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PROCEEDINGS OF 2002 BEIJING INTERNATIONAL GEOTHERMAL SYMPOSIUM

（29～31 Oct. 2002，Beijing，China）

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内 容 提 要

本论文集收集了来自16个国家的作者，包括不少国际地热界的知名学者，为2002年北京国际地热研讨会专门撰写的论文共61篇。论文集分为五个部分，即地热开发利用、地热与北京奥运、地热资源勘查与评价、地热资源管理、地热技术研究与应用。这些论文较全面地反映了国际、国内以及北京地区地热开发利用，特别是直接利用的发展状况，介绍了地热资源勘查评价和地热田管理方面的经验和技术、地热直接利用的技术方法和措施、热泵技术和地热回灌技术等，总结了北京2008年奥运公园地区的地质勘查资料，研究了奥运公园及其周围地区的地热地质条件，提出了奥运公园地热开发的方向及一些非常有价值的具体措施。

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Inscription by Vice Premier of the State Council, P. R. C.

The geothermal resources in the Capital are highly precious, and we should attach great importance to the protection, rational development and use of the resources.

WEN Jiabao

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二〇〇二、九

Inscription by Vice Minister of the Ministry of Land and Resources，P. R. C.
Director General of China Geological Survey（CGS）

To carry out rational development，scientific utilization and effective protection to the geothermal resources in the Capital.

SHOU Jiahua
September 2002

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序

为落实北京市政府对绿色奥运的承诺，合理开发、科学利用北京地区的地热资源，实现地热资源的可持续利用，经市政府批准，我们于2002年10月29日至10月31日，在北京举办以“地热与北京2008奥运会”为主题的2002北京地热国际研讨会。会议以介绍国际、国内地热开发的现状和发展趋势为背景，与国际、国内地热专家、学者及政府有关部门官员共同研讨北京地热资源及其开发利用前景，地热资源为2008年北京奥运服务的可能性；探讨在地热大量开采的条件下对地热田的管理措施及可持续利用方案。

为开好这次会议，我们向国内外知名地热专家、地热界同行发出了参会的邀请，并征集会议论文。在国内外地热专家的热忱关心与积极支持下，会前我们收到许多国内外论文，经大会筹备组技术委员会组织专家审核后，选编了61篇，收入本论文集。其中涉及地热资源开发利用的21篇、地热与北京奥运7篇、地热资源勘查与评价11篇、地热资源管理8篇和地热应用技术研究14篇。

为使世界了解北京地热，北京地热界为会议撰写了北京的地热资源概况、地热资源勘查评价、典型地区地热资源开发、地热回灌、地热资源管理以及奥运公园地区的地热资源开发的可行性等多篇论文，这将有助于国内外地热界同行了解北京近期地热资源勘查开发利用情况及存在的一些问题，为北京地热资源的合理开发与可持续利用献计献策。

感谢国内外地热界同行为会议撰写了内容十分丰富的论文，尤其要感谢国际地热专家就世界地热能的利用、所在地区地热资源开发利用的范例以及地热在中国北京2008年奥运会的应用等撰写的论文，这些论著对我们了解世界地热资源开发利用的新动态、新经验，做好北京地热资源合理开发及奥运公园地区地热科学利用，实现可持续发展具有重要的指导意义。

祝贺2002北京地热国际研讨会圆满成功。

北京地热国际研讨会主席

2002年10月

FOREWORD

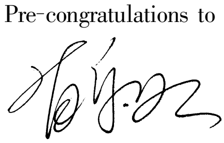
2002 Beijing International Geothermal Symposium, which has been approved by Beijing Municipal Government, with the theme of "Geothermal and the 2008 Olympics in Beijing" will be held in Beijing on 29～31 October 2002, in order for Beijing Municipal Government to implement the promise of "Green Olympics", for proper development, scientific utilization and sustainable exploitation of geothermal resources in the area of Beijing. During the symposium geothermal experts and scholars from home and abroad will exchange their worldwide experiences each other and deliberate together with government's officers from related departments around the theme of the symposium, including the prospects of development of geothermal resources in Beijing, the possibility of geothermal utilization in 2008 Olympic Games, the measures of management for geothermal field under large extraction and the scheme of sustainable exploitation of geothermal energy.

