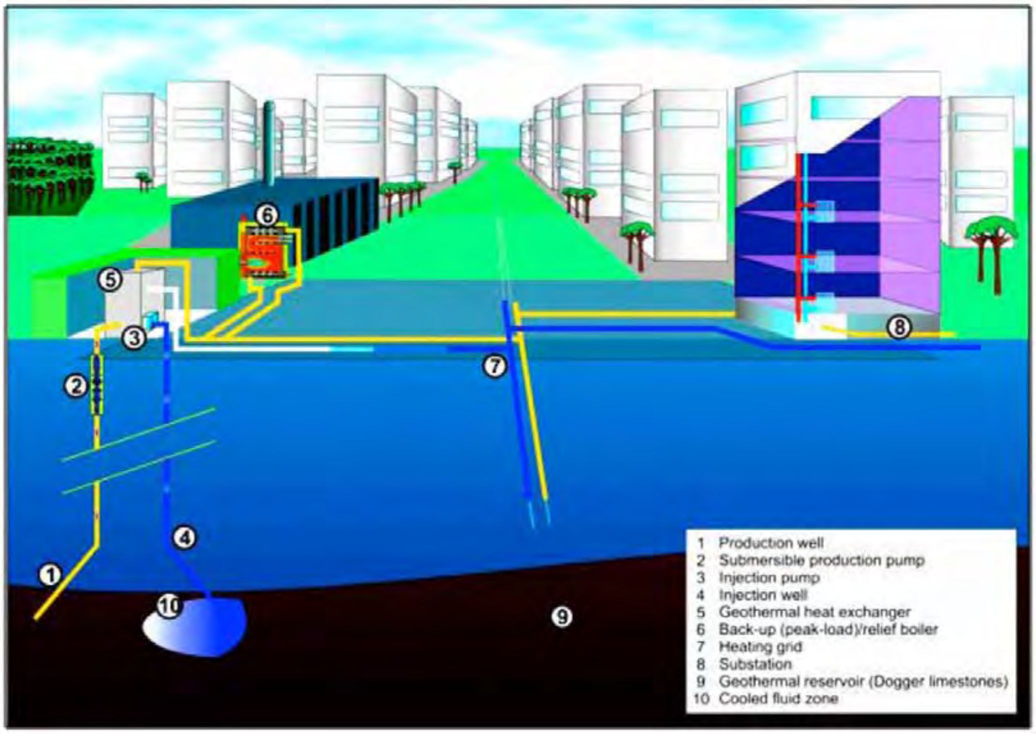

Figure 6. Generic schematic diagram of a geothermal district heating system in the Paris Area. Image Copyright GPC IP (France). Image reproduced from GEODH (2009), with permission.

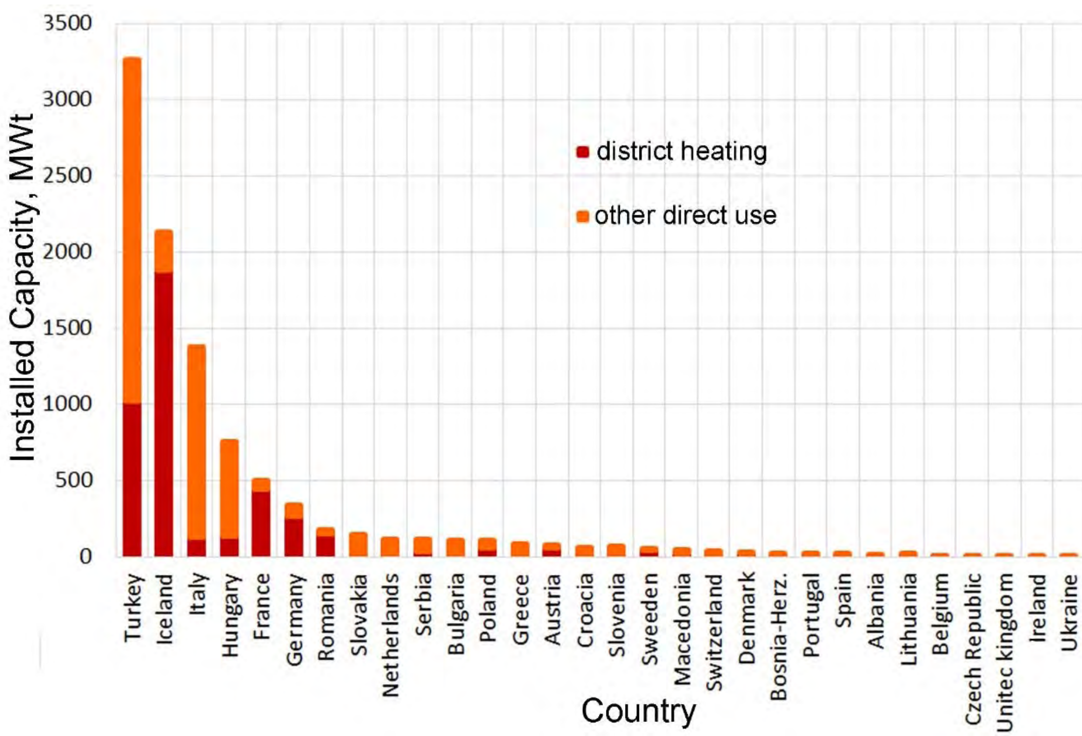

Figure 7. Geothermal direct use in Europe in 2016. Data from Sanner (2017), from EGEC (2016)

Heat Pumps

Geothermal (ground source or geoexchange) heat pumps may be used at most locations as they do not require above normal ground temperatures. They do not need high near-surface temperatures because the ground is used as thermal buffer in which heat is extracted and stored. Just as a refrigerator takes heat from the ice box and rejects it outside the refrigerator, a geothermal heat pump takes heat from inside a building and releases it into the ground in the summer. In the winter, the heat is taken out of the ground and released back into the building. Geothermal heat very economical to operate and typical payback from energy savings on heat-pump systems is five to seven years. Thus, geothermal heat pumps do not generate energy, but they are very efficient and typically reduce energy consumption for heating and cooling by 65 to 80%.

