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PROSPECTS FOR GEOTHERMAL ENERGY WORLDWIDE IN THE NEW CENTURY

Ingvar B. Fridleifsson,
United Nations University Geothermal Training Programme,
Orkustofnun - National Energy Authority
Grensasvegur 9, 108 Reykjavik, Iceland

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ABSTRACT

The prospects for geothermal development in the new century are evaluated on basis of trends in the last three decades. The potential role of geothermal energy is analysed in view of the increased emphasis on reduction of greenhouse gases following the United Nations conferences on the environment in Rio (1991) and Kyoto (1997). A comparison is made of geothermal energy with other new and renewable energy sources. Geothermal energy, with its proven technology and abundant resources, can make a significant contribution towards reducing the emission of greenhouse gases worldwide. It is necessary, however, that governments implement a legal and institutional framework and fiscal instruments allowing geothermal resources to compete with conventional energy systems. Assuming the worldwide annual growth rate to continue at 9%, the electricity production may reach some 130 TWh in 2010, and 320 TWh in 2020. Assuming the annual growth rate for direct use to continue at 6%, the energy production may reach some 80 TWh in 2010, and 140 TWh in 2020. Recent developments in the application of the ground source heat pump has made it possible for all countries to use the heat of the earth for heating and/or cooling, as appropriate.This suggests the estimated growth rate of 6% to be a conservative forecasting value for direct use. If the recent escalation in world oil prices (from 10 USD/barrel in February 1999 to 24 USD in September 1999) continues, the growth rate for both electric and direct use of geothermal energy is likely to increase significantly.

1. INTRODUCTION

Geothermal energy has been used in a few countries for bathing and washing for thousands of years. But it is only in the present century that it has been harnessed on a large scale for other purposes such as space heating, industry, and the production of electricity. It was indeed at the very beginning of the 20th century (in 1904) that Prince Piero Ginori Conti initiated electric power generation with geothermal steam at Larderello in Italy. The first large scale municipal district heating service started in Iceland in the 1930's. Geothermal energy has been produced commercially for some 70 years, and on the scale of hundreds of MW for four decades both for electricity generation and direct use. The utilisation has increased rapidly during the last three decades, and during 1975-1995, the growth rate for electricity generation worldwide has been about 9% per annum and about 6% per annum for the direct use of geothermal energy. This is one of the highest growth rates for a single energy source over so long a period of time.

In a short time a new century will start, indeed a new millenium. On such an occasion it is of considerable interest to look at what the prospects are for geothermal energy in the near future. What has been achieved in the 20th century and what is likely to be achieved in the 21st century? A new estimate of the geothermal potential of the world (Björnsson et al., 1998), shows the Useful Accessible Resource Base for electricity production to be some 12,000 TWh/a. A very small fraction of the geothermal potential has been developed so far. There is ample space for an accelerated use of geothermal energy for electricity generation in the near future. The scope for direct use of geothermal energy is even more plentiful, as the Useful Accessible Resource Base is estimated 600,000 EJ, which corresponds to the present direct use of geothermal energy for some 5 million years (Björnsson et al., 1998).

With both ample resources and a relatively mature technology at hand, the question of future development of geothermal energy utilisation boils down to economic and political competitiveness with other energy sources on the market in the different countries. Amongst the factors that are likely to affect the development of geothermal worldwide are: a) the development of world prices of oil and gas and other competing energy sources; b) the increased emphasis on reduction of greenhouse gases following the United Nations conferences on the environment in Rio (1991), and Kyoto (1997); c) the comparison of geothermal with other Anew and renewable@ energy sources which also reduce greenhouse gases; d) technological developments that may reduce the production prices of geothermal energy; and e) public and political acceptance of geothermal energy. The manpower development may also be a critical factor, especially in the developing countries.

2. PRESENT SITUATION

There are records of geothermal utilization in 46 countries in the world (Stefansson and Fridleifsson, 1998). The electricity generated in these countries is about 44 TWh/a, and the direct use amounts to about 38 TWh/a (Table 1). Geothermal electricity generation is equally common in industrialised and developing countries, but plays a more important role in the latter. The world distribution of direct utilisation is different. With the exception of China, the direct utilisation is a serious business mainly in the industrialised 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. Direct use of geothermal is very limited in Africa, Central and South America as well as the Asian countries apart from China and Japan.