Our invitation and call for paper were fortunately gotten active responses from famous geothermal experts and fraternities both at home and abroad. They contributed their papers for the symposium. The technical committee of the symposium selected 61 papers herein for the proceedings through relevant experts' appraisal. These papers cover various aspects related to the geothermal exploitation and utilization (21), the geothermal and the 2008 Olympics in Beijing (7), the exploration and assessment of geothermal resources (11), the management of geothermal resources (8) and the research and application of techniques (14).

In order to show geothermal development in Beijing, local geothermal professionals prepared a series of papers involving geothermal resources exploration and assessment, typical utilization, geothermal reinjection, resources management and the feasibility of geothermal application for the 2008 Olympics in Beijing. It will be helpful for the geothermal fraternities to know geothermal status and problems in Beijing. We welcome you to contribute ideas and exert efforts for our better future.

Great thanks to every geothermal professionals from home and abroad for your valuable recommendations. We greatly appreciate international geothermal experts' contribution, especially for those comments from the top-grade authorities in the world. They introduced worldwide status of development and utilization of geothermal resources, with typical demonstration, and suggested proper application for the 2008 Olympics in Beijing. Their experiences are very useful for our sustainable development of geothermal resources in Beijing.

Pre-congratulations to the satisfactory success of the 2002 Beijing International Geothermal Symposium!



MIAO Leru
Chairman of the 2002 Beijing International Geothermal Symposium
in October of 2002

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GEOTHERMAL EXPLOITATION AND UTILIZATION

WORLDWIDE UTILIZATION OF GEOTHERMAL ENERGY AND ITS APPLICATION TO 2008 OLYMPIC GAMES IN BEIJING, CHINA

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Abstract Geothermal energy has been used for electric power production, starting experimentally in Italy in 1904, and with the first commercial plant in 1913 at Larderello. This followed with plants in Mexico, New Zealand and at The Geysers in the United States. At present there are about 8,000 MWe installed in 22 countries, producing about 50,000 GWh/yr. Direct heat utilization has a much longer history, with early uses of hot springs at least 10,000 years ago. Early documentation of direct-use has not been consistent, and often left out key countries. The first reliable report on this use appeared in the 1970s. Today there are reported uses in at least 58 countries, with an estimated installed capacity of 15,200 MWt and annual production of 53,000 GWh. The capacity increase over the past 30 years has been 8.6% for electricity production and 9.7% for direct-use, compounded annually. The energy savings amounts to and equivalent 26.7 million tonnes of fuel oil and 23.8 million tonnes of carbon annually. Recommendations for the 2008 Summer Olympics in Beijing include utilization of the potential high temperature geothermal resource for binary power generation and direct cooling; the intermediate temperature geothermal resource for heating domestic hot water (showers, kitchen use, tap water) and swimming pools; and the low temperature resources for heating and cooling with geothermal heat pumps.

Keywords worldwide geothermal use, power generation, direct-use, geothermal heat pumps, 2008 Olympics, Beijing

1 INTRODUCTION

Early humans probably used geothermal water that occurred in natural pools and hot springs for cooking, bathing and to keep warm. We have archeological evidence that the Indians of the Americas occupied sites around these geothermal resources for over 10,000 years to recuperated from battle and take refuge. Many of their oral legends describe these places and other volcanic phenomena. Recorded history shows uses by Romans, Japanese, Turks, Icelanders, Central Europeans and the Maori of New Zealand for bathing, cooking and space heating. Baths in the Roman Empire, the middle kingdom of the Chinese, and the Turkish baths of the Ottomans were some of the early uses of balneology; where, body health, hygiene and discussions were the social custom of the day. This custom has been extended to geothermal spas in Japan, Germany, Iceland, countries of the former Austro-Hungarian empire, the Americas and New Zealand.

Other early uses included the geothermal water at Huaqingchi Hot Spring in China; where, a bathing and treatment facility was built in the Qin Dynasty (over 2,000 years ago), and a hot spring at Xiaotangshan near Beijing used for recreation for about 800 years by the royal family, and other high-ranking officials in the Ming and Qing Dynasties. Early industrial applications include chemical extraction from the natural manifestations of steam, pools and mineral deposits in the Larderello region of Italy. Serious industrial activity began only after the discovery of boric acid in the hot pools in 1777. The first attempt at using these minerals was made in 1810, and nine factories were built between 1816 and 1835. A flourishing chemical industry was in operation by the early 1900′s. At Chaudes-Aigues in the heart of France, the world's first geothermal district heating system was started in the 14th century and is still going strong.