Geothermal heat pumps are suitable for use at all scales from individual detached homes to apartment dwellings to commercial, office and industrial buildings. Ground loops, the component of the system through which heat is exchanged with the ground, may be sized to serve more than one building. Multiple heat pumps of different capacities may exchange heat with a single ground loop, with each heat pump controlled by its own heating and cooling temperature controls. Heat pump capacity in many European countries is growing steadily with dramatic growth in a few countries, as shown in Figure 8 (Sanner, 2017).

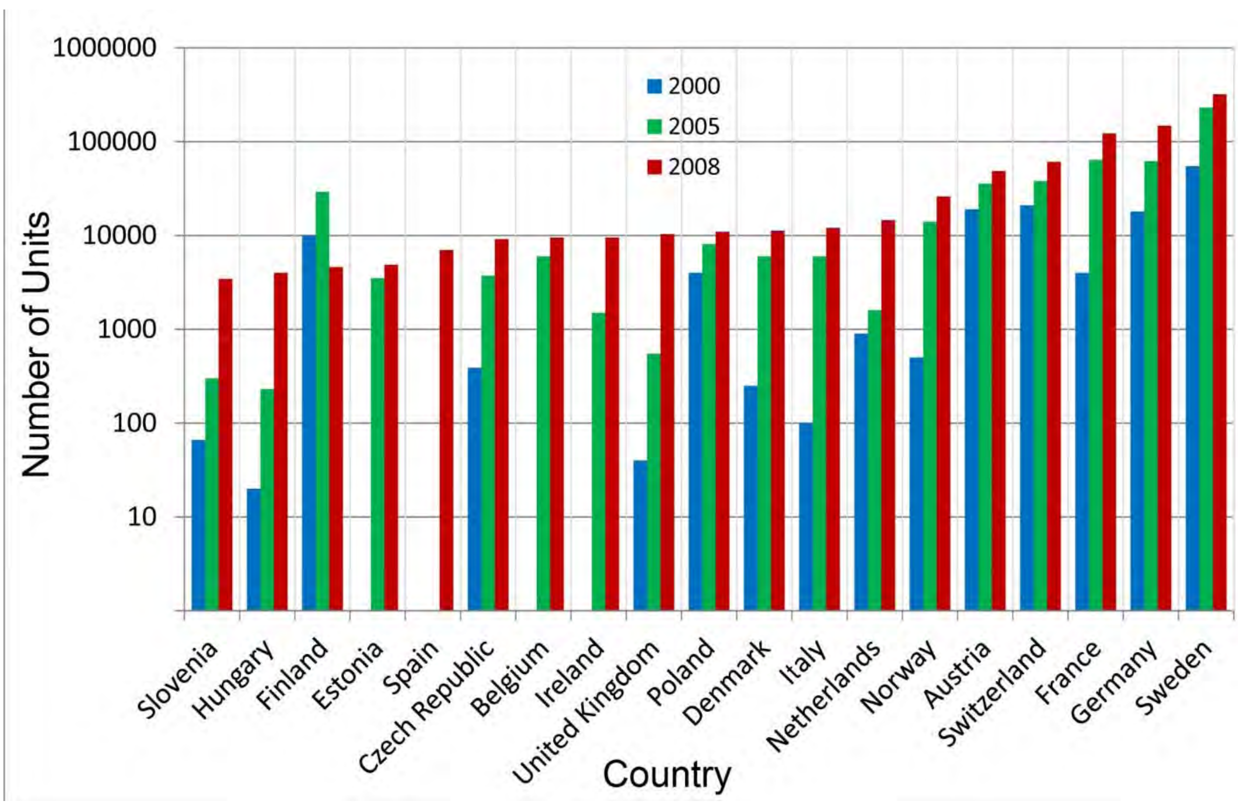

Figure 8. Growth in heat supplied geothermal heat pumps in various European countries. Data from Sanner (2017), after data from EurOberservER.

Concluding Remarks

Geothermal energy continues to grow slowly in contributing to the global renewable electrical power producing market. In this market it is limited to making major contributions for the foreseeable future to areas where moderate- to high-temperature hydrothermal geothermal resources are within a few kilometers of the surface. In a few countries, such as Iceland, the Philippines, Indonesia, and Kenya, geothermal power resources are growing rapidly and have the potential to make major, if not majority contributions to the national electrical economies. In many other nations, geothermal may be a valuable minor, distributed electrical contributor.

As discussed in this report, geothermal resources have much more to contribute than electricity. Europe has probably seen the greatest resurgence of direct use and geothermal heat pumps in the past fifty years and continues to expand its use of these resources. During 2017 the Chinese central government announced that it would make a large investment in geothermal development. The largest portion of these funds was not to be in developing geothermal resources for electricity generation, but in resources for direct use and geothermal heat pumps.

Deep in the crust is the ultimate prize for geothermal development and the target for EGS. However, extracting energy from high temperatures at great depth with little intrinsic permeability is a great challenge with today's technology. There are many more modest resources available with current technology.

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