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GEOTHERMAL ENERGY AMONG THE WORLD'S ENERGY SOURCES

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ABSTRACT

The world primary energy consumption is about 400 EJ/year. It is mostly provided by fossil fuels (79%). 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/year, 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.

In 2005, geothermal resources have been identified in some 90 countries and there are quantified records of geothermal utilisation in 72 countries. Electricity is produced by geothermal in 23 countries. In 2004, the worldwide use of geothermal energy was about 57 TWh/a of electricity, and 76 TWh/a for direct use. The electricity production increased by 16% from 1999 to 2004 (annual growth rate of 3%). The direct use increased by 43% from 1999 to 2004 (annual growth rate of 7.5%). El Salvador, Costa Rica and Nicaragua are among the six top countries in the share of geothermal electricity in their national electricity production. Geothermal power stations provide about 12% of the total electricity generation of the four countries Costa Rica, El Salvador, Guatemala and Nicaragua. Only a small part of the geothermal resources in the region has been harnessed so far.

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 (WEC). 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; Fridleifsson, 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 enviornmental 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.
Source: World Energy Assessment (WEA, 2000)

	EJ per year
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.

TABLE 2: World Primary Energy Consumption in 2001.
Source: World Energy Assessment (WEA, 2004)

Energy Source	**Primary energy (exajoules)**	**Percentage**
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**

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).

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 has been 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.

TABLE 3: Electricity generation and direct use of geothermal energy in 2004.
Data from Bertani (2005), and Lund et al. (2005)

	Electricity generation			**Direct Use**		
	Installed capacity MWe	**Total production**		**Installed capacity MWt**	**Total production**	
		GWh/a	**%**		**GWh/a**	**%**
Africa	136	1088	2	190	763	1
America	3941	26794	47	8988	12119	16
Asia	3290	18903	33	5044	17352	23
Europe	1124	5745	12	13628	42916	56
Oceania	441	2791	5	418	2793	4
Total	**8933**	**56786**	**100**	**28268**	**75943**	**100**

In 2005, geothermal resources have been identified in some 90 countries and there are quantified records of geothermal utilisation in 72 countries. Electricity is produced by geothermal in 23 countries. In 2004, the worldwide use of geothermal energy amounted to about 57 TWh/a of electricity (Bertani, 2005) and 76 TWh/a for direct use (Lund et al., 2005). The electricity production increased by 16% from 1999 to 2004 (annual growth rate of 3%). The direct use increased by 43% from 1999 to 2004 (annual growth rate of 7.5%). Table 4 lists the top fifteen countries in geothermal electricity production and in geothermal direct use in the world in 2004 (in GWh/year).

The main types of direct use of geothermal energy are space heating 52% (thereof 32% using heat pumps), bathing and swimming (including balneology) 30%, horticulture (greenhouses and soil heating) 8%, industry 4%, and fish farming 4% (Lund et al., 2005).The main growth in the direct use sector has during the last decade been in the geothermal (ground-source) heat pumps. This is due, in part, to the ability of geothermal heat pumps to utilise groundwater or ground-coupled temperatures anywhere in the world. Almost all of the installations of the ground-source heat pumps occur in North America and Europe, increasing from 26 countries in 2000 to 33 countries in 2005 (Lund et al., 2005).

TABLE 4: Top fifteen countries in geothermal use in 2004.
Data on electricity from Bertani (2005) and on direct use from Lund et al. (2005)

Geothermal electricity production		**Geothermal direct use**	
	GWh/a		**GWh/a**
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

It is of great interest to note that among the top fifteen countries in electricity production with geothermal, there are ten developing countries. Among the top fifteen countries in direct use of geothermal, there are six developing and transitional countries. Table 5 shows the top fifteen countries with the highest % share of geothermal in their national electricity production. Special attention is drawn to that El Salvador, Costa Rica and Nicaragua are among the six top countries in Table 5, and Guatemala in eleventh place Many of the leading geothermal experts in the top countries are graduates of the UNU-GTP in Iceland.

TABLE 5: Top fifteen countries with highest % share of geothermal in their national electricity production and number of UNU Fellows trained in Iceland

Geothermal electricity production			
Country	**GWh/a**	**% national electricity**	**Number of UNU-GTP Fellows**
El Salvador	967	22.0	22
Kenya	1,088	19.2	39
Philippines	9,253	19.1	31
Iceland	1,483	17.2	
Costa Rica	1,145	15.0	13
Nicaragua	271	9.8	5
Guadeloupe (France)	102	9.0	
New Zealand	2,774	7.1	
Indonesia	6,085	6.7	20
Mexico	6,282	3.1	4
Guatemala	212	3.0	3
Italy	5,340	1.9	
USA	17,917	0.5	
Japan	3,467	0.3	
China	96	30% of Tibet	64

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, 6, 7 and 8 is extracted from Table 7 of the World Energy Assessment overview and 2004 Update (WEA, 2004).