As described above, we know that there have been many countries where geothermal has been used in the past, but most of this utilization has not been documented. However, a recent publication (1999): *Stories from a Heated Earth—Our Geothermal Heritage* (edited by R. Cataldi, S. Hodgson and J. Lund) describes many of these early uses prior to the industrial revolution. This publication covers more than 25 countries with historical information taken from the works of archaeologists, historians, geographers, anthropologists, scientists and engineers. Thus, we now have in a single reference documenting the early uses of geothermal energy —from hot spring bathing to the use of geothermal material such as obsidian and tuff, along with the legends and myths associated with fumaroles, hot springs and volcanic eruption. These uses continues today with electric power generation, and space heating and cooling.

2 DEVELOPMENTS IN THE 20TH CENTURY

2.1 Electric Power Generation

The first use of geothermal energy for electric power production started in Italy with experimental work by Prince Gionori Conti between 1904 and 1905. The first power plant (250 kWe) was commissioned in 1913 at Larderello. These developments were followed by Wairakai, New Zealand in 1958; an experimental plant at Pathe, Mexico in 1959; and at The Geysers in the United States in 1960. The first international geothermal meeting to report on geothermal utilization was the UN Conference on New Sources of Energy held in Rome in 1961 where developments in Italy, New Zealand, USA and Iceland were discussed (Smith, 1964). At that time, Iceland was proposing a plant at Hveragerdi and the experimental installation at Pathe was not mentioned. This was followed by the UN Symposium on the Development and Utilization of Geothermal Resources at Pisa in 1970 (Facca, 1970). Based on these reports and subsequent reports presented at the 2nd UN Symposium on the Development and Use of Geothermal Resources at San Francisco in 1975 (Armstead, 1975a), the GRC Annual meetings (1981, 1985 and 1990) (DiPippo, 1981 and 1985; Huttrer, 1990), and at the World Geothermal Congress in Florence in 1995 (Huttrer, 1995), along with the current report by Huttrer (2000) the development of geothermal electric power is presented in Table 1.

Table 1 Worldwide Development of Geothermal Electric Power

Year	Installed MWe	Energy GWh/yr	Number	Participants of Countries
1940	130		1	Italy
1950	293		1	Italy
1960	386	2,600 est.	4	+NZ, Mexico, & USA
1970	678	5,000 est	6	+Japan & USSR
1975	1,310		8	+Iceland & El Salvador
1980	2,110		14	+China, Indonesia, Kenya, Turkey, Philippines, & Portugal
1985	4,764		17	+Greece, France & Nicaragua
1990	5,832		19	+ Thailand, Argentina, & Australia－Greece
1995	6,797		20	+Costa Rica
2000	7,974	49,261	21	+ Guatemala & Ethiopia －Argentina
2002	8,000	50,000	22	+Austria (est.)

Unfortunately, no estimates were made of the energy produced during the period 1975 to 1995. There also appears to be slight differences in the installed MWe numbers between various authors.

The growth rate for installed electric capacity started slowly at 5.6% annually from 1940 to 1960, depressed by World War II and the destruction of the Italian fields at the end of the war. From 1960 to 1970, the rate increased slightly to 5.8% annually, and then picked up dramatically from 1970 to 1980 at 12.0%, and 1980 to 1990 at 10.7%——the growth years for geothermal energy. From 1990, the rate has dropped to 2.7% per year as influenced by the slowdown in the world economy, especially in southeast Asia, and the availability of cheap fossil fuels. The growth rate over the past 30 years has averaged 8.6% compounded annually.

DiPippo (1998), estimates the current capital cost for U.S. geothermal plants as follows:

Geothermal Field or type	Period	Installed cost/kW
The Geysers	1980～1983	US $ 414～780*
Single Flash	1984～1988	US $ 2,500～3,000
Double Flash	1985～1988	US $ 1,900～2,700
Binary	1987～1993	US $ 3,030～4,000

* The Geyser's cost includes plant cost only; all the rest include field development.

