DIRECT USE OF GEOTHERMAL ENERGY AROUND THE WORLD

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SUMMARY

Geothermal energy has been produced commercially for nearly a century, and on the scale of hundreds of MW for over four decades both for electricity generation and direct use. The world direct-use energy production is about 37 TWh/a (installed capacity of 10,000 MWt in nearly forty countries), and is, with the exception of China, mainly in the industrialized, and central and eastern European countries. Fourteen countries have installed capacities over 100 MWt. The main uses are space heating (33%), heat pumps (12%) for heating and cooling, bathing (19%), greenhouses (14%), aquaculture (11%) and industry (10%). 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. Geothermal energy, with its proven technology and abundant resources, can make a very 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 and securing economic support in consideration of the significant environmental benefits of this energy source.

INTRODUCTION

Geothermal utilization is commonly divided into two categories (i.e., electric production and direct application). The minimum production temperatures in a geothermal field generally required for the different types of use are shown in Figure 1 (Lindal, 1973). The boundaries, however, serve only as guidelines. Conventional electric power production is limited to fluid temperatures about 150°C, but considerably lower temperatures can be used with the application of binary fluids (outlet temperatures commonly at 100°C). The ideal inlet temperatures into houses for space heating using radiators is about 80°C; but, by using radiators of floor heating, or by applying heat pumps or auxiliary boilers, thermal waters with temperatures only a few degrees above the ambient can be used beneficially.

It is a common misconception that direct use of geothermal is confined to low-temperature resources. High-temperature resources can, of course, also be used for heating and drying purposes even if the process is at a very low temperature. Refrigeration is, in fact, only possible with temperatures above about 120°C. The world's two largest industrial companies using geothermal energy (the Kawerau paper mill in New Zealand and the Kisilidjan diatomite plant in Iceland) both use high-temperature steam for their processes. The largest geothermal district heating service in the world (the Reykjavik District Heating serving about 152 thousand people), obtains 75% of its heat from low-temperature fields (85 - 130°C) and 25% from a high-temperature field (300°C production temperature). In addition to the straightforward use of hot water or steam, combined heat and power units and cascaded use (where a number of temperature requirements are met from a single source) offer the potential for maximum energy extraction and economics.

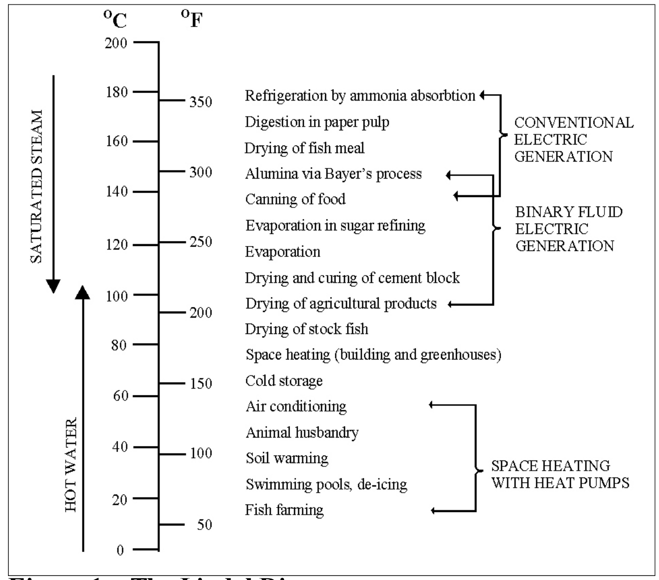

Figure 1. The Lindal Diagram.

WORLDWIDE USE OF GEOTHERMAL ENERGY

Geothermal energy has been produced commercially for nearly a century, and on scale of hundreds of MW for over four decades both for electricity generation and direct use. At present, 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 37 TWh/a (Table 1). Geothermal electricity generation is equally common in industrialized and developing countries, but plays a more important role in the latter. 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. Direct use of geothermal is very limited in Africa, Central and South America, as well as the Asian countries apart from China and Japan.

