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# WORLD STATUS OF GEOTHERMAL ENERGY USE OVERVIEW 1995-1999

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## 1. INTRODUCTION

Early humans probably used geother-mal 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 recuperated 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 Ro-man 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 discus-sions were the social custom of the day. This custom has been extended to geother-mal spas in Japan, Germany, Iceland, countries of the former Austro-Hungarian empire, the Americas and New Zealand.

Other early uses included the geother-mal water at Huaqingchi Hot Spring in Chi-na; where, a bathing and treatment facility was built in the Qin Dynasty (over 2,000 years ago), and a hot spring at Ziaotang-shan near Beijing used for recreation for about 800 years by the royal family, and other high-ranking officials in the Ming and Qing Dynasties. Early industrial applica-tions include chemical extraction from the natural manifestations of steam, pools and mi-neral 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 1900's. At Chaudes-Aigues in the heart of France, the world's first geothermal district heating system was started in the 14$^{th}$ century and is still going strong.

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 public-cation (1999): *Stories from a Heated Earth - Our Geothermal Heritage* (edited by R. Cataldi, S. Hodgson and J. Lund) 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, his-torians, geographers, anthropologists, sci-entists 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 erup-tion. These uses continues today with elec-tric power generation, and space heating and cooling.

## 2. DEVELOPMENTS IN THE 20$^{TH}$ CENTURY

### 2.1 Electric Power Generation

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 po-wer plant (250 kWe) was commissioned in 1913 at Larderello. These developments were followed by Wairakai, New Zealand in 1958; an experimental plant at Pathe, Mexico in 1959; and at The Geysers in the United States in 1960. The first internati-onal geothermal meeting to report on geo-thermal utilization was the UN Conference on New Sources of Energy held in Rome in 1961 where developments in Italy, New Zealand, USA and Iceland were discussed (Smith, 1964). At that time, Iceland was proposing a plant at Hveragerdi and the experimental installation at Pathe was not mentioned. This was followed by the UN Symposium on the Development and Utili-zation of Geothermal Resources at Pisa in 1970 (Facca, 1970). Based on these re-ports and subsequent reports presented at the 2nd UN Symposium on the Development and Use of Geothermal Resources at San Francisco in 1975 (Armstead, 1975a), the GRC Annual meetings (1981, 1985 and 1990) (DiPippo, 1981 and 1985; Huttrer, 1990), and at the World Geothermal Con-gress in Florence in 1995 (Huttrer, 1995), along with the current report by Huttrer (2000) the development of geothermal electric power is presented in Table 1.

Table 1. Worldwide Development of Geothermal Electric Power

| Year | Installed MWe | Energy GWh/yr | Number | Participants of Countries (Lund) |
|---|---|---|---|---|
| 1940 | 130 | | 1 | Italy |
| 1950 | 293 | | 1 | Italy |
| 1960 | 386 | 2,600 est. | 4 | + NZ, Mexico, & USA |
| 1970 | 678 | 5,000 est | 6 | + Japan & USSR |
| 1975 | 1,310 | | 8 | + Iceland & El Salvador |
| 1980 | 2,110 | | 14 | + China, Indonesia, Kenya, Turkey, Philippines, & Portugal |
| 1985 | 4,764 | | 17 | + Greece, France & Nicaragua |
| 1990 | 5,832 | | 19 | + Thailand, Argentina, & Australia - Greece |
| 1995 | 6,797 | | 20 | + Costa Rica |
| 2000 | 7,974 | 49,261 | 21 | + Guatemala & Ethiopia, Argentina |

Unfortunately, no estimates were ma-de of the energy produced during the period 1975 to 1995. There also appears to be slight differences in the installed MWe num-bers between various authors.

The growth rate for installed electric capacity started slowly at 5.6% annually from 1940 to 1960, depressed by World War II and the destruction of the Italian fields at the end of the war. From 1960 to 1970, the rate increased slightly to 5.8% annually, and then picked up dramatically from 1970 to 1980 at 12.0%, and 1980 to 1990 at 10.7% - the growth years for geo-thermal energy. From 1990, the rate has dropped to 3.2% per year as influenced by the slowdown in the world economy, espe-cially in southeast Asia, and the availability of cheap fossil fuels. The growth rate over the past 30 years has averaged 8.6% compounded annually.