Estimates of the current cost of producing power is as follows (Wright, 2000):

The Geysers:	1.5 to 2.5 cents/kWh
Single flash:	2 to 4 cents/kWh
Binary:	3 to 5 cents/kWh (heavily dependent on size)
New construction:	5 to 6.5 cents/kWh

2.2 Direct Heat Utilization

Even though the direct-use of geothermal energy has a much longer history of use than electric power generation, the numbers are less reliable. In fact, it is difficult to compare installed capacity and annual use, due to the inclusion or exclusion of bathing, swimming and balneology figures. This has not been consistent, as in the early years this use was not included, but in the current report it is included (1985 on, but not in a consistent manner). Also, values prior to 1970 were not summarized and up to 1980 could only be estimated from country descriptions in rapporteur reports. The early reports did not include China, a large user of geothermal energy for direct use, due to the political situation at the time, and also did not include the United States; even though, a geothermal district heating system had been installed in Boise, Idaho in 1890 and individual wells had been utilized in Klamath Falls since the 1930s for home heating. Finally, since many direct-uses are small and not concentrated in one place, they are often overlooked by authors reporting on their country.

As a result, the 1961 UN conference in Rome reported only developments in Iceland, New Zealand, Italy, Japan and Kenya (Bodvarsson, 1964). This report described district heating of 45,000 houses in Reykjavik, use of 1,000 wells in Rotorua for space heating, heating of 95,000 m^2 of greenhouses in Iceland, production of 21,000 tons/yr of salt in Japan, the pulp and paper plant at Kawerau, the chemical industry at Larderello, pig raising in New Zealand, and chicken hatching in Kenya. The 1970 report of the UN meeting in Pisa included descriptions from Hungary, Iceland, Italy, Japan, New Zealand, and the USSR (Einarsson, 1970). As mentioned above, China and the United States were not included. The data in Table 2 is based on information in the 1970 UN Conference in Pisa, a report by Lawrence Livermore Laboratory in 1975 (Howard, 1975), the second UN Conference in San Francisco (Armstead, 1975b), papers by Lund in 1979 and 1982, reports from the GRC annual meetings in 1985 and 1990 (Gudmundsson, 1985; Freeston, 1990), the World Geothermal Congresses in 1995 in Italy (Freeston, 1996), and the current paper by Lund and Freeston (2000). Starting in 1995, geothermal heat pumps (ground-source heat pumps) were included in the reports and are now a significant part of the totals.

Table 2 Worldwide Development of Geothermal Direct Heat Utilization

Year	Installed MWt	Energy Wh/yr	Number of countries	Participants Reporting
1960			5	Iceland, Italy, New Zealand, Japan and Kenya
1970	800 est.	2,200 est.	6	+ Hungary & USSR − Kenya
1975	1,300 est		10	+ France, Philippines, Turkey & USA
1980	1,950		14	+ Austria, Czechoslovakia, Germany & Taiwan
1985	7,072	23,960	24	+ Australia, Canada, China, Columbia, Denmark, Mexico, Poland, Romania, Switzerland & Yugoslavia
1990	8,064		30	+ Algeria, Belgium, Bulgaria, Ethiopia, Greece, Guatemala, Thailand, & Tunisia − some countries not reporting
1995	8,664	31,236	30	Argentina, Georgia, Israel, Macedonia, Serbia, Slovakia, & Sweden − some countries not reporting
2000	15,145	52,976		see Lund and Freeston (2001)
2002	15,200	53,000	58	estimated

The large increase in installed capacity between 1980 and 1985 is due to the inclusion of pool heating at spas in Japan along with the first available data from China.

The annual capacity growth rate from 1970 to 1980 was 9.3%, from 1980 to 1990 was 15.2% (which was strongly influenced by data from Japan and China), and from 1990 to 2002 was 5.4%. The overall growth rate over the past 30 years has averaged 9.7% compounded annually. The large increases from 1970 to 1990 (average annual of 12.2%) and the recent reduction from 1990 to present, was influenced by the same factors as in the case of the electric power generation, except that the availability of cheap fossil fuels in recent years had a much larger effect than the economic slowdown in southeast Asia.

Examples of current district heating costs are 0.23 to 0.42 cents/1000 kcal (0.27 to 0.49 cents/kWh) in Turkey, compared to 3.4 cents/kWh for natural gas and 11.2 cents/kWh for electricity based heating (Mertoglu, et al., 1999). The Klamath Falls, Oregon district heating system charges 1.6 to 2.0 cents/kWh (not including capital cost) (Lund, 1999). This is 50%~80% of the natural gas cost, depending upon the efficiency of the gas conversion, and the comparable cost for electricity in the city is 5.5 cents/kWh. Construction costs for heating in Turkey are 850 to 1,250 US $/kW and the cost per residence is around 2,000 US $, an investment that is amortized in 5 to 10 years. Stefansson (1999) reports an average consumer heating cost in 1995 for four European countries as 2.4 cents/kWh.

