STATUS, DEVELOPMENT AND PROSPECTS OF GEOTHERMAL ENERGY

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The basis of geothermal energy is the immense heat content of the earth's interior. It is constantly supplied by the decay of natural radioisotopes, since billions of years. The resource is vast and ubiquitous and has a correspondingly large potential for utilization. There are two main lines of geothermal energy utilization: power generation and direct use. Worldwide base-load electricity production is currently about 60 TWh, with 10 GWe capacity; until 2050 the capacity could grow over 150 GWe, with Enhanced Geothermal Systems significantly more. Geothermal technologies operate with little or no greenhouse gas emissions since no burning processes are involved; in 2050 the CO_2 emission avoidance would amount to several hundred million tons per year.

Keywords power generation, direct use, CO_2 emission avoidance

1. INTRODUCTION

The basis of geothermal energy is the immense heat content of the earth's interior. Since billions of years it is constantly supplied by the decay of natural radioisotopes. About 99% of the earth's volume has temperatures >1000 °C, with only 0.1% at temperatures <100 °C. The total heat content of the earth is about 10^{13} EJ and it would take over 109 years to exhaust it through today's global terrestrial heat flow. Thus the resource is vast and ubiquitous and has a correspondingly large potential for utilization. Geothermal energy is available round around the clock all year. There are two main lines of geothermal energy utilization: power generation and direct use.

2. STATUS OF GEOTHERMAL ENERGY WITHIN THE RENEWABLES

The potential of geothermal energy is considered highest within the renewables in terms of capacity (EJ/year; [1]): Geothermal 5000, Solar 1600, Wind 650, Biomass 275, Hydro 50. Geothermal power is well positioned within the renewables, especially in terms of the availability factor: on the average, geothermal power plants are operational 75 % of the time. With l.0 % of installed capacity geothermal power plants produce 1.8 % global electricity. Annual electricity production is currently on the same order of magnitude as of wind energy and an order of magnitude larger than with solar energy. Geothermal power plants are characterized by the production of base-load electricity. Table 1 shows the installed capacity and electricity production in 2005 for renewable energy sources, namely hydro, biomass, wind, geothermal, and solar energy.

3. GEOTHERMAL POWER GENERATION AND DIRECT USE

Geothermal electricity generation started in Italy more than 100 years ago. Today 24 countries generate base-load electricity. Capacity in 2007 was about 10 GWe and electricity production 60 TWh [2]. Conventional geothermal power plants operate world-wide, mainly in geologically favorable areas such as volcanic regions but recently geothermal power plants started to operate also in "non-volcanic" countries like Austria and Germany.

Table 1. Electricity from renewable sources in 2005. Compiled from Tables in 2007 Survey of Energy Resources [3].

Technology	Installed capacity		Production per year		Availability factor
	GWe	%	TWh/yr	%	%
Hydro	778	87.5	2,837	89	42
Biomass	40	4.5	183	5.7	52
Wind	59	6.6	106	3.3	21
Geothermal	9	1.0	57	1.8	72
Solar	4	0.4	5	0.2	14
Total	890	100	3,188	100	41

Direct application of geothermal energy (for space heating, agriculture, bathing etc.) is reported from 72 countries. The worldwide direct use of geothermal heat is currently about 300 PJ/yr. The highest growth rate is with geothermal heat pumps (GHP), one of the fastest growing renewable energy technologies; world-wide production increases (in PJ/yr): 14.6 in 1995, 23.3 in 2000, 87.5 in 2005. GHPs provide space heating, cooling and also domestic hot water. Table 2 shows the „top fifteen" in geothermal power production and direct use.

4. GEOTHERMAL SUSTAINABILITY AND ECONOMICS

Geothermal energy can be used in a "sustainable" manner, which means that the production system applied is able to sustain the production level over long times [4]. The longevity of production can be secured and sustainable production achieved by using moderate production rates, which take into account the local resource characteristics (field size, natural recharge rate, etc.).

Table 2. Top fifteen countries utilising geothermal energy in 2005. Data on electricity from [5] and on direct use from [6].

Geothermal electricity production		Geothermal direct use	
Country	GWh/yr	Country	GWh/yr
USA	17,917	China	12,605
Philippines	9,253	Sweden	10,000
Mexico	6,282	USA	8,678
Indonesia	6,085	Turkey	6,900
Italy	5,340	Iceland	6,806
Japan	3,467	Japan	2,862
New Zealand	2,774	Hungary	2,206
Iceland	1,483	Italy	2,098
Costa Rica	1,145	New Zealand	1,968
Kenya	1,088	Brazil	1,840
El Salvador	967	Georgia	1,752
Nicaragua	271	Russia	1,707
Guatemala	212	France	1,443
Turkey	105	Denmark	1,222
Guadeloupe (France)	102	Switzerland	1,175

According to the World Energy Outlook statistics [7] the production cost of geothermal electricity compares favourably to other renewables (Table 3). Currently the installation cost of geothermal power plants is around 3.0 – 4.5 million €/MWe, the production cost 40 – 100 €/MWh [8].

Table 3. Electricity production cost from renewables [7]

Power plant type	Generation cost (US cent/kWh)
Hydro	2 – 10
Geothermal	2 – 10
Wind	4 – 8
Biomass	3 – 12
Solar PV	25 – 160
Concentrated solar	12 – 34

For direct use the average unit cost of heat for geothermal district heating is 2.0 €/GJ (€ in 2005); with geothermal heat pumps the cost of combined heating/cooling is 16.0 €/GJ [9]. More relevant is the return of investment time, which is 4 – 8 years for GHPs.

