HISTORY, PRESENT UTILIZATION AND FUTURE PROSPECTS OF GEOTHERMAL ENERGY WORLDWIDE - 2006

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ABSTRACT

Geothermal energy has been used for centuries for bathing, cooking and space heating. More recently district heating and industrial processing along with geothermal heat pumps have become part of the direct-use mix. Geothermal electric power generation was started in Italy in 1904, with the first commercial plant on line in 1913. Total the installed capacity for direct use is 28,268 MWt producing 75,943 GWh/yr in 72 countries. The installed capacity for electric power is 8,933 MWe generating 56,786 GWh/yr in 24 countries. Energy savings amount to an equivalent 270 million barrels (41 million tonnes) of fuel oil.

Key Words: geothermal energy, direct-use, electric power, heat pumps, energy savings.

1. 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.

Other early uses included the geothermal water at Huaqingchi Hot Spring in China; where, a bathing and treatment facility was built in the Qin Dynasty (over 2,000 years ago), and a hot spring at Ziaotangshan near Beijing used for recreation for about 800 years by the royal family and other high-ranking officials in the Ming and Qing Dynasties. Spas were also popular in Mexico – Montezuma, the great Aztec leader, spent time at Agua Hedionda to recuperate from his strenuous duties; which was later developed into a fashionable spa by the Spaniards. Early industrial applications include chemical extraction from the natural manifestations of steam, pools and mineral deposits in the Larderello region of Italy. Serious industrial activity began only after the discovery of boric acid in the hot pools in 1777. The first attempt at using these minerals was made in 1810, and nine factories were built between 1816 and 1835. A flourishing chemical industry was in operation by the early 1900s. 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 going strong. The first geothermal district heating system in the United States was on Warm Springs Avenue in Boise, Idaho; built in 1892 to heat up to 450 homes, is still operating.

The first use of geothermal energy for electric power production started 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. 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. 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.

As described above, we know that there have been many countries where geothermal has been used in the past, but most of this utilization has not been documented. However, a recent publication: *Stories from a Heated Earth - Our Geothermal Heritage* (Cataldi, et al., 1999), describes many of these early uses prior to the industrial revolution. This publication covers more than 25 countries with historical information taken from the works of archaeologists, historians, geographers, anthropologists, scientists and engineers. Thus, we now have in a single reference documenting the early uses of geothermal energy -- from hot spring bathing to the use of geothermal material such as obsidian and tuff, along with the legends and myths associated with fumaroles, hot springs and volcanic eruption. These uses continue today with electric power generation, and space heating and cooling.

2. UTILIZATION IN 2005

Based on 68 country update papers submitted to the World Geothermal Congress 2005 (WGC2005) held in Turkey, the follow figures on worldwide geothermal electric and direct-use capacity, are reported. A total of 72 countries have reported some utilization from WGC2000 and WGC2005, electric, direct-use or both (Lund and Freeston, 2001; Lund, et al., 2005; Bertani, 2005) (Table 1).

Table 1. Total Geothermal Use in 2005

Use	Installed Power MW	Annual Energy Use GWh/yr	Capacity Factor	Countries Reporting
Electric Power	8,933	56,786	0.73	24
Direct-Use	28,268	75,943	0.31	72

The figures for electric power capacity (MWe) appear to be fairly accurate; however, several of the country's annual generation values (GWh) had to be estimated which amounted to only 0.5% of the total. The direct-use figures are less reliable and probably are understated by as much as 20%. The author is also aware of at least four countries, which utilize geothermal energy for direct-heat applications, but did not submit reports to WGC2005. The details of the present installed electric power capacity and generation, and direct-use of geothermal energy can be found in Bertani (2005), and Lund, Freeston and Boyd (2005). These data are summarized as follows:

Table 2. Summary of Regional Geothermal Use in 2005

	Electric Power		Direct-Use	
Region	% 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

A review of the above data shows that in electric power generation each major continent has approximately the same percentage share of the installed capacity and energy produced with North America and Asia having over 80% of the total. Whereas, with the direct-use figures, the percentages drop significantly from installed capacity and energy use for the Americas (32.3 to 16.7%) due to the high percentage of geothermal heat pumps with low capacity factor for these units in the United States. On the other hand, the percentages increased for the remainder of the world due to a lesser reliance on geothermal heat pumps, and the greater number of operating hours per year for these units.

