THE ROLE OF GEOTHERMAL ENERGY IN THE WORLD

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INTRODUCTION

Geothermal energy, in the broadest sense, is the natural heat of the earth. Immense amounts of thermal energy are generated and stored in the earth's core, mantle, and crust. The heat is transferred from the interior towards the surface mostly by conduction, and this conductive heat flow makes temperatures rise with increasing depth in the crust on average 25 - 30°C/km. This is called the geothermal gradient. The recoverable thermal energy theoretically suitable for direct applications has been estimated at 2.9 x 10^{24}> Joules, which is about 10,000 times the present annual world consumption of primary energy without regard to grade (Armstead, 1983). Most of the earth's heat is, however, far too deeply buried to be tapped by man, even under the most optimistic assumptions of technological development. Geothermal energy has at present a considerable economic potential only in areas where thermal water or steam is concentrated at depths less than 3 km (1.9 mi) in restricted volumes analogous to oil in commercial oil reservoirs. The drilling technology is similar for geothermal fluid as for oil. But as the energy content of a barrel of oil is much greater than an equivalent amount of hot water, the economic requirements for permeability of the formations and the productivity of the geothermal wells are much higher than for oil wells. Geothermal production wells are commonly 2 km (1.2 mi) deep, but rarely much over 3 km (1.9 mi) at present.

Exploitable geothermal systems occur in a number of geological environments. High-temperature fields used for conventional power production (with temperature above 150°C) are largely confined to areas with young volcanism, seismic and magmatic activity. Low-temperature resources can, on the other hand, be found in most countries. They are formed by the deep circulation of meteoric water along the faults and fractures, and by water residing in high-porosity rocks, such as sandstone and limestone at sufficient depths for the water to be heated by the earth's geothermal gradient. Such formations are widespread in all continents, and for example in China, geothermal water can be produced from drillholes in most provinces. The heat resources in hot, but dry, (low porosity) rock formations are found in most countries, but are as yet not economically viable for utilization.

Geothermal utilization is commonly divided into two categories: electricity production and direct application. Conventional electric power production is limited to fluid temperatures above 150°C, but considerably lower temperatures can be used with the application in binary fluids (outlet temperatures commonly about 70°C). The ideal inlet temperature into houses for space heating is about 80°C; but, by application of larger radiators in houses/or the application of heat pumps or auxiliary boilers, thermal water with temperatures only a few degrees above the ambient temperature can be used beneficially. The use of ground-source heat pumps for space heating and space cooling is, for example, expanding at a very fast rate both in the USA and in Europe. The direct utilization of geothermal heat utilizes mostly known technology and straightforward engineering. However, in some cases, the technology is complicated by dissolved solids or gases in the geothermal fluid. The technology, reliability, economics and environmental acceptability of geothermal steam and water has been demonstrated throughout the world.

WORLD DISTRIBUTION OF GEOTHERMAL UTILIZATION

The International Geothermal Association (IGA) was founded in 1989 and has about 2,000 members in all parts of the world. At the World Geothermal Congress (WGC'95) convened by the IGA in Florence (Italy) in May 1995, there were participants from over 70 countries, and country updates were presented from 48 countries. These were summarized by Freeston (1996) and Huttrer (1995). Evaluating available data after the WGC'95, Stefansson (1995) described the status of geothermal development in 83 countries and quantified the use of geothermal energy in 47 of these. He reported the worldwide installed capacity for electricity generation 6,543 MW_e and the installed capacity for direct use 9,047 MW_t. The figures for the produced (or consumed) energy are, however, quite similar. Annually, about 38 TWh are generated in geothermal power plants; whereas, the annual use of direct heat amounts to about 34 TWh (Stefansson, 1995). Table 1 shows the installed capacities and energy production in 1994 (electricity generation and direct use) in the 25 leading geothermal countries around the world (data from Stefansson, 1995).

Electricity is being produced from geothermal resources in 21 countries. There are 15 countries with an installed capacity over 10 MW_e, thereof 6 industrialized countries (total installed capacity 4,088 MW_e, Russia included), and 9 developing countries (total installed capacity 2,441 MW_e). There are 8 countries (4 developing and 4 industrialized) with over 100 MW_e, and 4 with over 500 MW_e installed (Italy 626 MW_e, Mexico 753 MW_e, Philippines 1,051 MW_e, and USA 2,817 MW_e).