5. Future trends and prospects

Currently, two main trends are evident: 1) the development of conventional geothermal power plants in geologically favourable regions, mainly in developing countries like Indonesia and the Philippines, 2) dissemination of geothermal heat pumps systems in countries not yet applying this technology. Future technologies like Enhanced Geothermal Systems (EGS, [10]) for co-generation will see rapid and wide-scale distribution worldwide, provided their establishment and operational experience confirm the expected results.

Quantitative development trends for coming decades can only be estimated. Figure 1 is from a recent study prepared for the Intergovernmental Panel on Climate Change, IPCC [8]. It is considered possible to increase the installed world geothermal electricity capacity from the current 10 GW to 70 GW in 2050 with present technology, and to 140 GW with enhanced technology. The potential may be estimated orders of magnitude higher based on enhanced geothermal systems (EGS) technology.

6. Environmental benefits, by saving CO_2 emissions

Geothermal technologies operate with little or no greenhouse gas (GHG) emissions since no burning processes are involved. CO_2 emission from geothermal power plants in high-temperature fields is about 120 g/kWh with current technology and expected to decrease to 10 g/kWh with improved technology. Geothermal electricity production of about 1000 TWh/yr in 2050 will mitigate (depending on what is substituted) hundreds of million tons CO_2/yr.

Geothermal heat pumps driven by fossil fuelled electricity reduce the CO_2 emission by at least 50% compared with fossil fuel fired boilers. If the electricity that drives the geothermal heat pump is produced from a renewable energy source like hydropower or geothermal energy the emission savings are up to 100%. When considering the projected world-wide growth of direct use including geothermal heat pumps the CO_2 emission saving amounts to about 300 million tons of CO_2 in 2050 [8].

10. Conclusions

The basis of geothermal energy is the immense heat content of the earth's interior; since billions of years it is constantly supplied by the decay of natural radioisotopes.

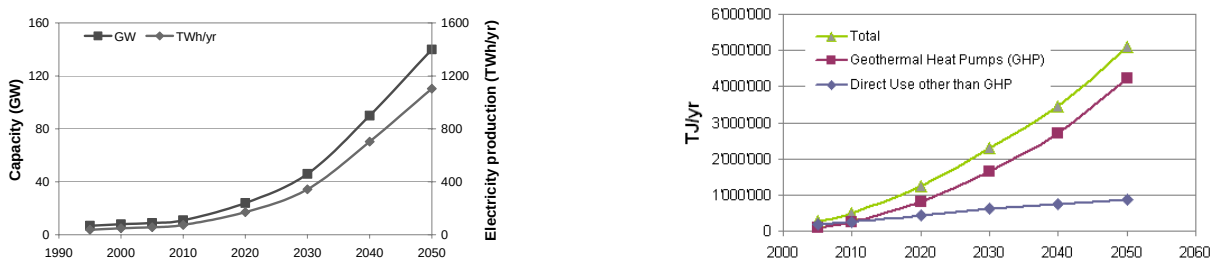

Fig. 1. Projection of geothermal power development (left); projection of direct use heat production development (right) to 2050. From [8].

Thus the resource is vast and ubiquitous and has a correspondingly large potential for utilization.

Without utilization, the terrestrial heat flow (from a capacity of 40 million MW thermal power) is lost to the atmosphere. Instead, the heat flow can be diverted towards heat sinks created by utilization. Geothermal energy is well positioned within the renewables, especially in terms of potential and availability (production versus installed capacity).

There are two main lines of geothermal energy utilization: power generation and direct use. Base-load electricity is produced from geothermal resources in 24 countries, five of which obtain 15-22% of their national electricity production from geothermal energy. The worldwide power production is about 60 TWh/yr of electricity. Present investment cost in geothermal power stations is 2-4.5 million €/MWe, and the generation cost is 40-100 €/MWh.

Direct application of geothermal energy (for space heating, agriculture, bathing etc.) is reported from 72 countries. The worldwide direct use of geothermal heat is currently about 300 PJ/yr. The highest growth rate is with geothermal heat pumps (GHP), one of the fastest growing renewable energy technologies. World-wide production increases (in PJ/yr): 14.6 in 1995, 23.3 in 2000, 87.5 in 2005. GHPs provide space heating, cooling and also domestic hot water.

Geothermal technologies operate with little or no greenhouse gas emissions since no burning processes are involved. Power generation as well as direct use already contribute to the reduction of CO_2 emissions. Further deployment, – depending on future growth rates – could reduce CO_2 emissions even more significantly.

It is considered possible to increase the installed world geothermal electricity capacity from the current 10 GW to 70 GW with present technology, and to 140 GW with enhanced technology until 2050. Successful Enhanced Geothermal Systems (EGS) could increase the capacity by at least an order of magnitude. Production from direct use in 2050 has been estimated at 5.1 EJ/yr, with the GHP portion at 4.2 EJ/yr.

Geothermal energy is available day and night every day of the year and can thus serve as a supplement to energy sources, which are only available intermittently. Renewable energy sources can contribute significantly more to the mitigation of climate change by cooperating than by competing.

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