

WORLD-WIDE DIRECT USES OF GEOTHERMAL ENERGY 2000

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ABSTRACT

The worldwide application of geothermal energy for direct utilization is reviewed. This paper attempts to update the previous survey carried out in 1995 by one of the co-authors (Freeston) and presented at the World Geothermal Congress in Florence, Italy. For each of these updates since 1975, the recording of data has been similar, but not exactly the same. As in 1995, an effort was made to quantify geothermal heat pump data and the investment in geothermal energy development. Final update papers were received from 60 countries, of which 55 reported some form of geothermal direct utilization. An estimate of the installed thermal power at the end of 1999 (1995 in brackets) from the current reports is 16,209 MWt [8,660 MWt] utilizing at least 64,416 kg/s [37,050 kg/s] of fluid, and the thermal energy used is 162,009 TJ/yr [112,441 TJ/yr]. The distribution of the thermal energy used by category is approximately 37% for space heating, 22% for bathing and swimming pool heating, 14% for geothermal heat pumps, 12% for greenhouse heating, 7% for aquaculture pond and raceway heating, 6% for industrial applications, less than 1% each for agricultural drying, snow melting, air conditioning and other uses. The reported data for number of wells drilled was 1,028, work by professional over the five-year period was 3,363 pers on-years, and the total investment over the five years was 841 million US\$, indicating minimum values.

INTRODUCTION

Approximately a year in advance, forms for the update for electric and direct-use of geothermal energy were mailed to representatives in 85 countries in preparation for the World Geothermal Congress 2000 (WGC2000) in Japan. The forms, consisting of eight tables, were updated from those utilized in the 1995 survey, especially in terms of how to make the necessary calculations for installed power and energy utilized. The tables were also made available on the Internet through the Geo-Heat Center web site. These eight tables were to be completed, where applicable, and attached to the various country update papers submitted to WGC2000. Approximately 75 countries responded with abstracts, and then 65 of these with draft papers and 60 with a final paper of which 55 countries had some direct utilization of geothermal energy. Unfortunately, not all countries responded in a similar manner, as some had only limited exploration data to report, while others had difficulty obtaining temperature and flow data for the various uses. In some cases, with the help of the authors extensive knowledge and international experience, reasonable estimates were made of various uses, especially that for geothermal heat pumps, pools and resorts. We often had to refer to other

publications for data to augment the country update papers. The authors plan to update and/or correct the data after WGC2000.

The assumption used in the analysis were similar to that use in previous survey with the methods of calculation listed at the top of the various tables, namely:

$$\begin{aligned} \text{Installed thermal power (MWt)} &= m \text{ (kg/s)} \times (t_i - t_o) \\ &\quad (\text{°C}) \times 0.004184 \\ \text{Energy Used (TJ/yr)} &= \text{annual average flow rate (kg/s)} \\ &\quad \times (t_i - t_o) (\text{°C}) \times 0.1319 \\ \text{Capacity factor} &= \text{TJ/yr} \times 0.03171/\text{MWt} \\ &\quad \text{where } m = \text{max. flow rate, } t_i = \text{inlet temperature, and} \\ &\quad t_o = \text{outlet temperature.} \end{aligned}$$

Both swimming pools and other aspects of balneology are included where they are identified. Heat pumps, as in 1995, are included and they make a significant contribution to the totals.

DATA SUMMARY

Table 1 is a summary, by country, of the peak flow rates, capacity, annual utilization, and capacity factor, wells drilled, professional person-years and investment reported by the various authors. There are 55 countries reporting use, as compared to 28 in 1995 and 24 in 1985. The maximum flow rate is at least 54,416 kg/s, an increase of 51.2% over 1995, total capacity is 16,210 MWt, an 87.1% increase over 1995, and energy utilization is 162,009 TJ/yr, a 44.1% increase over 1995. These numbers correspond to an 8.61% annual compounded growth for flow rate, a 13.35% annual compounded growth for capacity, and a 7.58% annual compounded growth for utilization over this five-year period. Thus, it appears that the growth rate has increased in recent years, despite the low cost of fossil fuels, economic down turns, and other factors. It should be noted that part of the growth from 1995 to present is due to better reporting, and includes some countries with geothermal uses that were missed in previous reports. The capacity factor is an indication of the amount of use (i.e., a capacity factor of 1.00 would indicate that the system is used at a maximum the entire year, and 0.5 would indicate using the system for 4,380 equivalent full-load hours per year). The world wide average for the capacity factor is 0.32 compared to 0.41 in 1995.