Quantified direct use of geothermal resources is known in some 35 countries (Stefansson, 1995). There are 30 countries with an installed capacity of over 10 MW_t, thereof 12

Table 1. Electricity Generation and Direct Use of Geothermal Energy in 1994

	Electricity Generation		Direct Utilization	
	Installed Capacity MW_e	Annual Output GWh	Installed Capacity MW_e	Annual Output GWh
China	28	98	2,143	5,527
Costa Rica	60	447	--	--
El Salvador	105	419	--	--
France	4	24	456	2,006
Georgia	--	--	245	2,136
Hungary	--	--	638	2,795
Iceland	50	265	1,443	5,878
Indonesia	309	1,048	--	--
Italy	626	3,419	308	1,008
Japan	299	1,722	319	1,928
Kenya	45	348	--	--
Macedonia	--	--	70	142
Mexico	753	5,877	28	74
New Zealand	286	2,193	264	1,837
Nicaragua	70	--	--	--
Philippines	1,501	5,470	--	--
Poland	--	--	63	206
Romania	2	--	137	765
Russian Fed.	11	25	210	673
Serbia	--	--	80	600
Slovakia	--	--	100	502
Switzerland	--	--	110	243
Tunisia	--	--	90	788
Turkey	20	68	140	552
USA	2,817	16,491	1,874	3,859
Others	7	40	329	1,935
Total	6,543	37,952	9,047	33,514

industrialized countries (total 4,920 MW_t). There are 13 countries (2 developing, 4 central and eastern European, and 7 industrialized) with over 100 MW_t installed, and 4 countries with over 500 MW_t installed (China 2,143 MW_t, Hungary 638 MW_t, Iceland 1,443 MW_t, and USA 1,874 MW_t).

Based on this, one can generalize by saying that geothermal electricity production is equally common in industrialized and developing countries. Looking at the share of geothermally generated electricity in individual countries, it is clear that geothermal energy plays a much more significant role in the electricity production of the developing countries than the industrialized ones. Good examples of this are El Salvador, Kenya, Nicaragua, and the Philippines. In all of these countries, 10 - 20% of the electricity for the national grid is generated with geothermal steam. Costa Rica is likely to join this group of countries shortly, as Mainieri and Robles (1995) expect some 15% of the electricity of the country to be generated by geothermal in the year 2000. In Mexico, 4.6% of the electricity generated in 1994 was from geothermal (Quijano-Leon and Guiterrez, 1995). Geothermal electricity in Indonesia may reach a similar level (3 - 4%) in the next decade or so (Radja, 1995). Geothermal electricity is unlikely to be of equal significance for the energy sector of individual industrialized countries due to the high-electricity consumption per capita in these countries and the lack of sufficient geothermal resources. The only present exception to this statement is Iceland, where 5% of the electricity is being produced from geothermal (the remaining 95% by hydro).

The world distribution of direct utilization is different. With the exception of China, the direct utilization is a serious business mainly in the industrialized, and central and eastern European countries. This is to some extent understandable, as most of these countries have cold winters where a significant share of the overall energy budget is related to space heating. Furthermore, in many industrialized countries, the sun is not reliable for drying. Space heating is the dominant type of direct use (34%) of geothermal; but, other common types are bathing (14%), greenhouses (14%), heat pumps (13%) for air cooling and heating, fish farming (9%), and industry (9%). Freeston (1996), in his refined summary of the country updates of the WGC'95, states that it is evident from the papers that there is a large potential for the development of low-to-moderate enthalpy direct use across the world which is not being exploited due to financial constraints and low prices of competing forms of energy. The main potential for direct utilization in the developing countries is at present mainly in various drying processes (fruits, fish, etc.). Space cooling with geothermal energy will hopefully become an important sector for geothermal utilization in the future.

Electric generation cost with geothermal energy is commonly around 4 US cents/kWh. The production cost/kWh for direct utilization (space heating, horticulture, fish farming, industry, bathing, etc.) is highly variable, but commonly under 2 US cents/kWh.

