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Geothermal Energy amongst the World's Energy Sources

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ABSTRACT

The world primary energy consumption is about 400 EJ/a. It is mostly provided by fossil fuels (80%). The renewables collectively provide 14% of the primary energy, mostly in the form of traditional biomass (9%) and much less by large (>10MW) hydropower stations (2%) and the "new renewables" (2%). Nuclear energy provides 7% of the world primary energy. The World Energy Council expects the world primary energy consumption to have grown by 50-275% in 2050 depending on different scenarios. The renewable energy sources are expected to provide 20-40% of the primary energy in 2050. The technical potential of renewable energy sources is estimated 7600 EJ/a, and thus certainly sufficiently large to meet future world energy requirements. The question is how large a part of the technical potential can be harnessed in an economical, environmentally and socially acceptable way.

Of the total electricity production from renewables of 2968 TWh in 2001, 91% came from hydropower, 5.7% from biomass, 1.8% from geothermal and 1.4% from wind. Solar electricity contributed 0.06% and tidal 0.02%. A comparison of the renewable energy sources (data from the UN World Energy Assessment Report update, 2004) shows the current electrical energy cost to be 2-10 UScents/kWh for geothermal and hydro, 4-8 UScents/kWh for wind, 3-12 UScents/kWh for biomass, 25-160 UScents/kWh for solar photovoltaic and 12-34 UScents/kWh for solar thermal electricity. Heat from renewables is commercially competitive with conventional energy sources. The current cost of direct heat from biomass is 1-6 UScents/kWh, geothermal 0.5-5 UScents/kWh, and solar heating 2-25 UScents/kWh.

The significant fluctuations in oil prices caused by political unrest in key oil producing regions should encourage governments to focus more on indigenous energy sources to meet their basic energy requirements. Since 1973, five major disruptions in world oil supplies (>4 million barrels/day supply loss) have occurred and caused significant escalations of oil prices. Recent developments in the deregulation of the electricity markets and integration of the electricity networks in Europe have unstabilised electricity prices to consumers. This makes e.g. ground source heat pumps a favourable alternative as base load heat source in countries where electrical heating is common.

1. INTRODUCTION

In 2002 government leaders, heads of industry, civil society and representatives of United Nations organizations met in Johannesburg at the World Summit for Sustainable Development (WSSD). This conference brought energy issues to the centre of global debate. Energy is for the first time, in an intergovernmental process, directly linked to the Millennium Development Goals of the United Nations, which are an ambitious set of quantified development targets agreed on by the international community during the Millennium Assembly of the United Nations in 2000.

With increasing awareness of the detrimental effects of the burning of fossil fuels on the environment, there has been an increasing interest world wide in the use of clean and renewable energy sources. It is important for the proponents of renewable energy sources to be aware of the outlines of the world energy use. The present paper starts with a description of recent energy forecasts for the world in the new century and the increasing role that renewable energy sources are expected to play in the world energy mix. The forecasts referred to here have been initiated by the World Energy Council. The present use of energy sources is summarised. A comparison is made of geothermal energy with other renewable energy sources based on data presented in the World Energy Assessment report (WEA, 2000) and its 2004 update (WEA, 2004) prepared by the United Nations Development Programme (UNDP), the United Nations Department of Economic and Social Affairs (UN-DESA), and the World Energy Council (WEC). The present paper is largely based on two review papers recently published by the author (Fridleifsson, 2002; 2003).

2. WORLD ENERGY FORECASTS

Amongst the top priorities for the majority of the world´s population is access to sufficient affordable energy. There is a very limited equity in the energy use in the different parts of the world. Some 70% of the world´s population lives at per capita energy consumption level one-quarter of that of W-Europe, and one-sixth of that of the USA (WEC,1993). Two billion people, a third of the world´s population, have no access to modern energy services. A key issue to improve the standard of living of the poor is to make clean energy available to them at prices they can cope with. World population is expected to double by the end of the 21st century. To provide sufficient commercial energy (not to mention clean energy) to the people of all continents is an enormous task.

WEC has presented several scenarios for meeting the future energy requirements with varying emphasis on economic growth rates, technological progress, environmental protection and international equity (Nakicenovic et al., 1998). All the scenarios provide for substantial social and economic development, particularly in the developing countries. They provide for improved energy efficiencies and environmental compatibility. During 1990-2050, the primary energy consumption is expected to increase by some 50% according to the most environmentally conscious scenario and by some 275% according to the highest growth rate scenario. In the environmental scenario, the carbon emissions are expected to decrease slightly from 1990

levels. The high growth rate scenario is expected to lead to a doubling of the carbon emissions.