The 1961 Rome Conference reported the following figures on geother-mal electrical costs (Smith, 1964):

| Geothermal Field | Installed cost/ kW | Energy cost/kWh (net output) |
|---|---|---|
| The Geysers | US$152 | US$0.0025 |
| Wairakei | US$227 | US$0.0046 |
| Larderello | US$138 | US$0.0012 |
| Iceland (proposed) | US$364 | US$0.0079 |

This compares at that time with US$117 per installed kW and US$0.0012 per kWh of net output for two 150 MW units using “traditional fuels.”

DiPippo (1998), estimates the current capital cost for U.S. geothermal plants as follows:

| Geothermal Field or type | Period | Installed cost/kW |
|---|---|---|
| The Geysers | 1980-83 | US$ 414 - 780* |
| Single Flash | 1984-88 | US$ 2,500 - 3,000 |
| Double Flash | 1985-88 | US$ 1,900 - 2,700 |
| Binary | 1987-93 | US$ 3,030 - 4,000 |

* The Geyser's cost includes plant cost only; all the rest include field development.

Estimates of the current cost of producing power is as follows (Wright, 2000)

| | |
|---|---|
| The Geysers: | 1. 5 to 2.5 cents/kWh |
| Single flash: | 2 to 4 cents/kWh |
| Binary: | 3 to 5 cents/kWh (heavily dependent on size) |
| New construction: | 5 to 6.5 cents/kWh |

## 2.2 Direct Heat Utilization

Even though the direct-use of geo-thermal energy has a much longer history of use than electric power generation, the numbers are less reliable. In fact, it is difficult to compare install-led capacity and annual use, due to the inclusion or exclu-sion of bathing, swimming and bal-neology figures. This has not been consistent, as in the early years this use was not included, but in the current report it is included (1985 on - but not in a consistent manner). Also, values prior to 1970 were not summarized and up to 1980 could only be estimated from country descriptions in rapporteur reports. The early reports did not include China, a large user of geo-thermal energy for direct use, due to the political situation at the time, and also did not include the United States; even though, a geothermal district heating system had been installed in Boise, Idaho in 1890 and individual wells had been utilized in Klamath Falls since the 1930s for home heating. Finally, since many direct-uses are small and not concentrated in one place, they are often overlooked by authors reporting on their country.

As a result, the 1961 UN conference in Rome reported only developments in Ice-land, New Zealand, Italy, Japan and Kenya (Bodvarsson, 1964). This report described district heating of 45,000 houses in Rey-kjavik, use of 1,000 wells in Rotorua for space heating, heating of 95,000 $m^2$ of greenhouses in Iceland, production of 21,000 tons/yr of salt in Japan, the pulp and paper plant at Kawerau, the chemical In-dustry at Larderello, pig raising in New Zealand, and chicken hatching in Kenya. The 1970 report of the UN meeting in Pisa included descriptions from Hungary, Ice-land, Italy, Japan, New Zealand, and the USSR (Einarsson, 1970). As mentioned above, China and the United States were not included. The data in Table 2 is based on information in the 1970 UN Conference in Pisa, a report by Law-rence Livermore Laboratory in 1975 (Howard, 1975), the second UN Conference in San Francisco (Armstead, 1975b), papers by Lund in 1979 and 1982, reports from the GRC annual meetings in 1985 and 1990 (Gudmundsson, 1985: Frees-ton,1990), the World Geother-mal Congresses in 1995 in Italy (Freeston, 1996), and the current paper by Lund and Freeston (2000). Starting in 1995, geother-mal heat pumps (ground-source heat pumps) were included in the reports and are now a significant part of the totals.

The large increase in installed capacity between 1980 and 1985 is due to the inclusion of pool heating at spas in Japan along with the first available data from China.

The annual growth rate from 1970 to 1980 was 9.3%, from 1980 to 1990 was 15.2% (which was strongly influenced by data from Japan and China), and from 1990 to 2000 was 4.9%. The overall growth rate over the past 30 years has averaged 9.7% compounded annually. The large increases from 1970 to 1990 (average annual of 12.2%) and the recent reduction from 1990 to present, was influenced by the same factors as in the case of the electric power generation, except that the availability of cheap fossil fuels in recent years had a much larger effect than the economic slowdown in southeast Asia.