Utilization of geothermal resources to supply electricity and direct heat is energy efficient and competitive with other energy sources both in terms of the economics and the thermodynamic efficiency. The cascade use of the thermal fluid, whereby the high-enthalpy fluid is used for electricity generation and the lower temperature fluid is passed through a series of different uses, is practiced in many countries (e.g., Iceland, Italy and Japan) raising the overall efficiency. There is also the prospect of extracting a number of valuable minerals from the thermal fluids. This is also done in an energy efficient manner.

COMPARISON WITH OTHER "NEW AND RENEWABLES"

Table 2 is compiled from the Survey of Energy Resources 1995 published by the World Energy Council in conjunction with the 16th World Energy Congress in Tokyo. Since the detailed data on the different energy resources and their application is given in the same units, the survey gives a good opportunity to compare the development of the different energy resources. The table shows the installed capacity (MW-electric) and the electricity production per year (GWh/y) for geothermal, wind, solar and tidal resources.

In comparison with wind, solar and tidal energy, geothermal is clearly an advanced energy source with 61% of the total installed capacity and 86% of the total electricity production of these four sources. The relatively high share in the electricity production reflects the reliability of geothermal plants which commonly have a load factor and availability factor of 80 - 90%. This demonstrates one of the strongest comparative points of geothermal energy (i.e., that it is available day in and day out throughout the year). It is not dependent on whether it is day or night as solar energy is, or whether the wind blows strongly or not. It has an inherent storage capability and can be used both for base load and peak power plants. However, in most cases, it is more economical to run the geothermal plants as base-load suppliers; but, turning the plants off during the rainy season, when hydropower plants have plenty of water, will in many cases serve to replenish the geothermal reservoir and lengthen its economically useful lifetime.

Table 2. Electricity From Four Energy Resources in 1994

	Installed Capacity		Production Per Year	
	MWe	%	GWh/y	%
Geothermal	6,456	61	37,976	86
Wind	3,517	33	4,878	11
Solar	366	3	897	2
Tidal	261	3	601	1
Total	10,600		44,352	

Source: WEC Survey of Energy Resources (WEC, 1995).

The question of geothermal resources being renewable can be debated. Due to the steady heat flow from the inner parts of the earth, geothermal resources can be regarded as renewable. But on the time scale normally used in human society, geothermal resources are not renewable. They are renewable only if the heat extraction rate does not exceed the replenishment rate. But the same can be said for fuel wood and many types of biomass. The tree that you burn is not renewable. It turns into energy, ash and gases; but, you can grow a new tree, given enough time. A geothermal system can in many cases be recharged as a battery.

Utilizing the natural flow from geothermal springs does not affect them. Exploitation through drill holes and by the application of downhole pumps nearly always leads to some physical or chemical changes in the reservoir and/or its near vicinity which lead to a reduction and may lead to the depletion of the geothermal resource so far as a particular energy utility is concerned. The key to a successful geothermal project is to secure by careful reservoir evaluation and monitoring that the geothermal reservoir will last through the lifetime (or at least the depreciation time) of the respective geothermal installations.

Fridleifsson and Freeston (1994) referred to geothermal resources as being sustainable resources, where by careful matching of utilization with field performance, the enthalpy, temperature, mass removed, reservoir pressure, etc., can achieve an equilibrium and performance can be maintained, at least over the life of the mechanical plant. This may mean that the initial performance of a plant may exceed the equilibrium condition and as the field is developed and utilized, a run down occurs in these parameters down to the equilibrium condition. Each field is likely to be unique in this respect, and its performance will depend on many factors, including the amount and quantity of the recharge if any, whether there is reinjection and where it is sited relative to the production zone, reservoir characteristics of permeability, porosity, temperature, etc.

Properly implemented, geothermal energy is a sustainable resource and benign to the environment. The emission of greenhouse gases is minimal compared to fossil fuel. The removal of hydrogen sulphide from high-temperature steam and the reinjection of spent geothermal fluids into the ground make the potential negative environmental effects negligible.

