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Characteristics, development and utilization of geothermal resources – a Nordic perspective

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Geothermal energy is classified as a renewable energy source and it utilizes the heat generated in the earth primarily from the natural radioactive decay of isotopes of uranium, thorium and potassium. Heat is extracted from the earth to generate geothermal energy via a carrier, usually water occurring either in the liquid or steam phase. In the late 19th century and the early 20th century, the first developments of geothermal resources for power generation and household heating got underway successfully. Many of these geothermal fields are still being utilized today, proving their sustainability. Today geothermal energy is being utilized in more than 72 countries around the world and of the Nordic countries Iceland and Sweden have been in the forefront in each of their respective fields. While geothermal heat pumps are widely used for space heating in Sweden, geothermal energy covers 55% of the primary energy consumption in Iceland where it is used for space heating, power generation and industrial purposes. Future developments aim at expanding the range of viable geothermal resources by improving the capabilities to generate electricity from geothermal resources at temperatures as low as 100°C, as well as developing geothermal resources where water needs to be introduced, so-called hot dry rock resources. But the biggest expansion is expected to continue to be in the installations of geothermal heat pumps.

Introduction

Early humans probably used geothermal water that occurred in natural pools and hot springs for cooking, bathing and to keep warm. We have archeological evidence that the Indians of the Americas occupied sites around these geothermal resources for over 10,000 years to recuperate from battle and take refuge. Many of their oral legends describe these places and other volcanic phenomena. Recorded history shows uses by Romans, Japanese, Turks, Icelanders, Central Europeans and the Maori of New Zealand for bathing, cooking and space heating. Baths in the Roman Empire, the middle kingdom of the Chinese, and the Turkish baths of the Ottomans were some of the early uses of balneology, where body health, hygiene and discussions were the social custom of the day. This custom has been extended to geothermal spas in Japan, Germany, Iceland, and countries of the former Austro-Hungarian Empire, the Americas and New Zealand. Early industrial applica-

tions include chemical extraction from the natural manifestations of steam, pools and mineral deposits in the Larderello region of Italy, with boric acid being extracted commercially starting in the early 1800s. At Chaudes-Aigues in the heart of France, the world's first geothermal district heating system was started in the 14th century and is still in use. The oldest geothermal district heating project in the United States is on Warm Springs Avenue in Boise, Idaho, which came on line in 1892 and continues to provide space heating for up to 450 homes.

The first use of geothermal energy for electric power production was in Italy with experimental work by Prince Gionori Conti between 1904 and 1905. The first commercial power plant (250 kWe) was commissioned in 1913 at Larderello, Italy. An experimental plant was installed in The Geysers in 1932 and provided power to the local resort. These developments were followed in New Zealand at Wairakei in 1958; an experimental plant at Pathe, Mexico in 1959; and the first commercial plant at The Geysers in the United States in 1960. Japan followed with 23 MWe at Matsukawa in 1966. All of these early plants used steam directly from the earth (dry steam fields), except for New Zealand, which was the first to use flashed or separated steam for running the turbines. The former USSR produced power from the first true binary power plant, 680 kWe using 81°C water at Paratunka on the Kamchatka peninsula—the lowest temperature at that time. Iceland first produced power at Namafjall in the northern part of the country, from a 3 MWe non-condensing turbine. These were followed by plants in El Salvador, China, Indonesia, Kenya, Turkey, Philippines, Portugal (Azores), Greece and Nicaragua in the 1970s and 1980s. Later plants were installed in Thailand, Argentina, Taiwan, Australia, Costa Rica, Austria, Guatemala, Ethiopia, with the latest installations in Germany and Papua New Guinea. (See Cataladi, et al., 1999 for more background on the historical uses of geothermal energy.)

Types of geothermal resources

Geothermal energy comes from the natural heat of the earth primarily due to the decay of the naturally radioactive isotopes of uranium, thorium and potassium. Because of the internal heat, the Earth's surface heat flow averages 82 mW/m² which amounts to a total heat loss of about 42 million megawatts. The estimated total thermal energy above mean surface temperature to a depth of 10 km is 1.3×10^{27} J, equivalent to burning 3.0×10^{17} barrels of oil. Since the global energy consumptions for all types of energy are equivalent to use of about 100 million barrels of oil per day, the Earth's energy to a depth of 10 kilometers could theoretically supply all of mankind's energy needs for six million years (Wright, 1998).