Table 2. Worldwide Development of Geothermal Direct Heat Utilization

| Year | Installed MWt | Energy GWh/yr | Number of countries | Participants reporting |
|---|---|---|---|---|
| 1960 | | | 5 | Iceland, Italy, New Zealand, Japan and Kenya |
| 1970 | 800 est. | 2,200 est. | 6 | + Hungary& USSR - Kenya |
| 1975 | 1,300 est | | 10 | + France, Philippines, Turkey & USA |
| 1980 | 1,950 | | 14 | + Austria, Czechoslovakia, Germany & Taiwan |
| 1985 | 7,072 | 23,960 | 24 | + Australia, Canada, China,Columbia, Denmark, Mexico, Poland, Romania, Switzerland & Yugoslavia |
| 1990 | 8,064 | | 30 | + Algeria, Belgium, Bulgaria, Ethiopia, Greece, Guatemala, Thailand, & Tunisia - some countries not reporting |
| 1995 | 8,664 | 31,236 | 30 | Argentina, Georgia, Israel, Macedonia, Serbia, Slovakia, & Sweden - some countries not reporting |
| 2000 | 12,965 | 43,746 | 55 | see Lund and Freeston (2000) |

Reported cost for district heating in Iceland at the 1961 Rome Conference was (Smith, 1964):

| | |
|---|---|
| Production cost: | US$0.30 to 0.48 per Gcal (0.026 to 0.041 cents/kWh) |
| Total cost to consumer: | US$4.00 per Gcal (about 60% of the heating cost based on oil) (0.344 cents/kWh) |

Examples of current district heating costs are 0.23 to 0.42 cents/1000 kcal (0.27 to 0.49 cents/kWh) in Turkey, compared to 3.4 cents/kWh for natural gas and 11.2 cents/kWh for electricity based heating (Mertoglu, et al., 1999). The Klamath Falls, Oregon district heating system charges 1.6 to 2.0 cents/kWh (Lund, 1999). This is 50% - 80% of the natural gas cost, depending upon the efficiency of the gas conversion, and the comparable cost for electricity in the city is 5.5 cents/kWh. Construction costs for heating in Turkey are 850 to 1,250 US$/kW and the cost per residence is around 2,000 US$, an investment that is amortized in 5 to 10 years. Stefansson (1999) reports an average consumer heat-ing cost in 1995 for four European countries as 2.4 cents/kWh.

## 1. UTILIZATION IN 2000

Based on 60 country update papers submitted to the World Geothermal Congress 2000 supplemented with other current reports, the follow figures on worldwide geothermal electric and direct-use capacity, and energy use was determined. A total of 59 countries reported some utilization, either electric, direct-use or both (Table 3).

The figures for electric power capacity (MW) appear to be fairly accurate; however, several of the country annual generation values (GWh) had to be estimated which amounted to only 0.5% of the total.

Table 3. Total Geothermal Use in 2000

| Use | Installed Power MW | Annual Energy Use GWh/yr | Capacity Factor | Countries Reporting |
|---|---|---|---|---|
| Electric Power | 7,974 | 49,261 | 0.71 | 21 |
| Direct-Use | 17,175 | 51,428 | 0.34 | 55 |

The direct-use figures are less reliable and probably are understated by as much as 20%. The author is also aware of at least seven countries which utilize geothermal energy for direct-heat applications, but did not submit reports to WGC2000. The details of the present electric power genera-tion and direct-use of geothermal energy can be found in Huttrer (2000), and Lund and Freeston (2000). These data are summarized as follows:

Table 4. Summary of Regional Geothermal Use in 2000

| | Electric Power | | | | Direct-Use | | | |
|---|---|---|---|---|---|---|---|---|
| Region | MWe | % | GWh/yr | % | MWt | % | GWh/yr | % |
| Africa | 53.5 | 0.7 | 396.5 | 0.8 | 121.0 | 0.7 | 491.7 | 1.0 |
| Americas | 3,389.9 | 42.5 | 23,341.9 | 47.4 | 5,954.5 | 34.7 | 7,265.9 | 14.1 |
| Central | 406.9 | | 2,190.9 | 4.2 | 34.8 | | | |
| North* | 2,983.0 | | 21,151.0 | | 5,907.8 | | 7,012.9 | |
| South | 0 | | 0 | | 42.5 | | 218.1 | |
| Asia** | 3,095.3 | 38.8 | 17,509.5 | 35.5 | 5,150.5 | 30.0 | 22,532.0 | 43.8 |
| Europe | 998.2 | 12.5 | 5,744.6 | 11.7 | 5,630.4 | 32.8 | 19,089.5 | 37.1 |
| Central/East | 0 | | 0 | | 1,139.4 | | 4,054.9 | |
| West/North*** | 975.2 | | 5,659.6 | | 3,871.5 | | 11,036.0 | |
| CIS**** | 23.0 | | 85.0 | | 557.0 | | 3,455.6 | |
| Oceania | 437.2 | 5.5 | 2,268.9 | 4.6 | 318.3 | 1.8 | 2,048.7 | 4.0 |
| TOTAL | 7,974.1 | | 49,261.4 | | 17,174.7 | | 51,427.8 | |