The scarcity of energy resources forecasted in the 1970s did not occur. With technological and economic development, estimates of the ultimately available energy resource base continue to increase. Economic development over the next century will apparently not be constrained by geological resources. Environmental concerns, financing, and technological constrains appear more likely to limit future development.

In all WEC´s scenarios, the peak of the fossil fuel era has already passed (Nakicenovic et al., 1998). Oil and gas are expected to continue to be important sources of energy in all cases, but the role of renewable energy sources and nuclear energy vary highly in the scenarios and the level to which these energy sources replace coal. In all the scenarios, the renewables are expected to become very significant contributors to the world primary energy consumption, providing 20-40% of the primary energy in 2050 and 30-80% in 2100. They are expected to cover a large part of the increase in the energy consumption and to replace coal.

It is a very legitimate question to ask whether these scenarios are realistic. Table 1 shows the technical potential of renewable energy resources (WEA, 2000). The technical potential is the yearly availability of the renewable resources.

There is no question that the technical potential of the renewables is sufficiently large to meet future world energy requirements. The question is, however, how large a part of the technical potential can be harnessed in an economical, environmentally and socially acceptable way. This will probably vary between the energy sources. It is worth noting, however, that the present annual consumption of primary energy in the world is about 400 EJ (Table 2).

Table 1: Technical potential of renewable energy sources (WEA, 2000)

	EJ/a
Hydropower	50
Biomass	276
Solar energy	1575
Wind energy	640
Geothermal energy	5000
TOTAL	**7600**

3. WORLD ENERGY SOURCES

Table 2 shows the world primary energy consumption in 2001 (WEA, 2004). Fossil fuels provide 80% of the total, with oil (35%) in first place, followed by coal (23%) and natural gas (22%). The renewables collectively provide 14% of the primary energy, mostly in the form of traditional biomass (9%) and much less by large (>10MW) hydro power stations (2%) and the "new renewables" (2%). Nuclear energy provides 7% of the world primary energy.

If we only look at the electricity production, the role of hydropower becomes much more significant. The world electricity production was about 14.000 TWh in 1998 as compared with 6.000 TWh in 1973 (IEA, 2000). Most of the electricity was produced by coal (38%), followed by hydro (18%), nuclear (17%), natural gas (16%) and oil (9%). Only 2% of the electricity was provided by the "new renewables" (small hydro, biomass, geothermal, wind, solar and tidal energy).

Table 2: World primary energy consumption in 2001 (WEA, 2004)

Energy Source	**Primary energy**	
	EJ	**%**
Fossil fuels	**332**	**79.4**
Oil	147	35.1
Natural gas	91	21.7
Coal	94	22.6
Renewables	**57**	**13.7**
Large hydro (>10 MW)	9	2.3
Traditional biomass	39	9.3
"New renewables" (biomass, geothermal,solar, small hydro (<10MW), tidal, wind)	9	2.2
Nuclear	**29**	**6.9**
Nuclear	29	6.9
Total	**418**	**100**

4. GEOTHERMAL ENERGY

Although geothermal energy is categorised in international energy tables amongst the "new renewables", it is not a new energy source at all. People have used hot springs for bathing and washing of clothes since the dawn of civilisation in many parts of the world. An excellent book was recently published with historical records and stories of geothermal utilisation from all over the world (Cataldi et al., 1999).

It was first in the 20th century that geothermal energy was harnessed on a large scale for space heating, industry, and electricity generation. Prince Piero Ginori Conti initiated electric power generation with geothermal steam at Larderello, Tuscany, in 1904. Commercial production of electricity started in Larderello in 1913. The first large scale municipal geothermal district heating service started in Iceland in 1930. Geothermal energy has been produced commercially for about ninety years, and for four decades on the scale of hundreds of MW both for electricity generation and direct use. The utilisation has increased rapidly during the last three decades. In 2000, geothermal resources have been identified in over 80 countries and there are quantified records of geothermal utilisation in 58 countries in the world.

In 1999, the worldwide use of geothermal energy amounted to about 49 TWh/a of electricity (Huttrer, 2001) and 53 TWh/a for direct use (Lund and Freeston, 2001). A recent estimate of the geothermal potential of the world (Stefansson, 1998), gives the total potential for the resources suitable for electricity generation (resource temperature in excess of 150°C) as 11,000 ± 1,300 TWh/a, and the total potential resources for direct use (resource temperature lower than 150°C) in excess of 1400 EJ/a (390,000 TWh/a heat). These figures for the potential cover both known and unidentified resources. Stefansson (1998) estimates the identified geothermal resources to be 2000 ± 140 TWh/a for electricity generation, and in excess of 7000 TWh/a heat for direct use. It is clear that the present use of geothermal energy (49 TWh/a for electricity and 53 TWh/a for direct use) is a very small fraction of the identified geothermal potential. There is certainly space for an accelerated use of geothermal energy both for electricity generation and direct use in the near future. With both ample resources and a relatively mature technology at hand, the question of future development of geothermal utilisation boils down to economic and political competitiveness with other energy sources on the market in the different countries.