Table 1. Electricity Generation and Direct Use of Geothermal Energy 1997 (Stefansson and Fridleifsson, 1998)

	Electricity Generation			Direct Use		
	Installed Capacity MWe	Total Production GWh/a	%	Installed Capacity MWt	Total Production GWh/a	%
European Union	754	3,832		1,031	3,719	
Europe, other	112	471		3,614	14,790	
Europe, total	866	4,303	10	4,645	18,509	50
North America	2,849	16,249		1,908	3,984	
Central and South America	959	6,869				
America, total	3,808	23,118	53	1,908	3,984	11
Asia	2,937	13,045	30	3,075	12,225	33
Oceania	365	2,901	6	264	1,837	5
Africa	45	390	1	71	355	1
World Total	8,021	43,756		9,963	36,910	

It is of interest to note that Europe has only a 10% share of the world total electricity generation with geothermal; whereas, it has about 50% share of the direct use. It is the reverse for the Americas, with a 53% share of the electricity generation and only 11% share of the direct use. For Asia, Oceania and Africa, the percentage share of the world total is similar for electricity generation and direct use.

DIRECT USE OF GEOTHERMAL ENERGY

Direct application of geothermal energy can involve a wide variety of end uses, as can be seen from Figure 1 (Lindal, 1973). It uses mostly existing technology and straightforward engineering. However, in some cases, the technology is complicated by dissolved solids or non-condensible gases in the geothermal fluids. The technology, reliability, economics, and environmental acceptability of direct use of geothermal energy has been demonstrated throughout the world. In comparison with electricity production from geothermal energy, direct utilization has several advantages, such as a much higher energy efficiency (50 - 70% as opposed to 5 - 20% for conventional geothermal electric plants), generally the development time is much shorter, and normally much less capital investment is involved. Last, but not least, direct application can use both high- and low-temperature geothermal resources and is, therefore, much more widely available in the world. Direct application is, however, much more site specific for the market, as steam and hot water is rarely transported long distances from the geothermal site. The longest geothermal hot water pipeline in the world is 63 km, in Iceland. The production cost/kWh for direct utilization is highly variable, but commonly under 2 U.S. cents/kWh.

Data is available for the direct use of geothermal resources in some forty countries. The quality of the data is, however, high variable. Country papers were presented for most of these countries in the "Proceedings of the World Geothermal Congress" in Florence (Italy) in 1995. Freeston (1996) summarized these papers and gave a very comprehensive description of the situation in each country. The International Geothermal Association is preparing a new collection of country papers and national energy data for the World Geothermal Congress in Japan in the year 2000.

Table 2 shows the installed capacity and produced energy in the top eight direct-use countries in the world. It is worth noting that the two countries with the highest energy production (Japan and Iceland) are not the same as the two with the highest installed capacities (China and USA). the reason for this is the variety in the load factors for the different types of use.

Table 2. Top Eight Countries in Direct Utilization (Stefansson and Fridleifsson, 1998)

	Installed MWt	Production GWh/a
Japan	1159	7500
Iceland	1443	5878
China	1914	4717
USA	1905	3971
Hungary	750	3286
New Zealand	264	1837
France	309	1359
Italy	314	1026

TYPES OF DIRECT USE

Lund (1996) has recently written a comprehensive summary on the various types of direct use of geothermal energy. Space heating is the dominant type (33%) of direct use in the world; but, other common types are bathing/swimming/balneology (19%), greenhouses (14%), heat pumps for air cooling and heating (12%), fish farming (11%), and industry (10%).

Table 3 shows the types of direct use of geothermal in the top four countries in direct utilization 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 "onsen" (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). 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 utilization of ground-source heat pumps for space heating.

Table 3. Types of Direct Use in the World and the Top Four Countries (in %)

	World	Japan	Iceland	China	USA
Space Heating	33	21	77	17	10
Heat Pumps (heating/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

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 seven 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 utilization 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 (18,500 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 U.S. $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.