***** includes Mexico
** includes Turkey
*** includes Azores and Guadelope
**** includes Russia and Georgia

The data for Japan and Hungary were modified from Lund and Freeston (2000) based on revised estimates for bathing and swimming pools (Fridleifsson, 2000).

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 almost 80% of the total. Whereas, with the direct-use figures, the percentages drop significantly from installed capacity and energy use for North America (37.4 to 14.1%) due to the high percentage of geo-thermal heat pumps with low capacity factor for these units. On the other hand, the percen-tages increased for the remainder of the world due to a lesser reliance on geo-thermal heat pumps, and the greater number of operating hours per years for these units.

### 3.1 Electric Power Generation

Electric power has been produced from geothermal energy in 23 countries; however Greece and Argentina have shut down their plants due to environmental and economic rea-sons. Since 1995, Ethiopia has joined the ranks of power producers with a 8.5 MW (gross) binary plant installed at Aluto, Langano, and

Guatemala has seen the installation of 5 MWe at Amatitlan and 27.7 MWe at Zunil. The ins-talled capacity in the United States has been reduced by 589 MWt since 1995 due to dec-lines in steam output in The Geysers. In an at-tempt 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 54 MW. A second, 66-km long pipeline from Santa Rosa is planned.

The countries with an increase of over 50% in installed capacity over the period 1995-2000 are Iceland, Portugal (Azores), Costa Rica, Russia, Indonesia, Philippines, El Salvador and New Zealand.

Based on country update papers for WGC2000, the projected installed capacity for 2005 is 11,414 MWe or a 43% increase (7.4% annual compounded growth rate) (Huttrer, 2000). This compares to 17% increase (3.1% annual) growth from 1995 to 2000. If the data from the United States were not considered due to its significant decline, the growth would have been 43% (7.4% annual). The same as predicted for the next five years.

One of the more significant aspects of geothermal power development, is the size of its contribution to certain national capacity. The following countries lead in this contribution with more than 5% of the electrical energy supplied by geothermal power (Huttrer, 2000)(Table 5):

Table 5. National Geothermal Contribution

| Country | % of National Capacity (MWe) | % of National Energy (GWh/a) |
|---|---|---|
| Philippines | 16.2* | 21.5 |
| El Salvador | 15.4 | 20.0 |
| Nicaragua | 17.0 | 17.2 |
| Iceland | 13.0 | 14.7 |
| Costa Rica | 7.8 | 10.2 |
| Kenya | 5.3 | 8.4 |
| New Zealand | 5.1 | 6.1 |
| Indonesia | 3.0 | 5.1 |

*Based on 1998 data from the EIA, Washington, D.C.

### 3.2 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 had to be obtained from other sources. For this reason, the values reported in Lund and Freeston (2000), have been updated for this report.

One of the significant changes for WGC2000 was the increase in the number of countries reporting use. Approximately 25 countries were added to the list in the current report as compared to 1995. In addition, the author is aware of seven countries (Armenia, Ethiopia, Malaysia, Mozambique, South Africa, Yemen and Zambia) that have geothermal direct-uses, but have not provided a report for WGC2000. Thus, there are at least 62 countries with some form of direct utilization of geothermal energy.

Another significant change from 1995 is the large increase in geothermal (ground-source) heat pump installations. They increased by 269% (30% annual growth) in capacity and 59% (10% annual growth) over the five year period. At present, they are the largest portion of the installed capacity (42%) and 14% of the annual energy use. The actual number of installed units is around 500,000 in 26 countries, mostly in the United States and Europe; however, the data are incomplete. The equivalent number of 12 kW units installed (the average size) is slightly over 570,000. The equivalent number of full-load opera-ting hours per year varies from 1,000 in the U.S., to over 6,000 in Sweden and Finland.