5. COMPARISON OF GEOTHERMAL WITH OTHER RENEWABLES

The World Energy Assessment report (WEA, 2000), prepared by UNDP, UN-DESA and the World Energy Council, was written as a contribution of the United Nations Commission on Sustainable Development to the "Rio Plus Ten" conference in Johannesburg 2002, more formally named the World Summit for Sustainable Development (WSSD). The report gives a very valuable and comprehensive description of the status of the world´s energy sources at the turn of the millennium. Chapter 7 of this voluminous report deals with the renewable energy technologies and includes a highly interesting table entitled "Current status and potential future costs of renewable energy technologies". An overview and update of the World Energy Assessment was published in 2004 (WEA, 2004), with much of the basic data coming from 2001 instead of 1998 in the first version (WEA, 2000).

The data presented here in Tables 2, 3, 4 and 5 is extracted from Table 7 of the World Energy Assessment overview and 2004 update (WEA, 2004).

Table 3 shows the status of electricity production from renewables. The total electricity production from renewables in 2001 was 2968 TWh. By far the largest contribution (91%) came from hydropower, but 5.7% from biomass, 1.8% from geothermal, and 1.4% from wind. The electricity production by solar energy constituted only 0.06% and from tidal energy 0.02%. The current energy cost is lowest for hydropower and geothermal, followed by biomass and wind. Solar photovoltaic electricity is by far the most expensive, but significant cost reductions are expected in the future. The annual % increase in the electricity production during 1997-2001 is 2-3% for hydro, biomass and geothermal, but reported 30% for wind and solar photovoltaic (WEA, 2004).

Table 4: Electricity from four renewable energy resources in 2001, c**ompiled from data in Table 7 in World Energy Assessment (WEA, 2004)**

	Operating capacity		Production/a	
	GWe	%	TWh	%
Geothermal	8	24.4	53	53.8
Wind	23	70.1	43	43.7
Solar	1.5	4.6	1.9	1.9
Tidal	0.3	0.9	0.6	0.6
Total	32.8	100	98.5	100

Table 4 shows the operating capacity and the electricity production in 2001 for four "new and renewable" energy sources, namely geothermal, wind, solar and tidal energy. The data for the table is compiled from Table 7 of the 2004 update of the World Energy Assessment (WEA, 2004). The table reflects clearly the variable capacity factor of the power stations using the four renewable sources. At the end of 2001, wind energy was in the leading position with regard to installed capacity (70.1%) followed by geothermal (24.4%). Geothermal was, however, the leading electricity producer with 53.8% of the total electricity production of the four, followed by wind energy with 43.7% of the electricity production. The relatively high share in the electricity production reflects the reliability of geothermal plants which can be operated at capacity factors in excess of 90%. Geothermal energy is independent of weather contrary to solar, wind, or 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 base load suppliers.

Table 5 shows the status of direct heat production from renewables. Biomass constitutes 87% of the total, solar heating 7% and geothermal 6%. The biomass shown here is, of course, only a fraction of the total use of biomass for heating purposes in the world, as fuel wood etc. is not included. The biomass energy shown here is restricted to heat embodied in steam (or hot water in district heating), often produced by combined heat and power production using forest residues, black liquor, or bagasse (WEA, 2004). Each of the energy sources are site specific and have their respective restraints.

Heat production from renewables is competitive with conventional energy sources. The current cost of direct heat from biomass is 1-6 US¢/kWh, geothermal 0.5-5 US¢/kWh, and solar heating 2-25 US¢/kWh (WEA, 2004).

As regards geothermal energy, it is widely used for municipal district heating systems, with the largest systems in Iceland, France, China and Turkey. Space heating of individual houses is also common (in many cases with heat pumps), not least in the USA, Sweden, and Switzerland. Long distance between the geothermal production field and the customer is not a big problem if space heating is required for most of the year. In Iceland, for example, the geothermal water is commonly piped 10-20 km from the geothermal fields to the towns. Transmission pipelines are mostly of steel insulated by rock wool (surface pipes) or polyurethane (subsurface). In recent years, several small villages and farming communities have successfully used plastic pipes (polybutylene) with polyurethane insulation as transmission pipes. The temperature drop is insignificant in large diameter pipes with high flow rate, exemplified by 1°C drop in a 27 km pipeline with 800 mm diameter and 5°C in a 11 km pipeline with 175 mm diameter. The temperature drop in a 19 km plastic pipeline with 110 mm diameter is 15°C.