Table 6 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 hydro-power, 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 6: 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	Current energy cost	Potential future energy cost	Turnkey investment cost	Increase in energy production 1997-2001
	TWh(e)	%	GWe	%	%	US¢/kWh	US¢/kWh	US$/kW	%/year
Hydro *	2700	90.95	715	90.76	35-60	2-10	2-10	1000-3500	2
Biomass	170	5.73	40	5.08	25-80	3-12	4-10	500-6000	3
Geothermal	53	1.79	8	1.01	45-90	2-10	1-8	800-3000	3
Wind	43	1.45	23	2.92	20-40	4-8	3-10	850-1700	30
Solar photovoltaic	1	0.06	1.1	0.19	6-20	25-160	5-25	5000-18000	30
thermal electricity	0.9		0.4		20-35	12-34	4-20	2500-6000	2
Tidal	0.6	0.02	0.3	0.04	20-30	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 7: Electricity from four renewable energy resources in 2001.
Compiled from data in Table 7 in World Energy Assessment (WEA, 2004)

	Operating capacity		**Production per year**	
	GWe	**%**	**TWh/y**	**%**
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 7 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 8 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.

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

6. DISCUSSION

The significant fluctuations in oil prices caused by political unrest in key oil producing regions encourage many governments to focus 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 great increase in world oil prices since 2004 (Figure 1) has a serious effect on the economy of most countries. In August 2006, the price of crude oil (Brent) surpassed USD 75/barrel, but had decreased to about USD 55/barrel in early November. The high oil prices of the last few years have encouraged many nations to increase markedly their use of geothermal energy and other indigenous energy resources.

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%).