On average, the temperature of the Earth increases with depth at about 30°C/km. Thus, assuming a conductive gradient and mean surface ambient temperature, the temperature of the earth at 10 km would be over 300°C. However, most geothermal exploration and use occurs where the gradient is higher, and thus where drilling is

shallower and less costly. These shallow depth geothermal resources occur due to: (1) intrusion of molten rock (magma) from depth, convecting great quantities of heat upwards; (2) high surface heat flow, due to a thin crust and high temperature gradient; (3) ascent of groundwater that has circulated to depths of several kilometers and been heated due to the normal temperature gradient; (4) thermal blanketing or insulation of deep rocks by thick formation of rocks such as shale whose thermal conductivity is low; and (5) anomalous heating of shallow rock by decay of radioactive elements, perhaps augmented by thermal blanketing (Wright, 1998).

Geothermal resources are usually classified as shown in Table 1, modeled after White and Williams (1975). These geothermal resources range from the mean annual ambient temperature of around 20°C to over 300°C. In general, resources above 150°C are used for electric power generation, although power has recently been generated at Chena Hot Springs Resort in Alaska using a 74°C geothermal resource (Lund, 2006). Resources below 150°C are usually used in direct-use projects for heating and cooling. Ambient temperatures in the 5 to 30°C range can be used with geothermal (ground-source) heat pumps to provide both heating and cooling.

Table 1 Geothermal resource types (°C).

Resource Type		Temperature Range (°C)
Convective hydrothermal resources	Vapor dominated	≈240°
	Hot-water dominated	20 to 350°+
Other hydrothermal resources	Sedimentary basin	20 to 150°
	Geopressured	90 to 200°
	Radiogenic	30 to 150°
Hot rock resources	Solidified (hot dry rock)	90 to 650°
	Part still molten (magma)	>600°

Worldwide utilization of geothermal energy

The utilization of geothermal energy resources falls into two categories, energy for electric power generation and direct-use, where space heating is the principal constituent of the latter. The latest numbers based on reports at the World Geothermal Congress in 2005 (WGC2005) show that geothermal energy is currently used in 72 countries (Lund, et al., 2005; Bertani, 2005 and 2007). In Table 2 and 3 the figures of worldwide and regional geothermal electric and direct-use capacity is presented. Further details of the present installed electric power capacity and generation, and direct-use of geothermal energy can be found in Bertani (2005, 2007), and Lund, Freeston and Boyd (2005).

Table 2 Total geothermal use in 2005 (based on reports at the World Geothermal Congress 2005 and Bertani, 2007).

Use	Installed Power (MW)	Annual Energy Use (GWh/yr)(est.)	Capacity Factor	Countries Reporting
Electric Power	9,732	61,865	0.73	24
Direct-Use	28,268	75,943	0.31	72

Table 3 Summary of regional geothermal use in 2005.

Region	Electric Power		Direct-use	
	%MWe	%GWh/yr	%MWt	%GWh/yr
Africa	1.5	1.9	0.7	1.1
Americas	43.9	47.0	32.3	16.7
Asia	37.2	33.8	20.9	29.4
Europe	12.4	12.4	44.6	49.0
Oceania	5.0	4.9	1.5	3.8

Electric power generation

Geothermal power is generated by using steam or a secondary working vapor to turn a turbine-generator set to produce electricity. A vapor dominated (dry steam) resource can be used directly, whereas a hot water resource needs to be flashed by reducing the pressure to produce steam. In the case of a low temperature resource, generally below 150°C, the use of a secondary low boiling point fluid (hydrocarbon or water-ammonia mixture) is required to generate the vapor, in a binary or organic Rankin cycle (ORC) plant. Usually a wet or dry cooling tower is used to condense the vapor after it leaves the turbine to maximize the temperature drop between the incoming and outgoing vapor and thus increase the efficiency of the operation.