THE ROLE OF GEOTHERMAL ENERGY IN ICELAND

Iceland is located astride the mid-Atlantic ridge, and is richly endowed with geothermal resources. Iceland has also large hydro-resources, which are used for the generation of electricity. In 1997, the total primary energy consumption in the country was 106 PJ or 2,541 thousand tonnes of oil equivalent. This was supplied by geothermal energy (48.1%), hydro-power (17.6%), oil (31.9%) and coal (2.4%). About 66% of the total primary energy consumption was thus served by renewable energy sources (geothermal and hydro). This is a higher share of renewable energy than in any other country.

Direct use is the main utilization of geothermal energy in Iceland (see Table 3 for types of use). At present, geothermal energy contributes only about 6% to the generation of electricity in the country, the main part being generated from hydro. By the year 2000, when the geothermal power plants presently under construction will be online, the share of geothermal energy in the electricity generation will be in excess of 15%. Two of the three main power plants have co-generation of electricity and hot water for district heating, thus securing efficient use of the geothermal resources.

The main reason for the advanced use of geothermal energy in Iceland is that geothermal energy is much cheaper than other energy sources for heating purposes. On average, the energy cost for heating is only some 20 - 30% of the cost by oil. The district heating companies are owned by the municipalities and are in most cases highly profitable. Typical prices of geothermal energy to the consumers for heating purposes are in the range 1.1 - 1.6 U.S. cents/kWh. The cost of electricity generation from geothermal steam is also quite favorable in Iceland, about 3 U.S. cents/kWh. The savings of the Icelandic economy by using geothermal energy for heating of houses instead of using imported oil, is estimated about 110 million U.S. $ per year or about 400 U.S. $ per capita.

INTEGRATED USE WITH OTHER ENERGY SOURCES

Geothermal plants are characterized by a low-operating cost, but a relatively high investment cost. The price of the heat/energy, therefore, implies a high-fixed cost which has to be taken into consideration when integrating geothermal into energy supply systems using two or more energy sources. Conventional development of geothermal energy requires 1 to 3 km deep wells, the drilling of which is relatively expensive. Once a geothermal plant is installed, the operating cost is very low, since water as the energy carrier is available on the spot. The “fuel” is paid up front with the drilling for the hot water/steam. Geothermal production wells have in several countries been operated for several decades with only minor servicing. Geothermal energy is very suitable for base-load plants and thus, can be in competition with other base-load plants such as heat and power co-generation units. The decision pro or contra geothermal energy use will always depend on the actual location, and the importance that people give to clean environment which comes with geothermal.

With due consideration to the above mentioned economic constraints, geothermal district heating plants can be combined very favorably with conventional peak-load plants. The latter have a low investment cost, high operation cost and high pollution. Therefore, they are kept in operation for as short periods as possible. In Europe, it is common practice that such plants cover the peak load, but produce only 10 - 20% of the amount of heat required annually. Thus, the above economic constraints have only little influence on the ecological advantages of geothermal energy. In case the temperature of the geothermal reservoir is not sufficient for the district heating system, then it can be raised by heat pumps or auxiliary boilers. These systems produce significantly less emission of greenhouse gases than conventional thermal plants using fossil fuels.

ENVIRONMENTAL CONSIDERATIONS

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 analyzed and monitored. The amounts depend on the geological conditions of different fields.

It should be stressed that 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.

GROWTH OF GEOTHERMAL DEVELOPMENT

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 (Fridleifsson and Freeston, 1994). As long as the oil and gas prices stay at the present low levels, it is rather unlikely that we will see again the very high annual growth rates for geothermal electricity of 17% as was the case during the oil crises of 1978-1985. The growth rate is, however, quite high due to the fact that geothermal energy is one of the cleanest energy sources available on the market. During 1975 -1995, the world average growth rate in geothermal utilization for electricity generation was 9% p.a., which is one of the highest growth rates experienced in the use of a single energy source.

The average growth rate in the direct use of geothermal energy seems to have been about 6% p.a., during the last decade. It is high affected by the competing prices of oil and gas on the world market. The large potential and growing interest for the development of direct applications in China for fish farming, public baths, greenhouses and district heating, and the great surge of installations of geothermal heat pumps in recent years exemplified by the USA, Switzerland and Germany, give a cause for optimism for the growth rate of direct applications.

