

WORLDWIDE GEOTHERMAL DEVELOPMENT AND INTERNATIONAL COOPERATION

Ingvar B. FRIDLEIFSSON

United Nations University Geothermal Training Programme,
Orkustofnun, Grensasvegur 9, 108 Reykjavik, Iceland

ABSTRACT

Geothermal energy has come of age as an energy source. It is found in most parts of the world and is harnessed by conventional technology. Commercial production on the scale of hundreds of MW has been undertaken for over three decades both for electricity generation and direct utilization. Some 80 countries have identified geothermal resources, and about 50 have quantifiable geothermal utilization at present. Electricity is produced from geothermal in 21 countries (total production 38 TWh/a) and direct application is recorded in 35 countries (34 TWh/a). Geothermal electricity production is equally common in industrialized and developing countries, but plays a more important role in the latter. Apart from China, direct use is mainly in the industrialized countries and Central and Eastern Europe. Most of the developing countries as well as Central and Eastern European countries still lack trained manpower, but there is a surplus in many industrialized countries. During 1973-1992, investments in geothermal energy amounted to approximately 22 billion USD. The large share of the private sector in the investments shows its confidence in this energy source. Data presented in the WEC Survey of Energy Resources 1995 on the "new renewables" (geothermal, solar, wind, and tidal energy) shows that geothermal has the largest installed electrical capacity (61%) and electricity production (81%) in the world of these four sources. A summary is given on the activities of the International Geothermal Association (IGA) and other international cooperation in geothermal energy. Some sections of the present paper have previously been published in Fridleifsson (1996).

GEOLOGICAL ENVIRONMENT OF GEOTHERMAL RESOURCES

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 2.9×10^{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 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 deep, but rarely much over 3 km at present.

Exploitable geothermal systems occur in a number of geological environments. High temperature fields used for conventional power production (with temperatures 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 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 drill holes 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, i.e. 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 of binary fluids (outlet temperatures commonly about 70°C). The ideal inlet temperatures 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

At the World Geothermal Congress (WGC'95) convened by the International Geothermal Association (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 Hutterer (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 industrialized countries (total 4.920 MW_t), 11 Central and Eastern European countries (total 1.616 MW_t), and 7 developing countries (total 2.491 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 year 2000. In Mexico, 4.6% of the electricity generated in 1994 was from geothermal (Quijano-Leon and Gutierrez, 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 the 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.

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 _t	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	3.417	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	1.051	5.470	-	-
Poland	-	-	63	206
Romania	2	-	137	765
Russian Fed.	11	25	210	673
Serbia	-	-	80	660
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

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 practised 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 baseload 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	
	MW _e	%	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 e.g. 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 quality 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 fuels. 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.

INTERNATIONAL COOPERATION

The International Geothermal Association (IGA) was established in 1989. It has about 2,000 members in over 50 countries. It is a scientific, educational and cultural organization established to operate worldwide. It is a non-political, non-governmental, non-profit organization. The objectives of the IGA are to encourage research, development and utilization of geothermal resources worldwide through the compilation, publication and dissemination of scientific and technical data and information, both within the community of geothermal specialists and between geothermal specialists and the general public. The IGA cooperates and communicates with national and international governmental, institutional and private agencies in matters relating to the development and utilization of geothermal resources. It aims to serve as a public forum to provide objective and unbiased information on the nature of geothermal energy and its development. It

has published the quarterly IGA News since 1990.

An important milestone in the work of the IGA was the World Geothermal Congress in Florence (Italy) in May 1995 with participation from over 70 countries. There were 1,031 registrants, 282 accompanying persons, and 138 exhibitors. There were 535 scientific and technical papers published in the proceedings of the congress. The next World Geothermal Congress is planned to be held in Japan in June in the year 2000.

The membership of the IGA consists of individual members, corporate members, institutional members, student members and affiliated members, which are by far the most numerous. The affiliated members join the IGA through their national geothermal associations. There are about twenty national geothermal associations in the world. Twelve of these have already signed an affiliation agreement with the IGA. They are in the following countries: Canada, Georgia, Hungary, Indonesia, Lithuania, Mexico, New Zealand, Poland, Romania, Russia, Slovakia, and the USA. It is hoped that the national geothermal associations in Japan, China, Germany, Philippines, and Switzerland will join the IGA shortly. That will bring the membership of the IGA to over 3,000.