It is of interest to note that Europe has only a 10% share of the world electricity generation with geothermal whereas it has about 52% share of the direct use. It is the reverse for the Americas, with a 53% share of the electricity generation and only 10% share of the direct use. For Asia, Oceania and Africa, the percentage share of the world total is similar for electricity and direct use.

The installed geothermal electricity generation capacity was 5867 MWe in 1990, 6798 MWe in 1995, and 8239 in MWe 1998 (IGA homepage, 1999). The growth of the total generation capacity from 1990-1995 was 15.9% and in 1995-1998 some 17.5%. The largest additions in generation capacity during 1990-1998 have been in the Philippines (957 MW), Indonesia (445 MW), Italy (224 MW), Japan (315 MW), Costa Rica (120 MW), Iceland (95 MW), USA (75 MW), New Zealand (62 MW), and Mexico (43 MW). The electric generation cost is variable, but commonly around 4 UScents/kWh.

For a few countries (in particular Japan with its extensive use of hot water for bathing) the published data for direct use in 1990 and 1995 (Freeston 1996) is not directly comparable. A meaningful comparison of recent developments similar to that for the electricity generation capacity can therefore not be made. Space heating is the dominant type (33%) of direct use in the world (Lund, 1996), but other common types are bathing/swimming/balneology (19%), greenhouses (14%), heat pumps (12%) for air cooling and heating, fish farming (11%), and industry (10%).

Table 2 shows the types of direct use of geothermal in the top four countries in direct utilisation in the world, all of which have a well developed tradition for direct use. It is very interesting, however, to see that each of the countries has its speciality in the direct use of geothermal. Iceland is the leader in space heating. In fact, about 85% of all houses in the country are heated with geothermal (Ragnarsson, 1995). The USA leads the way in the application of heat pumps for heating and cooling buildings (Lund,1996). Over 70% of Japan´s direct use is for bathing/swimming/balneology at the famous Aonsen@ (Uchida, 1997). China has a more even distribution of the geothermal usage than the other countries, but nearly 50% of the use in China is for fish farming (Ren et al., 1990). This great diveristy in use suggests a large potential for future developments in both these and other countries. It is noticeable that of these four countries, as yet, only the USA makes a significant use of heat pumps. Several European countries (e.g. Germany, Switzerland, Sweden and France), however, also have a widespread utilisation of ground source heat pumps for space heating.

3. HEAT PUMP APPLICATIONS

Geothermal energy has until recently had a considerable economic potential only in areas where thermal water or steam is found concentrated at depths less than 3 km in restricted volumes analogous to oil in commercial oil reservoirs. This has recently changed with developments in the application of ground source heat pumps using the earth as a heat source for heating or as a heat sink for cooling, depending on the season. This has made it possible for all countries to use the heat of the earth for heating and/or cooling, as appropriate. It should be stressed that the heat pumps can be used basically everywhere and are not as site specific as conventional geothermal resources.

Switzerland, a country not known for hot springs and geysers, gives an example of the impact this can have on the geothermal applications in what previously would have been called non-geothermal countries. The use of heat pumps in Switzerland (Rybach and Goran, 1995) amounts to 228 GWh/y. The population of the country is about 7 million. If the same level of use would materialize in other European countries north of the Alps and west of the Urals (350 million people), the utilisation of geothermal through heat pumps would amount to some 11,400 GWh. This is comparable to the total direct use of geothermal in Europe at present (19,800 GWh/y).

Geothermal heat pumps have been found to perform very well throughout the USA for heating and cooling buildings. At the end of 1997, over 300,000 geothermal heat pumps were operating nationwide in homes, schools and commercial buildings for space heating and space cooling (air conditioning), providing some 8,000-11,000 GWh/y of end use energy according to different estimates. The geothermal heat pumps have been officially rated among the most energy efficient space conditioning equipment available in the USA. They reduce the need for new generating capacity and are found to perform at greater efficiencies than conventional air source heat pumps used for air conditioning. Financial incentive schemes have been 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 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. Financial incentive schemes have also been set up in European countries such as Germany and Switzerland.