Currently electric power is being produced from geothermal energy in 24 countries over the world with the leading ones shown in Table 4 (Bertani, 2005 and 2007). Since 2000, the installed capacity in the world has increased by almost 1,000 MWe. This increase has been generated partly through installation of new plants as well as through a reinjection project to invigorate The Geysers field in northern California. One of the more significant aspects of geothermal power development is the size of its contribution to national and regional capacity and production of countries. The following countries or regions lead in this contribution with more than 5% of the electrical energy supplied by geothermal power based on data from WGC2005 and is shown in Table 5 (Bertani, 2005).

Table 4 Leading countries in electric power generation from geothermal energy (>100 MWe)(Bertani, 2005 and 2007).

Country	Installed Capacity MWe	Running Capacity MWe	Annual Energy Produced GWh/yr (est.)	Running Capacity Factor	Number Units of Operating
United States	2687	1935	16,200	0.95	209
Philippines	1970	1856	9,340	0.57	57
Indonesia	992	992	7,200	0.83	15
Mexico	953	953	6,280	0.75	36
Italy	811	711	5,430	0.87	32
Japan	535	530	3,470	0.75	19
New Zealand	472	373	2,570	0.79	33
Iceland	421	421	3,090	0.84	19
El Salvador	204	189	1,540	0.93	5
Costa Rica	163	163	1,150	0.80	5
Kenya	129	129	1,090	0.96	9

Table 5 National and regional geothermal power contributions.

Country or region	% of National or Regional Capacity (MWe)	% of National or Regional Energy (GWh/yr)
Tibet, China	30.0	30.0
San Miguel Island, Azores, Portugal	25.0	n/a
Tuscany, Italy	25.0	25.0
El Salvador	14.0	24.0
Iceland	13.7	16.6
Philippines	12.7	19.1
Nicaragua	11.2	9.8
Kenya	11.2	19.2
Lihir Island, Papua New Guinea	10.9	n/a
Guadeloupe (Caribbean)	9.0	9.0
Costa Rica	8.4	15.0
New Zealand	5.5	7.1

Since 2000, additional plants have been installed in Costa Rica, France on Guadeloupe in the Caribbean, Iceland, Indonesia, Kenya, Mexico, and Philippines. In 2004 Germany installed a 210 kW binary plant at Neustadt Glewe and a 6 MWe plant has been installed on Papua New Guinea to generate electricity for the remote Lihir mine. Russia has completed a new 50 MWe plant at Kamchatka. More recently, a 200 kW binary plant using 74°C geothermal water and 4°C cooling water was installed at Chena Hot Springs Resort in Alaska (Lund, 2006).

Electric power generation from geothermal energy in the Nordic countries

Iceland

Iceland is located on the Mid-Atlantic Ridge, which transects the country from southwest to northeast along an active volcanic rift zone, where many high-temperature fields ($>200^{\circ}\text{C}$ at 1 km) are located. Iceland is therefore currently the only Nordic country where geothermal energy can be used to generate electricity. Electricity is generated from six power plants located on central volcanoes and systems within the active volcanic zone of Iceland (Figure 1). The first geothermal power plant in Iceland, a 3 MWe back pressure unit, was installed at Bjarnaflag on the Namafjall field in northern Iceland, and was put into production in 1969. In 1977, another two power plants were put into production, at Krafla and Svartsengi. At the Krafla central volcano in northern Iceland the National Power Company (Landsvirkjun) is operating a power plant with two 30 MWe double-flash condensing turbines (Ragnarsson, 2005). Electricity is produced from three well-fields in the Krafla geothermal system with temperatures of up to $320\text{--}350^{\circ}\text{C}$. The Svartsengi co-generation power plant is located on the Reykjanes peninsula. The plant utilizes geothermal brines at 240°C with a salinity two-thirds that of seawater. The power plant is owned by Sudurnes Regional Heating and has gradually been enlarged over the years so that currently the installed capacity is 200 MWt for hot water production and 45 MWe for power generation. Sudurnes Regional Heating commenced generating power in the new Reykjanes power plant in 2006. The power plant has an installed capacity of 100 MWe, which is generated from geothermal brine at a temperature of $280\text{--}310^{\circ}\text{C}$ and with the salinity of seawater. Two power plants operated by Reykjavík Energy are located at Hengill central volcano in southwestern Iceland (Figure 1). Nesjavellir is a co-generation power plant, where fresh water is heated by geothermal steam in heat exchangers (Gunnarsson et al., 1992). The plant began production in 1990, initially providing hot water mainly for district heating in the capital of Reykjavík, but