2.1 Electric Power Generation

Electric power has been produced from geothermal energy in 27 countries; however, Greece, Taiwan and Argentina have shut down their plants due to environmental and economic reasons. Since 2000 the installed capacity in the world has increased almost 1,000 MWe. Since 2000, additional plants have been installed in Costa Rica, in France at Guadeloupe, Iceland, Indonesia, Kenya, Mexico, and Philippines. Germany has installed a 210-kWe binary plant at Neustadt Glewe and a 6-MWe plant has been installed on Papua New Guinea to generate electricity for a remote mine. Russia has completed a new 50-MWe plant on Kamchatka. The operating capacity in the United States has increased since 1995 due to completion of the two effluent pipelines injecting treated sewage water at The Geysers. In an attempt to bring production back, the Southeast Geysers Effluent Recycling Project is now injecting 340 l/s of treated wastewater through a 48-km long pipeline from Clear Lake, adding 77 MWe. A second, 66-km long pipeline from Santa Rosa was placed on-line in 2004, injecting 480 l/s that are projected to add another 100 MWe to The Geyser's capacity.

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 (Bertani, 2005)(Table 3):

Table 3. National and Regional Geothermal Power Contributions

Country or Region	% of National or Regional Capacity (MWe)	% of National or Regional Energy (GWh/yr)
Tibet	30.0	30.0
San Miguel Island, Azores	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

The worldwide installed capacity has the following distribution: 29% dry steam, 37% single flash, 25% double flash, 8% binary/combined cycle/hybrid, and 1% backpressure (Bertani, 2005).

A recent development was the dedication of a 200 kW binary power generator at Chena Hot Springs in Alaska in July of 2006. This unit uses the lowest temperature geothermal resource in the world for power generation at 74°C from United Technologies Corporation unit. It has the advantage of using cold river water at 4°C for the condenser which provides a large temperature difference (delta T) for maximum efficiency (Lund, 2006).

2.2 Direct Utilization

The world direct utilization of geothermal energy is difficult to determine; as, there are many diverse uses of the energy and these are sometimes small and located in remote areas. Finding someone, or even a group of people in a country who are knowledgeable on all the direct uses is difficult. In addition, even if the use can be determined, the flow rates and temperatures are usually not known or reported; thus, the capacity and energy use can only be estimated. This is especially true of geothermal waters used for swimming pools, bathing and balneology. Thus, it is difficult to compare changes from one report to the next. This was especially true of Japan and Hungary in the WGC2000 country updates, as a significant portion of this use was not reported, and was obtained from other sources. For this reason, the values reported in Lund and Freeston (2001), have been updated for this report based on data for WGC2005 (Lund, et al., 2005).

One of the significant changes for WGC2005 was the increase in the number of countries reporting use. Fourteen countries were added to the list in the current report as compared to 2000. In addition, the author is aware of four countries (Malaysia, Mozambique, South Africa, and Zambia) that have geothermal direct-uses, but did not provided a report for WGC2005. Thus, there are at least 76 countries with some form of direct utilization of geothermal energy.

Another significant change from 2000 is the large increase in geothermal (ground-source) heat pump installations. They increased by 198% (24% annual growth) in capacity and 272% (30% annual growth) over the five-year period to the year 2005. At present (2005), they are the largest portion of the installed capacity (56.5%) and 33.2% of the annual energy use. The actual number of installed units is around 1,700,000 in 33 countries, mostly in the United States and Europe; however, the data are incomplete. The equivalent number of 12-kWt units installed (the average size) is approximately 1,300,000. The equivalent number of full-load heating operating hours per year varies from 1,200 in the U.S., to over 6,000 in Sweden and Finland, with a worldwide average of 2,200 full-load hours/year.

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.

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 86 % of the country's space heating needs, which is important since heating is required almost all year and saves about 100 million US$ in imported oil. Turkey has increased their installed capacity over the past five years from 820 MWt to 1,495 MWt, most for district heating systems. This supplies heat to 103,000 equivalent residences. The Turkish projection for 2010 is 3,500 MWt, which will heat an equivalent 500,000 residences or about 30% of the residences in the country.