Examples of high growth rate in the direct use of geothermal are found in countries such as Turkey and Tunisia. In Turkey, the installed capacity for direct use (mostly space heating) was 140 MWt in 1994, and had grown to 274 MWt in May 1997. It is expected to be 2,500 MWt in year 2000 and 3,600 MWt in year 2005 (Simsek, 1997). In Tunisia, geothermally-heated greenhouses have expanded from 10,000 m^2 in 1990 to 800,000 m^2 in 1997 (Said, 1997). They are expected to reach 1,750,000 m^2 in the year 2002. The greenhouses in Tunisia do, in fact, replace cooling towers five months per year to cool irrigation water from deep wells from 75 to 30°C in oases in the Sahara Desert. The main products are tomatoes and melons for export to Europe.

WHAT IS EXPECTED OF GEOTHERMAL AND OTHER “NEW”AND RENEWABLES?

It is of interest to look at what is expected from geothermal energy in the future in international energy plans. Are there similar expectations for geothermal energy as there are for solar energy and wind energy? The world consumption of geothermal energy was about 13 Mtoe/a in 1995. With the high growth rate expected, the aggregate consumption of geothermal energy (for electricity and direct use) might be as high as 340 Mtoe/a by the year 2020 (Björnsson, et al., 1998). This is a very much higher figure than estimated for geothermal energy within the international energy community. A study organized by the World Energy Council (WEC Commission, 1993) includes forecasts for the various energy sources, including solar, wind, and geothermal energy, for the year 2020.

There are presented maximum and minimum possibilities, based on whether there will be major policy support or not. Table 4 shows that geothermal energy is expected to contribute some 40 Mtoe in the year 2020 in case of no special support and 90 Mtoe in the case of major policy support. Wind energy is expected to contribute 85 - 215 Mtoe, and solar energy 109 - 355 Mtoe in the minimum and maximum cases, respectively. The WEC Commission clearly expects relatively little from geothermal energy in the year 2020 irrespective of whether special policy support is given for the "new" energy sources or not. Both the minimum and maximum cases of the WEC Commission are very significantly lower than the 340 Mtoe/a by the year 2020 estimated as a realistic possibility by an Icelandic group in preparation for the 17th WEC Congress in Houston (Björnsson, et al., 1998).

Table 4. Expected Contributions from Three "New" Energy Sources in 2020 (WEC Commission, 1993)

	Minimum		Maximum (major policy support)	
	Mtoe	%	Mtoe	%
Solar	109	47	355	54
Wind	85	36	215	32
Geothermal	40	17	91	14
Total	234	100	661	100

The very low expectations that the WEC Commission has for the potential contribution from geothermal energy, compared to the other "new" energy sources, probably reflects to a certain extent the strength of the solar and wind energy lobbies. The geothermal community has the habit of being shy and keeping information to itself; whereas, the commercial interests of the manufacturing industries and the international associations behind solar and wind energy have secured greater success in public relations.

DISCUSSION

As shown in Table 1, the worldwide use of geothermal energy amounts to about 44 TWh/a of electricity and 37 TWh/a for direct use. 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, therefore, been developed so far, and 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 five million years.

Björnsson, et al. (1998) maintains 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 source.

Following the United Nations conferences on the environment in Rio (1991) and Kyoto (1997), 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 (USDOE-OGT, 1998). The following are amongst the strategic goals: a) supply the electric power needs of seven million U.S. homes (18 million people) from geothermal energy by the year 2010; b) expand direct use of geothermal resources and application of geothermal heat pumps to provide the heating, cooling and hot water needs of seven 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.

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. 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. Geothermal energy, with its proven technology and abundant resources, can make a very significant contribution towards reducing the emission of greenhouse gases worldwide. 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.

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GEO-HEAT CENTER QUARTERLY BULLETIN
ISSN 0276-1084
A Quarterly Progress and Devlopment Report
on the Direct Utilization of Geothermal Resources

This article is in the Vol 19, No. 2 bulletin

This material was prepared with the support of the U.S. Department of Energy (DOE Grant No. DE-FG07-90ID 13040). However, any opinions, findings, conclusions, or recommendations expressed herein are those of the author(s) and do not necessarily reflect the view of DOE.