The national geothermal associations have a wide range of activities in their countries such as seminars, conferences and training courses, and several of them publish a newsletter or a magazine. The largest of the national associations is the Geothermal Resources Council (GRC) in the USA. It mainly focuses on the needs of the geothermal community in the USA with its publications (GRC Bulletin, the Transactions of its Annual Meeting (conference) and special publications), training courses and seminars. It has always had a number of international members and has been fairly active internationally through the years with workshops and training courses in several countries. The GRC organized very successful international geothermal symposia in Hawaii in 1985 and 1990. These served a similar role as the United Nations symposia in Rome (1960), Pisa (1970), San Francisco (1975), and the World Geothermal Congress in Florence (1995). Prior to the establishment of the IGA in 1989, the GRC functioned in many ways as the main forum for international cooperation in geothermal energy.

The idea to establish the IGA was first considered at the UN Symposium on Geothermal Energy held in Pisa (Italy) in 1970. It was, however, not until in 1986 that a group of international geothermal specialists relaunched the idea within the GRC and an organizational working group was set up (see article in IGA News, No. 1, 1990). The working group met in the USA, New Zealand, Mexico and Italy. Senior members of the GRC were instrumental in establishing the IGA together with prominent geothermal specialists from Iceland, Italy, Mexico, and New Zealand. The IGA was formally founded in May 1989 in Castelnuovo V.C. (Larderello, Italy). The association is registered under the laws of New Zealand. The IGA Secretariat was first established in Pisa (Italy). It was moved from there to Berkeley (California, USA) in 1991, moved to Taupo (New Zealand) in 1995, and it is expected to move again in 1998.

The division of work between the national associations and the IGA is basically in that the former focus on activities in their own countries and in cooperation with their nearest neighbours whereas the IGA works internationally. The first regional branch of IGA, the European Branch, was established in 1992. Its functions are to promote geothermal development in Europe, to stimulate participation of European members in all IGA activities, to promote educational activities and organize meetings and other events of geothermal interest in Europe, to collect news for IGA News in Europe, and to disseminate IGA material among the European membership. It is expected that similar regional branches will be established in the future in other continents in order to decentralize the activities of the IGA and focus its activities not only on world issues but also on regional issues in geothermal.

The IGA, through its widely distributed membership, has many advantages to serve and support international organizations that want to promote geothermal development. As yet, however, the IGA has very limited funds for its activities. One of the priority issues on the agenda of the IGA is the dissemination of knowledge and technical transfer. This activity is expected to complement the international geothermal training schools, which are financed through the aid programmes of the host countries and to some extent by the United Nations system. The IGA is considering, through its education committee, to start a series of travelling courses (2 weeks) whereby a small group of experts would visit several countries and give the same course to a large group of geothermalists in individual countries or groups of countries. In this way, a larger number of people in the recipient countries would have the opportunity of getting in contact with up to date technology in their respective fields than is possible at the international schools. IGA is seeking financing for this activity.

In addition to the activities of the IGA, the GRC and other national geothermal associations, there is a wide range of international cooperation activities in professional associations (mainly in science and engineering), under the auspices of the various agencies of the United Nations (such as UNDP, UN University, UNESCO, ECLAC, ESCAP, International Atomic Energy Agency (IAEA), and multilateral organizations such as the European Commission, the International Energy Agency, the Latin American Energy Organization (OLADE) etc. Several professional associations include geothermal

energy sessions in their regular conferences, and geothermal interest groups have been established within some, such as the working group on Water-Rock Interaction within the International Association of Geochemistry and Cosmochemistry which has held international symposia every three years since 1974 partly dealing with geothermal matters. Bilateral agencies (such as the Japan International Cooperation Agency and the US AID) have also been instrumental in initiating and organizing as well as funding geothermal cooperation in various parts of the world.

A large part of the funding of geothermal projects in the developing countries has come through loans from multilateral banks such as the World Bank (IDA and IBRD), the regional development banks (Asian Development Bank, Interamerican Development Bank, African Development Bank, European Investment Bank, Nordic Investment Bank etc.), and through export credit agencies (especially the export-import banks of Japan and the USA).