3 UTILIZATION IN 2002

Based on 60 country update papers submitted to the World Geothermal Congress 2000 supplemented with other current reports, the follow figures on worldwide geothermal electric and direct-use capacity, are estimated. A total of 59 countries reported some utilization, either electric, direct-use or both (Table 3).

The figures for electric power capacity (MW) appear to be fairly accurate; however, several of the

Table 3 Total Geothermal Use in 2002

Use	Installed Power MW	Annual Energy Use GWh/yr	Capacity Factor	Countries Reporting
Electric Power	8,000	50,000	0.71	22
Direct-Use	15,200	53,000	0.40	58

country annual generation values (GWh) had to be estimated which amounted to only 0.5% of the total. The direct-use figures are less reliable and probably are understated by as much as 20%. The author is also aware of at least seven countries which utilize geothermal energy for direct-heat applications, but did not submit reports to WGC2000. The details of the present electric power generation and direct-use of geothermal energy can be found in Huttrer (2000), and Lund and Freeston (2001). These data, with estimated changes to 2002, are summarized in Table 4.

The data for Japan and Hungary were modified from Lund and Freeston (2000) based on revised estimates for bathing and swimming pools (Fridleifsson, 2000) (Lund and Freeston, 2001).

A review of the above data shows that in electric power generation each major continent has approximately the same percentage share of the installed capacity and energy produced with North America and Asia having almost 80% of the total. Whereas, with the direct-use figures, the percentages drop significantly from installed capacity and energy use for North America (28.6% to 13.2%) due to the high percentage of geothermal heat pumps with low capacity factor for these units. On the other hand, the percentages increased for the remainder of the world due to a lesser reliance on geothermal heat pumps, and the greater number of operating hours per years for these units.

Table 4 Summary of Regional Geothermal Use in 2002 (estimated from WGC2000 data)

	Electric Power				Direct-Use			
Region	MWe	%	GWh/yr	%	MWt	%	GWh/yr	%
Africa	55	0.7	400	0.8	125	0.8	505	1.0
Americas	3,410	42.6	23,700	47.4	4,400	29.0	7,280	13.7
Central	410		2,200		5		40	
North *	3,000		21,500		4,350		7,020	
South	0		0		45		220	
Asia **	3,100	38.8	17,600	35.2	4,610	30.3	24,235	45.7
Europe	1,000	12.5	6,000	12.0	5,720	37.6	18,915	35.7
Central/East	0		0		1,285		4,405	
West/North ***	975		5,900		3,875		11,040	
CIS ****	25		100		560		3,465	
Oceania	435	5.4	2,300	4.6	345	2.3	2,065	3.9
TOTAL	8,000		50,000		15,200		53,000	

* includes Mexico; ** includes Turkey; *** includes Azores and Guadelope; **** includes Russia and Georgia.

3.1 Electric Power Generation

Electric power has been produced from geothermal energy in 24 countries; however Greece and Argentina have shut down their plants due to environmental and economic reasons. Since 1995, Ethiopia has joined the ranks of power producers with a 8.5 MW (gross) binary plant installed at Aluto, Langano, Guatemala has seen the installation of 5 MWe at Amatitlan and 27.7 MWe at Zunil, and Austria and Australia have installed two small binary plants each. Both Mexico and the Philippines are actively increasing their capacity, and Russia in completing a new 50 MWe plant on Kamchatka (Povarov, et al., 2001). The installed capacity in the United States has been reduced by 589 MWe since 1995 due to declines in steam output in The Geysers. In an attempt to bring production back, the Southeast Geysers Effluent Recycling Project is now injecting 340 L/s of treated wastewater through a 48km long pipeline from Clear Lake, adding 54 MW. A second, 66km long pipeline from Santa Rosa is planned.

The countries with an increase of over 50% in installed capacity over the period 1995～2000 are Iceland, Portugal (Azores), Costa Rica, Russia, Indonesia, Philippines, El Salvador and New Zealand.

Based on country update papers for WGC2000, the projected installed capacity for 2005 is 11,414 MWe or a 43% increase (7.4% annual compounded growth rate) (Huttrer, 2000). This compares to 17% increase (3.1% annual) growth from 1995 to 2000. If the data from the United States were not considered due to its significant decline, the growth would have been 43% (7.4% annual). The same as predicted for the next five years.