4. GROWTH RATE OF GEOTHERMAL DEVELOPMENT

The utilisation of geothermal energy has increased rapidly in the last three decades, and during 1975-1995, the growth rate for electricity generation worldwide has been about 9% per annum. This is one of the highest growth rates for a single energy source over so long a period of time. The growth rate for direct use has been estimated some 6% per annum. The growth rates have in the past been significantly affected by the prices of the competing fuels, especially oil and natural gas, on the world market (Fridleifsson and Freeston, 1994). During the oil crises in 1978-1985, the annual growth rate for geothermal electricity was 17%. Figure 1 shows how direct use development in France was affected by the drop in oil and gas prices in 1985.

In order to make a long term prognosis for the development, the safest way is probably to extrapolate the trend of the past. Assuming the growth rate of 9% per annum to continue for another twenty-five years, we can expect the installed capacity to be some 10,400 MWe in year 2000, 25,000 MWe in year 2010, and 58,000 MWe in year 2020 (Table 3). The annual electricity generation shown in Table 3 is based on the assumption that the utilisation factor will be similar to that of year 1997 (Stefansson and Fridleifsson, 1998).

Assuming the annual growth rate for direct use to continue being about 6% for the next two decades, the installed capacity can be estimated to be 11,500 MWt in year 2000, around 21,000 MWt in year 2010, and some 37,000 MWt in year 2020 (Table 3). This is not taking into account the rapid development of heat pumps for heating and cooling in recent years.

The application of the ground source heat pump opens a new dimension in the scope for using the earth´s heat, as heat pumps can be used basically everywhere and are not site specific as conventional geothermal resources. In a matter of five years, this sector has grown e.g. in the USA from 400 MWt in 1990 to over

1,400 MWt in 1994. A fast development is also encountered in countries such as Switzerland, Germany, and Sweden. This is not taken into account in the forecast presented in Table 3 for direct use. The forecast might therefore be somewhat pessimistic, even if we assume the oil prices to remain at the low levels of the 1990's.

In spite of the low oil prices in the last fifteen years, the growth rate has been quite high due to the fact that geothermal energy is a low cost option for many countries, and it is generally acknowledged that geothermal energy is one of the cleanest energy sources available on the market. If the recent escalation in world oil prices (from 10 USD/barrel in February 1999 to 28 USD in mid-February 2000) continues (Figure 2) , there is little doubt that the growth rate for both electric and direct use of geothermal energy will increase significantly. The market for direct use of geothermal is mainly in the industrialised countries and China. It appears to be even more affected by the competing prices of oil and gas than the market for electric generation.

The growth rate is furthermore dependent on the availability of funding and thus the confidence of both public and private investors in the energy source. A worldwide survey (Fridleifsson and Freeston, 1994) showed that the total investments in geothermal energy during 1973-1992 amounted to approximately 22 billion USD. During the two decades, 30 countries invested each over 20 million USD, 12 countries over 200 million USD, and 5 countries over 1 billion USD. During the first decade, 1973-1982, public funding amounted to 4.6 billion USD and private funding to 3 billion USD. During the second decade, 1983-1992, public funding amounted to 6.6 billion USD and private funding to 7.7 billion USD. 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 enterprise in this energy source and demonstrates that geothermal energy is commercially viable.

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 the Philippines (Vasquez and Javellana, 1997) and Indonesia (Radja, 1997; Aryawijaya, 1997). The participation of private operators is presently being considered in a number of developing countries, including Costa Rica, Kenya, China and Vietnam.

5. ENVIRONMENTAL ISSUES

Following the United Nations conferences on the environment in Rio (1991) and Kyoto (1997), most industrialised nations have set up a strategy to reduce air pollution. The European Union has committed itself to reducing the overall emission of greenhouse gases by at least 8% below 1990 levels in the commitment period 2008-2012. Prior to the year 2012 only geothermal energy, hydro, and to a lesser extent wind energy, appear technically ready to make a significant contribution towards an overall reduction in the CO_2 emissions in Europe. In spite of this, as yet, the role of geothermal energy is very limited in the energy strategy plans for Europe.

The situation in the USA is considerably brighter at present for the development of geothermal energy. The U.S. Department of Energy´s Office of Geothermal Technologies has recently identified five strategic goals for geothermal energy as a preferred alternative to polluting energy sources (U.S. DOE OGT, 1998). The following are amongst the strategic goals: a) Supply the electric power needs of 7 million U.S. homes (18 million people) from geothermal energy by the year 2010; b) Expand direct uses of geothermal resources and application of geothermal heat pumps to provide the heating, cooling, and hot water needs of 7 million homes by the year 2010; c) Meet the basic energy needs of 100 million people in developing countries by using U.S. geothermal technology to install at least 10,000 MW by the year 2010; d) By the year 2010, develop new technology to meet 10% of U.S. non-transportation energy needs in subsequent years.