3. ENERGY SAVINGS

The total geothermal electricity produced in the world is equivalent to saving 96.6 million barrels (14.5 million tonnes) of fuel oil per year (generating electricity with a 0.35 efficiency factor). This produces a savings of between 3 (natural gas), 13 (oil) or 15 (coal) million tonnes of carbon pollution annually. The total direct-use and geothermal heat pump energy use in the world is equivalent to savings of 129.2 million barrels (19.4 million tonnes) of fuel oil per year (generating electricity with a 0.35 efficiency factor). This produces a savings of between 4 (natural gas), 17 (oil) or 19 (coal) million tonnes of carbon pollution annually. If the replacement energy for direct-use was provided by burning the fuel directly, then about half this amount would be saved in heating systems (35% vs. 70% efficiency). If the savings in the cooling mode of geothermal heat pumps is considered, then this is equivalent to an additional savings of 44.7 million barrels (6.7 million tonnes) of fuel oil per year or from 1 (natural gas), 7 (oil), or 8 (coal) million tonnes of carbon pollution annually.

The equivalent savings in the production of CO_2 from geothermal electricity production from fuel oil is 51 million tonnes and from direct-use 67 million tonnes. The corresponding figures for natural gas and coal are 12 and 59 million tonnes for electricity, and 16 and 78 for direct-use (at 35% plant efficiency). Similar numbers of natural gas, oil and coal can be determined for sulfur oxides (SO_x) and nitrogen oxides (NO_x) at 0, 0.3 an 0.3 million tonnes and 2.8, 9.6 and 9.6 thousand tonnes respectively for electricity, and 0, 0.5 and 0.5 million tonnes and 3.8, 12.4 and 12.4 thousand tonnes respectively for direct-use (Goddard and Goddard, 1990). For direct-use, the values would be approximately half if the heat energy was used directly instead of being provided by electricity.

In total, the savings from present worldwide geothermal energy production, both electric and direct-use, is summarized in Table 4.

Table 4. Energy and Greenhouse Gas Savings from Geothermal Energy Production

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
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 injected, the above pollutants are essentially eliminated.

4. CONCLUSIONS

Geothermal growth and development of 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 slow down 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 those installed in Germany and Austria. 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.

It is difficult to make projections into the future, but based on trends over the past 30 years and anticipated increases of fossil fuel costs that are now over US$ 60 per barrel; the following two scenarios can be attempted. Scenario I assumes a conservative increase of only 5% annually and Scenario II assume the more optimistic trend of 10% annual increase.

Geothermal energy certainly has the potential to achieve these numbers, and if the emphasis on reducing greenhouse gases and particulate emissions continues, then geothermal energy should be an important part of any future energy mix.

Table 5. Projected Geothermal Development for 2010 and 2015

	Scenario I (5%/yr)				Scenario II (10%/yr)			
	2010		2015		2010		2015	
	MW	TWh/yr	MW	TWh/yr	MW	TWh/yr	MW	TWh/yr
Electric Power	11,400	73	14,600	93	14,400	92	23,200	148
Direct-Use	36,100	97	46,000	124	45,500	122	73,300	197

REFERENCES

Bertani, R., 2005. "World Geothermal General 2001-2005 -- State of the Art." *Geothermics*, Vol 34, No. 6 (Dec.), Elsevier, Amsterdam, Netherlands, pp. 651-690.

Cataldi, R., S. Hodgson and J. Lund (editors), 1999. *Stories from a Heated Earth – Our Geothermal Heritage*. Geothermal Resources Council, Davis, CA, p. 569

Goddard, W. B. and C. B. Goddard, 1990. "Energy Fuel Sources and Their Contribution to Recent Global Air Pollution Trends." Geothermal Resources Council *Transactions*, v. 14, Davis, CA, pp. 643-649.

Lund, J. W., 2006. "Chena Hot Springs" Geo-Heat Center Quarterly Bulletin, v. 27, n. 3 (September), Klamath Falls, Oregon, pp. 2-4.

Lund, J. W., D. H. Freeston and T. L. Boyd, 2005. "Worldwide Direct-Uses of Geothermal Energy 2005." *Geothermics*, Vol. 34, No. 6 (Dec.), Elsevier, Amsterdam, Netherlands, pp. 691-727.

Lund, J. W. and D. H. Freeston, 2001. "World-Wide Direct Uses of Geothermal Energy 2000." *Geothermics*, v. 30, n.1, Elsevier, Oxford, UK, pp. 29-68 (updated and revised).