One of the more significant aspects of geothermal power development, is the size of its contribution to certain national capacity. The following countries lead in this contribution with more than 5% of the electrical energy supplied by geothermal power (Huttrer, 2000) (Table 5).

Table 5 National Geothermal Contribution

Country	% of National Capacity (MWe)	% of National Energy (GWh/a)
Philippines	16.2 *	21.5
El Salvador	15.4	20.0
Nicaragua	17.0	17.2
Iceland	13.0	14.7
Costa Rica	7.8	10.2
Kenya	5.3	8.4
New Zealand	5.1	6.1
Indonesia	3.0	5.1

* Based on 1998 data from the EIA, Washington, D. C.

3.2 Direct Utilization

The world direct utilization of geothermal energy is difficult to determine, as there are many diverse uses of the energy and these are sometimes small and located in remote areas. Finding someone, or even a group of people in a country who are knowledgeable on all the direct uses is difficult. In addition, even if the use can be determined, the flow rates and temperatures are usually not known or reported; thus, the capacity and energy use can only be estimated. This is especially true of geothermal waters used for swimming pools, bathing and balneology. Thus, it is difficult to compare changes from one report to the next. This was especially true of Japan and Hungary in the WGC2000 country updates, as a significant portion of this use was not reported, and had to be obtained from other sources. For this reason, the values reported in Lund and Freeston (2000), have been updated in 2001.

One of the significant changes for WGC2000 was the increase in the number of countries reporting use. Approximately 25 countries were added to the list in the current report as compared to 1995. In addition, the author is aware of seven countries (Armenia, Ethiopia, Malaysia, Mozambique, South Africa, Yemen and Zambia) that have geothermal direct-uses, but have not provided a report for WGC2000. Thus, there are at least 62 countries with some form of direct utilization of geothermal energy.

Another significant change from 1995 is the large increase in geothermal (ground-source) heat pump installations. They increased by 269% (30% annual growth) in capacity and 59% (10% annual growth) over the five years period. At present, they are the largest portion of the installed capacity (42%) and 14% of the annual energy use. The actual number of installed units is around 500,000 in 26 countries, mostly in the United States and Europe; however, the data are incomplete. The equivalent number of 12 kW units installed (the average size) is slightly over 570,000. The equivalent number of full-load operating hours per year varies from 1,000 in the U. S., to over 6,000 in Sweden and Finland.

In terms of the contribution of geothermal direct-use to the national energy budget, two countries stand out: Iceland and Turkey. In Iceland, it provides 86% of the countries space heating needs, which is important since heating is required almost all year and saves about 100 million US $ in imported oil (Ragnarsson, 2000). Turkey has increased their installed capacity over the past five years from 140 MWt to 820 MWt, most for district heating systems. This supplies heat to 51,600 equivalent residences and engineering design to supply a further 150,000 residences with geothermal heat is complete. The Turkish projections for 2010 is 3,500 MWt which will heat an equivalent 500,000 residences or about 30% of the residences in the country (Batik, et al., 2000).

4 ENERGY SAVINGS

The total geothermal electricity produced in the world is equivalent to saving 84.5 million barrels (12.7 million tonnes) of fuel oil per year (generating electricity with a 0.35 efficiency factor). This produces a savings of between 2.6 (natural gas), 11.2 (oil) or 13.0 (coal) million tonnes of carbon pollution annually. The total direct-use and geothermal heat pump energy use in the world is equivalent to savings of 90.2 million barrels (13.5 million tonnes) of fuel oil per year (generating electricity with a 0.35 efficiency factor). This produces a savings of between 2.8 (natural gas), 11.9 (oil) or 13.8 (coal) million tonnes of carbon pollution annually. If the replacement energy for direct-use was provided by burning the fuel directly, then about half this amount would be saved in heating systems (35% vs. 70% efficiency). If the savings in the cooling mode of geothermal heat pumps is considered, then this is equivalent to an additional savings of 8.0 million barrels (1.2 million tonnes) of fuel oil per year or from 0.3 (natural gas), 1.2 (oil), or 1.4 (coal) million tonnes of carbon pollution annually. The above data is based on information provided by LLL (1997).

The equivalent savings in the production of CO_2 from geothermal electricity production from fuel oil is 40.8 million tons and from direct-use 43.3 million tonnes. The corresponding figures for natural gas and coal are 9.6 and 47.6 million tonnes for electricity,