Geothermal fluids contain a variable quantity of gas, largely nitrogen and carbon dioxide with some hydrogen sulphide and smaller proportions of ammonia, mercury, radon and boron. The concentration of these gases are usually not harmful, but should be analysed and monitored. The amounts depend on the geological conditions of different fields. The range in CO_2 emissions from high-temperature geothermal fields used for electricity production in the world is 13-380 g/kWh, whereas the CO_2 emissions are 453 g/kWh for natural gas, 906g g/kWh for oil and 1042 g/kwh for coal. Sulphur emissions are also significantly less for geothermal than fossil fuel electric power stations. The removal of hydrogen sulphide from geothermal steam is a routine matter in geothermal power stations where the gas content is high.

The gas emissions from low-temperature geothermal resources are normally only a fraction of the emissions from the high-temperature fields used for electricity production. The gas content of low-temperature water is in many cases minute, like in Reykjavik (Iceland), where the CO_2 content is lower than that of the cold groundwater. In sedimentary basins, such as the Paris basin, the gas content may be too high to be released, and in such cases the geothermal fluid is kept at pressure within a closed circuit (the geothermal doublet) and reinjected into the reservoir without any de-gassing taking place. Conventional geothermal schemes in sedimentary basins commonly produce brines which are generally reinjected into the reservoir and thus never released into the environment. The CO_2 emission from these is thus zero.

In most countries, a significant percentage of the energy usage is at temperatures of 50-100°C, which are common in low-enthalpy geothermal areas. Most of this energy is supplied by the burning of oil, coal or gas at much higher temperatures with the associated release of sulphur, carbon dioxide and other greenhouse gases. The scope for using geothermal resources alone as well as in combination with other local sources of energy is therefore very large. Geothermal energy, with its proven technology and abundant resources, can make a very significant contribution towards reducing the emission of greenhouse gases worldwide.

Bjornsson et al. (1998) maintain that if the development of hydro and geothermal energy is vigorously pursued, these resources could fulfill a very important bridging function during the next few decades until clean fuels technology and that of other renewables have matured enough to provide a meaningful share of the world energy supply. While the share of hydro power and geothermal energy resources in the world energy supply will remain modest, their technology is, in contrast to that of other renewables, mature with a century of practical experience. Unfortunately, very few decision makers at national not to mention world level realize the potential that geothermal energy may play in the world energy scenario as a clean and sustainable energy resource.

6. COMPARISON WITH OTHER ANEW AND RENEWABLES@

Table 4 is compiled (Fridleifsson, 1999) from the Survey of Energy Resources 1998 (WEC,1998) published by the World Energy Council in conjunction with the 17th World Energy Congress in Houston (Texas). Since the detailed data on the different energy resources and their application is given in the same units, the WEC Survey gives a good opportunity to compare the development of the different energy resources. All the data originates from the national energy authorities of the countries of the world. The table shows the installed capacity (MW-electric) and the electricity production per year (GWh/y) for geothermal, wind, solar and tidal resources at the end of 1996.

It is apparent that in 1996 geothermal energy was in the leading position with 52% of the total installed capacity and about 80% of the electricity generated by these four energy 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%. Geothermal energy is independent of weather contrary to solar, wind, and most hydro applications. 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 baseload suppliers. But turning them off during rainy seasons, when hydropower plants have plenty of water, will in many cases serve to replenish the geothermal reservoir and lengthen its economically useful lifetime.

7. CONCLUSIONS

The prospects for geothermal energy worldwide in the new century are relatively bright. There is a strong interest at the international level in reducing the emission of greenhouse gases. Geothermal energy has a big advantage in this respect compared with fossil fuels. The energy market is, however, very conservative when it comes to changes. It is necessary that governments implement a legal and institutional framework and fiscal instruments allowing geothermal resources to compete with conventional energy systems and securing economic support in consideration of the environmental benefits of this energy source. 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.