since 1998 has also been generating electricity. Today, the installed capacity is 120 MWe and 290 MWt. Electric power generation commenced at Hellisheidi power plant south of Hengill in 2006, which in the first stage has an installed capacity of 90 MWe, but drilling is currently in progress for further expansion of the power plant. Finally, among the first of its kind, a 2 MWe Kalina cycle binary generator was installed at Húsavík in northern Iceland in 2001. The plant is the only one located outside the active volcanic zone and utilizes $124\text{--}128^{\circ}\text{C}$ hot water from the Hveravellir geothermal field, which heats a mixture of water and ammonia in a heat exchanger (Hjartarson et al. 2005). This power plant provides about two thirds of the electricity requirements of the community at Húsavík. With the launch of Reykjanes and Hellisheidi power plants in 2006 the installed capacity has almost doubled in Iceland bringing it up to 422 MWe (Björnsson, 2006). Further developments are expected in the coming years to meet increasing demands from the expanding aluminum industry in Iceland.

With the incentive to enhance the economics of geothermal energy, the Iceland Deep Drilling Project has been underway since 2000 and is expected to start drilling a well to a depth of 4–5 km in the Krafla geothermal system in 2008. The project aims to encounter fluids at supercritical conditions of $450\text{--}600^{\circ}\text{C}$ (Fridleifsson and Elders, 2005). A successful outcome would give a unique opportunity to test the production and feasibility of utilizing supercritical fluids from the deep-seated parts of geothermal reservoirs.

Direct utilization worldwide

The main direct-use applications of geothermal resources are for heating and cooling. The main utilization categories are: (1) swimming, bathing and balneology; (2) space heating and cooling including district energy systems; (3) agricultural applications such as greenhouse and soil heating; (4) aquaculture application such as pond and raceway water heating; (5) industrial applications such as mineral extraction, food and grain drying; and, (6) geothermal (ground-source) heat pumps, used for both heating and cooling. Direct-use of

Figure 1 Geological map of Iceland with high and low temperature areas. Based on Geological map of Iceland (1:1 000 000) by Haukur Jóhannesson and Krislján Sæmundsson 1999, Icelandic Institute of Natural History.

Figure 2 Typical components of a direct-use heating system.

geothermal resources normally uses temperatures below 150°C. The main advantage of using geothermal energy for direct-use projects in this low- to intermediate-temperature range is that these resources are more widespread and exist in at least 80 countries at economic drilling depths. In addition, there are no conversion efficiency losses and projects can commonly use conventional water-well drilling and off-the-shelf heating and cooling equipment (allowing for the temperature and chemistry of the fluid). Most projects can be on line in less than a year. Projects can be on a small scale such as for an individual home, single greenhouse or aquaculture pond, but can also be a large scale operation such as for district heating/cooling, food and lumber drying, and mineral ore extraction.

It is often necessary to isolate the geothermal fluid from the user side to prevent corrosion and scaling. Care must be taken to prevent oxygen from entering the system (geothermal water normally is oxygen free), and dissolved gases and minerals such as boron, arsenic, and hydrogen sulfide must be removed or isolated as they are harmful to plants and animals. On the other hand carbon dioxide, which often occurs in geothermal water, can be extracted and used for carbonated beverages or to enhance growth in greenhouses. The typical equipment for a direct-use system is illustrated in Figure 2, and includes downhole and circulation pumps, heat exchangers (normally the plate type), transmission and distribution lines (normally insulated pipes), heat extraction equipment, peaking or back-up plants (usually fossil fuel fired) to reduce the use of geothermal fluids and reduce the number of wells required, and fluid disposal systems (injection wells). Geothermal energy can usually meet 95% of the annual heating or cooling demand, yet only be sized for 50% of the peak load.