6. DISCUSSION

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. The use of ground source heat pumps has changed this. In this case, the earth is the heat source for the heating and/or the heat sink for cooling, depending on the season. This has made it possible for people in 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.

The significant fluctuations in oil prices caused by political unrest in key oil producing regions should encourage governments to focus more on indigenous energy sources to meet their basic energy requirements. Since 1973, four major disruptions in world oil supplies (>4 million barrels/day supply loss) have occurred and caused significant escalations of oil prices (IEA, 2003). These were in 1973-1974 (Arab-Israeli War), 1978-1979 (Iranian Revolution), 1980-1981 (Iran-Iraq War), and 1990-1991 (Gulf Crisis). A new wave of oil price escalations came with the terrorist attacks in the USA on 11th September 2001. This was prolonged by the war in Afghanistan and the war in Iraq as well as its aftermath. The world oil prices in 2004 are having a serious effect on the economy of most countries. This should encourage many nations to increase markedly their use geothermal energy and other indigenous energy resources.

Fridleifsson.

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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. According to a report of the European Commission (Annual Energy Review, 1998), the contribution of renewables in the EU was 5.3% in 1996. The largest contributor was biomass (62.1%), followed by hydropower (33.0%), geothermal (3.7%) wind (0.6%), solar (0.3%), and others (0.3%). Stefansson (1999) points out how the two energy sources, hydro and biomass, dominate the present contribution of renewables in Europe. The only other renewable source with more than 1% contribution is geothermal energy. He states that "there might be a possibility to increase the contribution from a given energy source several times during the next 10-15 years, but it is unrealistic to assume that the energy production for a given source can be increased by a factor of 100 or 1000 during this time".

Only hydro, biomass, geothermal, and wind energy, appear technically ready to make a significant contribution towards an overall reduction in the CO_2 emissions in Europe by 2012. In spite of this, as yet, the role of geothermal energy is very limited in the energy strategy plans for Europe. In 2004, several countries richly endowed with geothermal resources have become members of the European Union. Amongst these are Hungary, Poland, Slovakia and Slovenia. This will hopefully strengthen the presently weak political support for the development of geothermal energy in Europe.

International forecasts expect the share of renewable energy sources in the world energy mix to increase very significantly in the new century (to 30-80% in 2100). How large the share of geothermal energy will be at the end of the new century is much dependant on the actions of the geothermal community and the countries leading geothermal development.

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Table 3: Status of electricity production from renewables, end 2001
(data extracted from Table 7 of 2004 update of World Energy Assessment (WEA, 2004))

	Energy production in 2001		Operating capacity, end 2001		Capacity factor	Average Capacity factor	Current energy cost	Potential future energy cost	Turnkey investment cost	Increase in energy produ. 1997-2001
	TWhe	%	GWe	%	%	%	US¢/kWh	US¢/kWh	US$/kW	%/a
Hydro *	2700	90.95	715	90.76	35-60	43	2-10	2-10	1000-3500	2
Biomass	170	5.73	40	5.08	25-80	49	3-12	4-10	500-6000	3
Geothermal	53	1.79	8	1.01	45-90	76	2-10	1-8	800-3000	3
Wind	43	1.45	23	2.92	20-40	21	4-8	3-10	850-1700	30
Solar		0.06		0.19						
photovoltaic	1		1.1		6-20	10	25-160	5-25	5000-18000	30
thermal electr.	0.9		0.4		20-35	26	12-34	4-20	2500-6000	2
Tidal	0.6	0.02	0.3	0.04	20-30	23	8-15	8-15	1700-2500	0
Total	2968.5		787.8							

* Large hydro stations produce 2600 TWh (capacity 690 GWe) and small 100 TWh (25 GWe).

Table 5: Status of direct heat production from renewables, end 2001
(data extracted from Table 7 of 2004 update of World Energy Assessment (WEA, 2004))

	Energy production in 2001	Operating capacity end 2001	Capacity factor	Average Capacity factor	Current energy cost	Potential future energy cost	Turnkey investment cost	Increase in inst. capac. last 5 years
	TWh-th	GWth	%	%	US¢/kWh	US¢/kWh	US$/kW	%/a
Biomass*	730	210	25-80	40	1-6	1-5	170-1000	2
Solar heat low temp.	57	57	8-20	11	2-25	2-10	300-1700	10
Geothermal	55	11	20-70	57	0.5-5	0.5-5	200-2000	10

* Table 7 (WEA, 2004) also shows ethanol under biomass, with operating capacity (end 2001) 18 billion litres, energy production of 450 PJ, current energy cost 8-25 $/GJ and future potential energy cost of 6-10 $/GJ.