MANPOWER DEVELOPMENT

One of the main constraints of geothermal energy development in many countries is a shortage of skilled manpower (geoscientists and engineers) with practical experience. The developing countries rely heavily on foreign consultants, but in many cases the consultants have to work for a considerable time in a given country to be able to adjust their expertise to the special characteristics of the geothermal resources in that country. It is very important to secure that the experience obtained during exploration and development of a particular field be maintained within the country when the consultants depart. This is best done by assigning fully qualified local experts to work as counterparts with the foreign consultants.

The lack of trained professionals has been addressed by aid programmes supporting the training of geothermal technologists. Such programmes have been operated since the 1970's at the geothermal schools in Iceland (the United Nations University Geothermal Training Programme in Reykjavik), Italy (the International School of Geothermics in Pisa, but the annual courses in Pisa have not been held since 1993), Japan (the Geothermal Research Centre at Kyushu University), Mexico (Autonomous University of Baja California in Mexicali), and New Zealand (the Geothermal Institute at the University of Auckland). However, the number of fully funded training places available per year is limited to about 50 (Iceland 16, Japan 15, New Zealand 20, Mexico 1 or 2) which is not sufficient as more and more countries are starting to use geothermal resources. The training at these centres is for scientists and engineers with university degrees. Some developing countries, for example the Philippines, have already built up a strong core of geothermal experts with the assistance of the international training centres and by suitably qualified staff working side by side with foreign consultants. Most of the developing countries, however, have a long way to go towards becoming self sufficient in the expertise needed to harness the geothermal energy resources that may reside unused in the countries.

The pioneering countries of geothermal development (Hungary, Iceland, Italy, Japan, New Zealand, and the USA) started basically from scratch in developing their geothermal resources. Engineers, geologists, chemists, and physicists combined forces within each country. The first groups of geothermal specialists were commonly built at government agencies such as the USGS (USA), DSIR (New Zealand), and the State Electricity Authority (later named Orkustofnun, Iceland). Much experience was drawn from established disciplines such as groundwater hydrology, mineral exploration, oil exploration, oil production etc. Many key people in the early days of geothermal development first met at the United Nations Conference on New Sources of Energy in Rome in 1961. That meeting was a milestone in international cooperation in geothermal energy research and development.

The large attendance at the United Nations Symposium on the Development and Utilization of Geothermal Resources in Pisa in 1970, showed that geothermal energy was already at that time taken seriously as an energy source in a large number of countries. At the onset of the first oil crisis in late 1972, there were well established geothermal specialist groups working in several countries. The oil crisis caused a wave of interest for new and renewable energy sources all over the world. Geothermal energy obtained a lot of attention, as, unlike most other "new" energy types, it was already an established commercial energy source in the pioneer countries mentioned above. International agencies, in particular within the United Nations system, had already after the Rome and Pisa conferences started providing technical assistance to the developing countries in geothermal exploration. This work was intensified. The late 1970's and early 1980's were boom years for geothermal consultants, as their services were requested both at home and abroad. Many international geothermal "experts" received their hands-on-training in consultancy work during these years. The overseas work was both in the developing countries and in the industrialized countries (such as in Europe).

This boom basically ended in 1985 with the sharp drop in oil prices on the world market. Since then, relatively few newcomers have been on the geothermal scene. Geothermal work has been drastically cut in many countries. There has been a large reduction in the number of personnel working in geothermal development in many industrialized countries. Many of these people transferred to work in environmental projects, nuclear waste disposal projects, oil and mineral

exploration. There has, however, been a high growth rate in geothermal development in several countries during much or parts of the period 1985-1995. This has particularly been the case in countries where geothermal energy has shown to be the least cost alternative to meet the expansion of the energy demand in the countries/regions concerned. Examples of such countries are China, Costa Rica, Iceland, Indonesia, Nicaragua, Philippines, and for a part of the time in California (USA). If (or when) the oil prices rise again to the levels of 1979-1984, it is very likely that a large number of countries will again start a progressive policy to develop their geothermal resources. The dust will be cleared off many project proposals from the 1980's that were put on the shelf. In our discussion on manpower requirements in geothermal, we should not forget that oil prices may start soaring again.

Significant experience in geothermal exploration and development is available in some 30 countries (Fridleifsson, 1995). But the manpower resources are unevenly distributed in the world. As mentioned earlier, a number of geothermal experts have become redundant in several of the industrialized countries since the mid-1980's 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. 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 travelling 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.

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 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 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 rates 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 Hutter (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 (Javellana *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 CO₂ 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 USD 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 US 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.

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