A summary of direct-use installed capacity and annual energy use are as follows: geothermal heat pumps 56.5% and 33.2%; bathing/swimming/spas 17.7% and 28.8%, space heating (including district heating) 14.9% and 20.2%; greenhouse heating 4.8% and 7.5%; aquaculture 2.2% and 4.2%; industrial 1.8% and 4.2%; agricultural drying 0.6% and 0.8%, cooling and snow melting 1.2% and 0.7%; and others 0.3% and 0.4%. District heating is approximately 80% of the space heating use. Figure 3 illustrates direct-use applications. The leading countries in the world are shown in Table 6.

In terms of the contribution of geothermal direct-use to the national energy budget, two countries stand out: Iceland and Turkey. In Iceland, it provides 89% of the country's space heating needs, which is important since heating is required almost all year and saves about US\$100M in imported oil. Turkey has increased its installed capacity over the past five years from 820 MWt to 1,495 MWt, mostly for district heating systems. A summary of some of the significant geothermal direct-use contributions to various countries is shown in Table 7.

Figure 3 Examples of direct-use applications (Courtesy of Geothermal Education Office).

Table 6 Top direct-use countries (Lund et al., 2005).

Country	GWh/yr	MWt	Main Applications
China	12,605	3,687	Bathing
Sweden	12,000	4,200	GHP
USA	8,678	7,817	GHP
Turkey	6,900	1,495	District heating
Iceland	6,806	1,844	District heating
Japan	2,862	822	Bathing (onsens)
Hungary	2,206	694	Spas/greenhouses
Italy	2,098	607	Spas/space heating
New Zealand	1,969	308	Industrial uses

Table 7 National geothermal direct-use contributions.

Iceland	provides 89% of country's space heating needs
Sweden	Provides around 10% of the heating demand with geothermal heat pumps from 350,000 units
Turkey	space heating has increased 50% in the past 5 years, supplying 65,000 equivalent residences and 30% of the country will be heated with geothermal by 2010
Tunisia	greenhouse heating has increased from 10 ha to 100 ha over the past 10 years
Japan	over 2,000 hot spring resorts, over 5,000 public bath houses, and over 15,000 hotels, visited by 14.5 million guests per years use natural hot springs
Switzerland	has installed 30,000 geothermal heat pumps = one/two km ² , and 1,000 boreholes are drilled annually. Drain water from tunnel are used to heat nearby villages and they have also developed several geothermal projects to melt snow and ice on roads
United States	has installed 700,000 geothermal heat pump units, mainly in the midwestern and eastern states, with a 15% annual growth. Installation of these units is around 50,000 to 60,000 per year.

Direct-use in Iceland

Utilization of geothermal energy for direct purposes such as bathing, cooking and washing probably extends back to the first settlement of Iceland. However, it was not until the early twentieth century that general development of geothermal energy for purposes such as household heating took place. In 1928, the first extensive geothermal development for district heating got underway, when the first wells were drilled in the Laugarnes low temperature field in Reykjavik. By 1930, a three-km long pipeline was installed to transport the hot water into the center of the city to provide heating for a primary school, the national hospital, 60 households as well as hot water for a swimming pool (Gunnlaugsson et al., 2000). The Reykir low temperature field, approximately 17 km from the centre of Reykjavik, was developed in the 1930s and further research later led to the development of another field, Ellidaar, within the city boundaries. Today, these fields are providing water with temperatures ranging from 85–130°C from 52 wells. Reykjavik Energy is managing the district heating in Reykjavik and these three fields have a capacity of 2250 l/s and provide 74% of the hot water consumption for district heating in the capital, while heated water pumped from Nesjavellir high temperature field c. 30 km east of the capital provides the remaining requirements (Gunnlaugsson et al., 2000).

Geothermal energy is abundant in Iceland with more than 250 low temperature areas straddling the volcanic zone and more than 25 high temperature areas within the volcanic zone (Figure 1). Thus, in most communities around the country exploration and development of both low and high temperature geothermal fields has, through the years, been successful to such an extent that today 89% of the households in Iceland are heated with geothermal energy (Björnsson, 2006). Geothermal energy is used for a wide variety of purposes in Iceland such as greenhouse, industrial drying, carbon dioxide production, fish farming, swimming pools and snow melting, and amounts to a share of 26.8% of the total utilization of geothermal energy in Iceland, while space heating accounts for 57.4% and electricity generation the remaining part. In total geothermal energy covers 55% of the primary energy consumption in Iceland.