The utilisation of geothermal energy has increased rapidly during the last three decades. Assuming the worldwide annual growth rate to continue at 9%, the electricity production may reach some 130 TWh in 2010, and 320 TWh in 2020. Assuming the annual growth rate for direct use to continue at 6%, the energy production may reach some 80 TWh in 2010, and 140 TWh in 2020. Recent developments in the application of the ground source heat pump opens a new dimension in the scope for using the earth´s heat, as heat pumps can be used basically everywhere and are not as site specific as conventional geothermal resources. This suggests the estimated growth rate of 6% to be a conservative forecasting value for direct use. If the recent escalation in world oil prices (from 10 USD/barrel in February 1999 to 28 USD in mid-February 2000) continues, the growth rate for both electric and direct use of geothermal energy is likely to increase significantly.

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Table 1. Electricity generation and direct use of geothermal energy 1997
(Based on data from Stefansson and Fridleifsson, 1998)

	Electricity generation			**Direct use**		
	Installed capacity MWe	**Total production GWh/a**	**Total production %**	**Installed capacity MWt**	**Total production GWh/a**	**Total production %**
European Union	754	3,832		1,031	3,719	
Europe, other	112	471		4,089	16,058	
Europe, total	866	4,303	10	5,120	19,777	52
N-America	2,849	16,249		1,908	3,984	
C&S America	959	6,869				
America, total	3,808	23,118	53	1,908	3,984	10
Asia	2,937	13,045	30	3,075	12,225	32
Oceania	365	2,901	6	264	1,837	5
Africa	45	390	1	71	355	1
World Total	**8,021**	**43,756**		**10,438**	**38,178**	

Table 2. Types of direct use in the world and the top four countries (in %)

	World	**Japan**	**Iceland**	**China**	**USA**
Space Heating	33	2	77	17	10
Heat Pumps (heating and cooling)	12	0	0	0	59
Bathing/Swimming/Balneology	19	73	4	21	11
Greenhouses	14	2	4	7	5
Fish Farming	11	2	3	46	10
Industry	10	0	10	9	4
Snow Melting	1	2	2	0	1
	100	**100**	**100**	**100**	**100**

Table 3. Potential development of the installed capacity and energy production from geothermal in the form of electricity (MWe) and direct use (MWt)

Year	Mwe	TWh/a	MWt	TWh/a
2000	10,400	57	11,500	44
2005	16,000	87	15,000	59
2010	25,000	134	21,000	79
2015	38,000	206	26,000	105
2020	58,000	318	37,000	141

Table 4. Electricity from four energy resources in 1996 (Compiled by Fridleifsson (1999) from the Survey of Energy Resources (WEC 1998)

	Installed capacity		Production per year	
	MWe	%	GWh/y	%
Geothermal	7.049	52.0	42.053	79.6
Wind	6.050	44.7	9.933	18.8
Solar	175	1.3	229	0.4
Tidal	264	2.0	602	1.2
Total	**13.538**	**100**	**52.817**	**100**

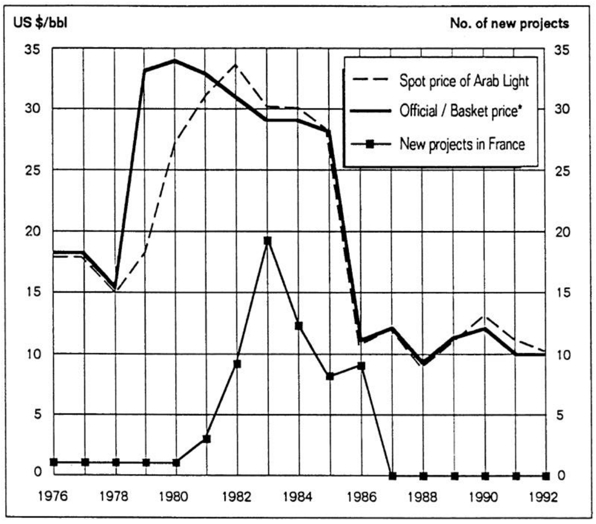

Figure 1. Yearly average price of crude oil adjusted for inflation and currency fluctuation in constant 1983 USD during 1976-1992 (from OPEC, 1993). Also shown is the number of new geothermal space heating projects commissioned per year in France (from Boisdet et al., 1990. The figure is reproduced from Fridleifsson and Freeston (1994).

Figure 2. Average price of crude oil (Brent) from January 1999 to mid-February 2000 (Source: Reuters)