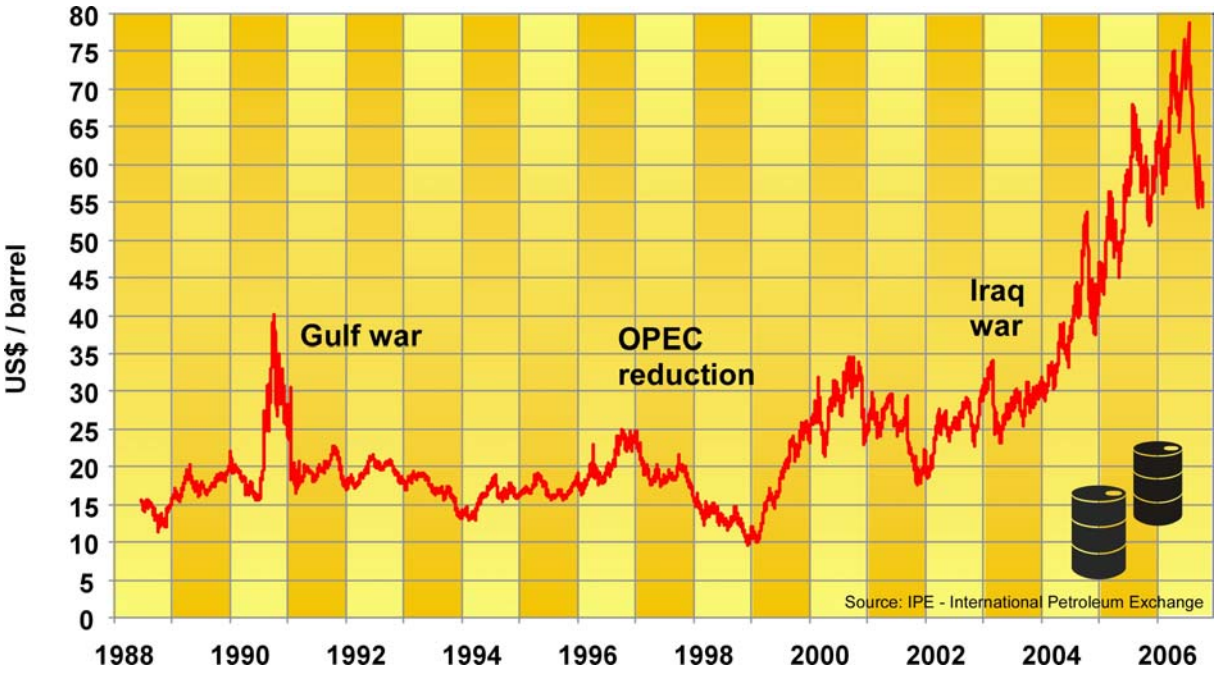

FIGURE 1: Average price of crude oil (Brent) June 1988 – November 2006

Central America is one of the world´s richest regions in geothermal resources. Geothermal power stations provide about 12% of the total electricity generation of the four countries Costa Rica, El Salvador, Guatemala and Nicaragua, according to data provided from the countries at the World Geothermal Congress in 2005 (Mainieri 2005; Rodriguez and Herrera 2005; Roldán Manzo 2005; Zuniga Mayorga 2005). The geothermal potential for electricity generation in Central America has been estimated to be some 4,000 MWe (Lippmann 2002). Only a small portion of the geothermal resources in the region has been harnessed so far (under 500 MWe).

Geothermal energy, with its proven technology and abundant resources, can make a significant contribution towards reducing the emission of greenhouse gases worldwide. It is necessary that governments implement a legal and institutional framework and fiscal instruments allowing geothermal resources to compete with conventional energy systems.

With the large untapped geothermal resources and the significant expertise and experience in geothermal development in the region, Central America may become an international example of how to reduce the overall emission of greenhouse gases in a large region. This should encourage the international financial community as well as the environmental movements to support the sustainable development of geothermal resources in Central America.

All the Central American countries (except Belize) are signatories of the Kyoto protocol, and are thus eligible for the Certified Emission Reduction Mechanism (CDM) credits. The CDM permits industrialized countries, which have emission targets under the Kyoto protocol, to invest in sustainable development projects in developing countries that reduce greenhouse gas emission, and thereby generate tradeable emission credits.

The Kyoto protocol will be reviewed in 2008 and negotiations started for a new protocol for the period2013 to 2017 (http://unfccc.int). The new protocol should be ready in 2009, as several years are needed for its ratification by the various countries. Countries which ratified the Kyoto protocol are responsible for about 55% of the world's CO_2 emissions. Unfortunately, the USA (which is responsible for some 25% of the world's greenhouse gas emissions) and Australia are not signatories of the Kyoto protocol. There are strong hopes in the international community that both of these countries as well as Argentina, Brazil, China, India and Mexico will sign the new protocol. The Stern Review on the Economics of Climate Change presented in October 2006 (Stern Review, 2006), with its dramatic picture of the consequences of present greenhouse gas emissions for mankind, has already put strong pressure on the international community to unite in reducing greenhouse gas emissions.

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Geothermal energy is a renewable, local and eco-friendly source of energy that is simultaneously efficient and economical. It offers considerable potential for heat and power generation.Â Geothermal energy around the world. The main producing countries are Japan, China, Russia, Central and Eastern European countries and the United States. France has nevertheless played a pioneering role in the development of geothermal energy, largely as a result of the doublet drilling technique (two wells, the first referred to as the production well, and the second as the re-injection well), and the Dogger aquifer in the Paris Region, which has the largest density of ongoing geothermal operations in the world. Geothermal: integral to government thinking on sustainable development. Geothermal energy, form of energy conversion in which heat energy from within Earth is captured and harnessed for electrical power generation, space heating and cooling, and various direct uses. Learn about the uses of geothermal energy and their history and about their economic and environmental pros and cons.Â The amount of usable energy from geothermal sources varies with depth and by extraction method.Â Such resources are typically limited to parts of the world characterized by recent volcanic activity or located along plate boundaries or within crustal hot spots. Even though there is a continuous source of heat within Earth, the extraction rate of the heated fluids and steam can exceed the replenishment rate, and, thus, use of the resource must be managed sustainably. Uses. People around the world use geothermal energy to produce electricity, to heat buildings and greenhouses, and for other purposes. The earth's core lies almost 4,000 miles beneath the earth's surface. The double-layered core is made up of very hot molten iron surrounding a solid iron center.Â Geothermal energy is called a renewable energy source because the water is replenished by rainfall, and the heat is continuously produced by the earth. 2. History of Geothermal Energy. Many ancient peoples, including the Romans, Chinese, and Native Americans, used hot mineral springs for bathing, cooking, and heating. Water from hot springs is now used world-wide in spas, for heating buildings, and for agricultural and industrial uses. Many people believe hot mineral springs have natural healing powers.