Geothermal (ground-source) heat pumps

Geothermal (ground-source) heat pumps (GHP) are one of the fastest growing applications of renewable energy in the world, with annual increases of 10% in about 33 countries over the past 10 years. Its main advantage is that it uses normal ground or groundwater temperatures (between about 5 and 30°C), which are available in all countries of the world. Most of this growth has occurred in the United States and Europe, though interest is developing in other countries such as Japan, China and Turkey. The present worldwide installed capacity is estimated at almost 15,400 MWt (thermal) and the annual energy use is about 87,500 TJ (24,300 GWh). The actual number of equivalent installed units (12 kW) is around 1,500,000, but the data are incomplete. Table 8 lists the countries with the highest use of GHPs.

GHPs come in two basic configurations: ground-coupled (closed loop) which are installed horizontally or vertically (Figure 4a), and groundwater (open loop) systems (Figure 4b), which are installed in wells and lakes. In the ground-coupled system, a closed

Figure 4 a) Closed loop heat pump systems (source: Geo-Heat Center); b) Open loop heat pumps systems (source: Geo-Heat Center).

Figure 5 Desuperheater in heating (a) and cooling (b) mode (source: Geo-Heat Center).

Table 8 Leading countries using GHP (Curtis et al., 2005).

Country	MWt	GWh/yr	Number installed
Austria	300	400	25,000
Canada	445	610	37,000
Germany	560	840	47,000
Sweden	4,200	12,000	350,000
Switzerland	530	790	44,000
USA	8,400	7,200	700,000

loop of pipe, placed either horizontally (1 to 2 m deep) or vertically (50 to 70 m deep) is placed in the ground and a water-antifreeze solution is circulated through the plastic pipes (high density polyethylene) to either collect heat from the ground in the winter or reject heat to the ground in the summer (Rafferty, 1997). The open loop system uses ground water or lake water directly in the heat exchanger and then discharges it into another well, into a stream or lake, or on the ground (say for irrigation), depending upon local laws. The type chosen depends upon the soil and rock type at the installation, the land available and/or if a water well can be drilled economically or is already on site.

A desuperheater can be provided to use reject heat in the summer and some input heat in the winter for the domestic hot water heating as shown in Figure 5. A small amount of electricity input is required to run a compressor; however, the energy output is in the order of four times this input. A desuperheater provides heat to the domestic hot water in the geothermal heat pump heating and cooling cycles. During heating (Figure 5a), heat can be removed for the desuperheater before it is provided to the normal heating system, however, with a loss in efficiency. During cooling (Figure 5b), heat can be rejected to the desuperheater before it is rejected to the ground or ground-water with no loss in efficiency. Unfortunately, a backup domestic hot water system must be provided, as the heat pump does not run 100% of the time, but does provide as much as 30 to 50% of the domestic hot water heating requirements which can be stored in a traditional insulated hot water tank. See Curtis et al. (2005) and Lund et al. (2003) for more background material.

Nordic countries

The obvious leader in geothermal heat pump installation is Sweden with many shallow bores and several very deep drillings, followed by Denmark with their two district heating plants. A summary of installations in the Nordic Countries is as follows (Table 9—based mainly of 2005 data; Sweden 2006 data).

Table 9 Geothermal heat pump installation data for the Nordic countries.

Country	Installed Capacity MWt	Annual Energy Use GWh/year	Number of Units
Denmark	330	1,220	43,250
Finland	195	600	30,000
Iceland	5	6	4
Norway	600	860	14,000
Sweden	4,200	12,000	350,000

Denmark

Denmark is noted for the two district heating plants using absorption heat pumps. The older installation, in operation since 1984, at Thisted in northern Jutland (Jylland), extracts heat from a 44°C, 19% salinity groundwater produced from 1.25 km depth (Mahler and Magtengaard, 2005). In 2000–2001, the plant was enlarged to 7 MWt capacity, producing 80 TJ/year (22 GWh/yr) of heat from 200 m³/hr of water, which is then reinjected. The most recent installation, the Margretheholm plant in Copenhagen, started operation in the fall of 2004. Absorption heat pumps use water from a well. A deviated production well and a vertical injection well have been drilled to produce heat from a 73°C sandstone aquifer. The Margretheholm plant has a capacity of 14 MWt and energy use of 380 TJ/year (106 GWh/yr), utilizing 235 m³/hr of 19% salinity water. A further 250 groundwater-based heat pumps and 43,000 other types of pumps (about 10 to 20% of which are vertical closed-loop) are also in operation. They extract approximately 3940 TJ/yr (1095 GWh/yr). The estimated installed capacity is 309 MWt

(assuming 3,500 full-load operating hours/yr). The total for Denmark is therefore 330 MWt and 4,400 TJ/year (1,222 GWh/yr).