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 countries space heating needs, which is important since heating is required almost all year and saves about 100 million US$ in imported oil (Ragnarsson, 2000). Turkey has increased their installed capacity over the past five years from 140 MWt to 820 MWt, most for district heating systems. This supplies heat to 51,600 equivalent residences and engineering design to supply a further 150,000 residences with geothermal heat is complete. The Turkish projections for 2010 is 3,500 MWt which will heat an equivalent 500,000 residences or about 30% of the residences in the country (Batik, et al., 2000).

## 1. ENERGY SAVINGS

The total geothermal electricity produced in the world is equivalent to saving 83.3 million barrels (12.5 million tonnes) of fuel oil per year (generating electricity with a 0.35 efficiency factor). This produces a savings of between 2.58 (natural gas), 11.03 (oil) or 12.81 (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 87.5 million barrels (13.1 million tonnes) of fuel oil per year (generating electricity with a 0.35 efficiency factor). This produces a savings of between 2.69 (natural gas), 11.52 (oil) or 13.37 (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 8.0 million barrels (1.2 million tonnes) of fuel oil per year or from 0.27 (natural gas), 1.18 (oil), or 1.37 (coal) million tonnes of carbon pollution annually. The above data is based on information provided by LLL (1997).

The equivalent savings in the production of $CO_2$ from geothermal electricity production from fuel oil is 40.2 million tons and from direct-use 42.0 million tonnes. The corresponding figures for natural gas and coal are 9.5 and 46.9 million tonnes for electricity, and 9.9 and 49.0 for direct-use (at 35% plant efficiency). Similar numbers of natural gas, oil and coal can be deter-mined for sulfur oxides ($SO_x$) and nitrogen oxides ($NO_x$) at 0, 0.25 an 0.26 million tonnes and 2.2, 7.6 and 7.6 thousand tonnes respectively for electricity, and 0, 0.26 and 0.28 million tonnes and 2.3, 7.9 and 7.9 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.

In total, the savings from present worldwide geothermal energy production, both electric and direct-use, is summarized in Table 6 and Table 7

Table 6. Fuel Oil and Carbon Savings from Geothermal Energy Production.

| Fuel Oil ($10^6$) | | Carbon ($10^6$ t) | | |
|---|---|---|---|---|
| Barrels | Tonnes | NG | Oil | Coal |
| 179.1 | 26.7 | 5.56 | 23.80 | 27.64 |

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.

## CONCLUSIONS

Geothermal growth and development has increased significantly over the past

30 years approaching 15% annually in the early part of this period, and dropping to below 5% annually in the last ten years due to an economic slow down in the Far East and the low price of competing fuels. At the start of this 30-year period, only eight countries reported electrical production and/or direct utilization from geothermal energy. By the end of this period, 59 countries reported utilizing geother-mal energy and another seven are known to be using this resource. This is over an eight-fold increase in participating countries. At least another 10 countries are actively exploring for geothermal resources and should be online by 2005.

Table 7. $CO_2$, $SO_x$ and $NO_x$ Savings from Geothermal Energy Production

| $CO_2$ ($10^6$ t) | | | $SO_x$ ($10^6$ t) | | | $NO_x$ ($10^3$ t) | | |
|---|---|---|---|---|---|---|---|---|
| NG | Oil | Coal | NG | Oil | Coal | NG | Oil | Coal |
| 19.4 | 82.2 | 95.9 | 0 | 0.51 | 0.54 | 4.5 | 15.5 | 15.5 |

It is difficult to make projections into the future, but based on trends over the past 30 years and anticipated increases in fossil fuel costs, the following two scenarios can be attempted. Scenario I assumes that the approximate 10% annual increase (typical for 1970 - 1990) will continue, and Scenario II assume the more optimistic trend of 15% 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.

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Table 8. Projected Geothermal Development for 2005 & 2010

| | Scenario I | | | | Scenario II | | | |
|---|---|---|---|---|---|---|---|---|
| | 2005 | | 2010 | | 2005 | | 2010 | |
| | MW | TWh | MW | TWh | MW | TWh | MW | TWh |
| Electric Power | 12,850* | 79 | 20,700 | 128 | 16,050 | 99 | 32,250 | 199 |
| Direct-Use | 27,650 | 83 | 44,550 | 133 | 34,550 | 103 | 69,500 | 208 |

* 11,414 MW estimated for 19 countries (Huttrer, 2000).


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