INVESTMENTS AND FUTURE DEVELOPMENT

At least 80 countries are potentially interested in geothermal energy development. Of these, some 50 have quantifiable geothermal utilization at present. A worldwide survey (Fridleifsson and Freeston, 1994) showed the total investments in geothermal energy during 1973-1992 to amount to approximately US $22 billion. During the two decades, 30 countries invested each over US $20 million, 12 countries over US $200 million, and 5 countries over US $1 billion. During the first decade, 1973-1982, public funding amounted to US $4.6 billion and private funding to US $3 billion. During the second decade, 1983-1992, public funding amounted to US $6.6 billion and private funding to US $7.7 billion. It is of special interest to note that the private investments in geothermal rose by 160%; whereas, the public investments rose by 43% for the period 1983-1992 as compared to 1973-1982 respectively. This shows the confidence of private enterprises in this energy source and demonstrates that geothermal energy is commercially viable.

The growth rate of geothermal development has in the past been significantly affected by the prices of the competing fuels, especially oil and natural gas, on the world market. As long as the oil and gas prices stay at the present level, it is rather unlikely that we will see again the very high annual growth rate for geothermal electricity of 17% as was the case during the oil crises in 1978-1985. The growth rate is, however, quite high due to the fact that geothermally generated electricity is the lowest cost option for many countries. In 1990, there were about 5,800 MW_e operational in electric power plants in the world, and about 6,800 MW_e in 1995. This gives a growth of about 16% over the period. The WGC'95 country reports summarized by Huttrer (1995) indicate that the world installed capacity may rise to some 10,000 MW_e by the year 2000. The present author, however, finds the figure likely to become closer to 8,500 MW_e with the largest additions (already planned or under construction) in the Philippines, Indonesia, Mexico, and Costa Rica. The participation of private operators in steam field developments through BOT (Build, Operate and Transfer), BOO (Build, Own and Operate) contracts and JOC (Joint Operation Contracts) have significantly increased the speed of geothermal development in countries such as the Philippines (Javeliana, et al., 1995) and Indonesia (Radja, 1995).

For the direct applications, the growth rate situation is more speculative at present, but again, highly affected by the competing prices of oil and gas on the world market. The large potential and the growing interest for the development of direct applications in China for fish farming, greenhouses and municipal space heating, and the great surge of installations of geothermal heat pumps in recent years exemplified by the USA, Switzerland, etc., give a cause for optimism for the growth rate of direct applications. This growth rate should perhaps be expected to be higher than that for electric generation, both because low-temperature geothermal resources are available in a much greater number of countries, and because direct application projects tend to be less capital intensive than the electric development. But private enterprise has, as yet, focussed more on electricity production for the national grids than on direct utilization which is commonly more site specific.

The introduction of CO_2 and other pollution taxes would significantly benefit geothermal development, as geothermal is one of the cleanest energy sources available on the world market. This may have an effect on the development rate. Such an effect is clearly seen from the financial incentive schemes recently introduced by several electric utilities in the USA encouraging house owners to use groundwater heat pumps for space cooling/heating purposes, and thus, reduce the peak loads on their electric systems. The Geothermal Heat Pump Consortium has recently established a US $100-million 6-year program to increase the geothermal heat pump unit sales from 40,000 to 400,000 annually, and thus, reduce greenhouse gas emissions by 1.5 million metric tonnes of carbon equivalent annually (Pratsch, 1996). One-third of the funding comes from the U.S. Department of Energy and the Environmental Protection Agency; whereas, two-thirds come from the electric power industry. The same type of development might be seen in other parts of the world in the next decade or two.

Geothermal exploration and exploitation requires skills from many scientific and engineering disciplines. Significant experience in geothermal exploration and development is available in some 30 countries (Fridleifsson, 1995). But the man-power resources are unevenly distributed in the world. A large number of geothermal experts have become redundant in several of the industrialized countries since the mid-1980s, and turned to other work. The developing countries have kept relatively more of their experts in geothermal work. Several developing countries have built up strong groups of geothermal professionals. Many of the key people of these groups have received training at the international geothermal schools operated in Iceland, Italy, Japan and New Zealand; but, most of the training has taken place on the job in the respective countries. The international geothermal schools have less than 60-fully funded places each year. More training is needed for people from many developing countries and the countries of central and eastern Europe at both professional and technician levels. In addition to long and short courses at the international schools, regional courses and specialized courses traveling from country to country should be considered. Many of these countries have completed initial surveys, and in some cases, have started utilization projects of their geothermal resources, and are at a stage of wishing to develop the resources using up-to-date technology. They are, however, handicapped both by the lack of finance and an infrastructure of trained personnel.

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