Finland

Based on limited information, approximately 10,000 geothermal heat pump units have been installed in Finland, producing 484 TJ/year (134 GWh/yr) from an installed capacity of 80.5 MWt, assuming 4,000 equivalent full-load hours per year based on 2000 data from Kukkonen. Based on data from the Finnish Heat Pump Association (Suomen Lampopumppuyhdistys—www.ivlampopumput.fi/eng.html), heat pump sales (both air-source and geothermal types) have increased annually by 50–100% over the last five years, so that in 2005 the estimated number of installed units was 30,000 of which geothermal was 25,000 units (Hirvon, 2002). A standard Finnish residence of 150 m² uses an average of 20,000 kWh/year, assuming a 5–8 kWt capacity unit (average COP of 3.1). Thus, the total installed capacity in Finland in 2002 was 162.5 MWt, using 1,220 TJ/year of geothermal energy (based on an average capacity of 6.5 kW). Extrapolating this to 2007, the estimated values are 30,000 geothermal heat pump units with an installed capacity of 195 MWt, using 2,160 TJ/year (600 GWh/year). Ground-source heat pumps in 2005 had captured 20 to 40% of the heating market shares in the country, increasing from less than one percent in 1995 and 13% in 2001. The average investment cost for a system is 16,000 Euros and the annual operating cost is 437 Euros. This compares to air source heat pumps of 9,000 Euros investment cost and 750 Euro annual operating cost. Air source units presently capture 10–30% of the heating system market.

Iceland

Geothermal heat pumps are utilized on a limited basis, with reports of only three locations: Akureyri, Grenivik and an unknown site in 2005. The total installed capacity is 4.0 MW producing 20 TJ/yr (5.6 GWh/yr) of space heating. Only two units are reported installed with a COP of 4.75 (Ragnarsson, 2005). Recent information (personal communication with Danielsson, 2007) indicates that few geothermal heat pumps have been installed in Iceland due to the readily available higher temperature geothermal resources used for space heating (there is little or no need for space cooling) and the low heat transfer coefficient of basaltic rock. One of note is a closed loop system using a 300 m deep well with an annual output of approximately 40,000 kWh and a COP of 3.3. Interestingly, about 15 air-to-air heat pumps have been installed since 2005, which are working extremely well. However, the geothermal and air-to-air units are relatively unknown in Iceland, and as a result not well accepted.

Norway

Norway is not considered a geothermal country; however about 150 geothermal heat pump systems sized for commercial or multi-family buildings have been installed (Midttrømme, 2005). Traditionally, these systems are used for heating only, but in some the exhaust ventilation is reinjected (stored underground) to provide additional heat for use in the winter. Increased interest in cooling in the commercial and industrial sectors is favoring ground-source heat pumps and underground thermal energy storage systems. As of 2003, there were 55,100 heat pumps installed in Norway, of which 5% were geothermal (i.e., 2,755). Norway has one of the largest geothermal heat pump installations in Europe, the system uses 180 boreholes to provide 9 MWt for heating and 6 MWt for cooling a school, shopping center, hotel offices and residential area covering a total of 180,000 m². In 2005, the total number of installed geothermal heat pump units was estimated at 14,000, with a capacity of 600 MWt. Over 90% of these installations are vertical boreholes of the ground-coupled type with a single U-type pipe installed. No figures are available on annual energy use, but using 2,000 full-load hours per year and a COP of 3.5, the annual energy use is estimated at 3,085 TJ/yr (857 GWh/yr).

Sweden

Sweden came in early with geothermal heat pumps for domestic heating. Already in 1985, there were some 50,000 units of ground-source heat pumps installed (Bjelm, 1983). Today, there are at least 350,000 units and the annual sale over the past 4–5 years has been around 40,000 units (Hellström, 2006). It is estimated that all these units produce about 10% of the heat demand in all single houses and official buildings in Sweden. The useful heat from the electric energy to the heat pump is not included here (Olof Andersson, personal communication, 2007). The annual energy use is estimated at 12,000 GWh/yr, making Sweden the largest GHP energy user in the Nordic countries and in the world in terms of GWh/yr.

Most of the geothermal heat pumps are small scale units for single houses but a few large ones with an installed capacity of 20 to 45 MWt are running. The largest is in Lund with an installed capacity of 47 MWt utilizing two heat pumps. It has been producing heat for the local district heating network since 1985 and the yearly production is around 235,000 MWh/yr. About 550 l/s is produced from four production wells with a temperature of around 20°C. The water is produced from about 700 m and re-injected in five wells some 1500 m away from the production wells. The project is a great success with very high availability and excellent economy. Production for domestic cooling is now becoming a new and more and more popular application of the use of ground source heat. It is estimated that at least 100 MWh/yr was produced during 2006 and a rapid increase is expected over the coming years.

Energy savings

Using geothermal energy in direct-use applications replaces fossil-fuel use and prevents the emission of greenhouse gases. Table 10 shows the savings brought about by the direct-use of geothermal energy assuming that it replaces electricity generated from fossil-fuels (conversion efficiency estimated at 0.35) If direct-use applications replace burning the fuel directly, then about half of this amount to fuel oil would be saved in heating systems (35% vs. 70% efficiency). Savings in the cooling mode of geothermal heat pumps is also included in the figures in Table 10. The savings in fossil fuel oil are equivalent to about three days (1%) of the world's consumption.

Table 10 Energy and greenhouse gas savings from geothermal energy production (after Goddard and Goddard, 1990).

	Fuel Oil (10 ⁶)			Carbon (10 ⁶ t)			CO ₂ (10 ⁶ t)			SO _x (10 ⁶ t)			NO _x (10 ³ t)		
	Barrels	Tonnes		NG	Oil	Coal	NG	Oil	Coal	NG	Oil	Coal	NG	Oil	Coal
Electric	96	15		3	13	15	12	51	59	0	0.3	0.3	2.8	9.6	9.6
Direct-use	174	26		5	24	27	16	67	78	0	0.5	0.5	3.8	12.4	12.4
TOTAL	270	41		8	37	42	28	118	137	0	0.8	0.8	6.6	22.0	22.0

It should be noted when considering these savings, that some geothermal plants do emit limited amounts of the various pollutants; however, these are reduced to near zero where gas injection is used and eliminated where binary power is installed for electric power generation. Since most direct-use projects use only hot water and the spent fluid is reinjected, the above pollutants are essentially eliminated.

Conclusions

Growth and development of geothermal electricity generation has increased significantly over the past 30 years approaching 15% annually in the early part of this period, and dropping to 3% annually in the last ten years due to an economic slowdown in the Far East and the low price of competing fuels. Direct-use has remained fairly steady over the 30-year period at 10% growth annually. The majority of the increase has been due to geothermal heat pumps. At the

start of this 30-year period, only ten countries reported electrical production and/or direct utilization from geothermal energy. By the end of this period, 72 countries reported utilizing geothermal energy. This is over a seven-fold increase in participating countries. At least another 10 countries are actively exploring for geothermal resources and should be online by 2010.

Developments in the future will include greater emphases on combined heat and power plants, especially those using lower temperature fluids down to 100°C. This low-temperature cascaded use will improve the economics and efficiency of these systems, such as shown by installations in Germany and Austria and at Chena Hot Springs, Alaska. At the other end of the scale the Iceland Deep Drilling Project aims at testing whether it is feasible to extract supercritical fluids at 450–600°C from the deeper parts of the geothermal reservoirs. Also, there is increased interest in agriculture crop drying and refrigeration in tropical climates to preserve products that might normally be wasted. Finally, the largest growth will include the installation and use of geothermal heat pumps, as they can be used anywhere in the world, as shown by the large developments in Switzerland, Sweden, Austria, Germany and the United States.

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