Again, as in 1995, the countries with the largest utilization are China, Iceland and the United States, with Turkey moving into the top four, together accounting for over half (54%) of the world's geothermal energy utilization. Austria, Canada, Sweden, Switzerland, and Turkey have produced the largest energy utilization increase in the past five years by almost doubling their use; the first four country's increase is due to geothermal heat pump installations and Turkey's due to the numerous new district heating systems brought on line.

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Table 1. Summary of direct-use data from individual countries. (blanks indicate no value reported)

Country	Flow kg/s	Capacity MWt	Annual TJ/yr	Utilization GWh/yr	Capacity factor	Wells drilled	Person-years	Funds million \$
Algeria	516	100.0	1,586	441	0.50		27	
Argentina	2,515	25.7	449	125	0.55	9	202	6
Australia	90	10.4	294	82	0.90	0	60	
Austria	210	255.3	1,609	447	0.20	17		
Belgium	58	3.9	107	30	0.87			
Bulgaria	1,690	107.2	1,637	455	0.48		85	0.13
Canada		377.6	1,023	284	0.09			
Caribbean Islands		0.1	1	0	0.62	0	0	0.3
Chile		0.4	7	2	0.55			
China	12,677	2,814.0	31,403	8,724	0.35			
Columbia	222	13.3	266	74	0.63		68	6.15
Croatia	927	113.9	555	154	0.15	1	91	1.9
Czech Republic		12.5	128	36	0.33		106	0.3
Denmark	44	7.4	75	21	0.32			
Finland		80.5	484	134	0.19			
France	2,793	326.0	4,895	1,360	0.48	1		
Georgia	894	250.0	6,307	1,752	0.80			
Germany	371	397.0	1,568	436	0.13	16		
Greece	258	57.1	385	107	0.21	75	200	
Guatemala		3.4	107	30	1.00	1	10	
Honduras	12	0.7	17	5	0.76		14	
Hungary	677	328.3	2,825	785	0.27	4	20	0.5
Iceland	7,619	1,469.0	20,170	5,603	0.44	241	250	90
India	316	80.0	2,517	699	1.00	73	14	
Indonesia		7.3	43	12	0.19			
Israel	1,672	63.3	1,713	476	0.86			
Italy	1,656	325.8	3,774	1,048	0.37	1	50	10
Japan	1,670	257.5	5,836	1,621	0.72			
Jordan	574	153.3	1,540	428	0.32			
Kenya		1.3	10	3	0.25			
Korea	1,054	51.0	1,077	299	0.67	164	42	276
Lithuania	13	21.0	599	166	0.90	6	102	23.94
Macedonia	761	81.2	510	142	0.20	1	55	15
Mexico	4,367	164.2	3,919	1,089	0.76	0	20	0
Nepal	25	1.1	22	6	0.66		8	0.007
Netherlands		10.8	57	16	0.17			
New Zealand	132	307.9	7,081	1,967	0.73	1	200	50
Norway		6.0	32	9	0.17			
Peru		2.4	49	14	0.65			
Philippines		1.0	25	7	0.79			
Poland	242	68.5	275	76	0.13		166	12
Portugal	49	5.5	35	10	0.20	7		
Romania	890	152.4	2,871	797	0.60	14	181	24
Russia	1,466	307.0	6,132	1,703	0.63	306	1043	
Serbia	827	80.0	2,375	660	0.94	5	23	
Slovak Republic	623	132.3	2,118	588	0.51	4	95	11.75
Slovenia	656	42.0	705	196	0.53	18	43	16.08
Sweden	455	377.0	4,128	1,147	0.35			
Switzerland	120	547.3	2,386	663	0.14	4	58	230
Thailand		0.7	15	4	0.68			
Tunisia		19.7	174	48	0.28			
Turkey	700	820.0	15,756	4,377	0.61	15	120	25
United Kingdom	25	2.9	21	6	0.23			
United States	4,550	5,366.0	20,302	5,640	0.12	44	10	42
Venezuela		0.7	14	4	0.63			
GRAND TOTAL	54,416	16,210.7	162,009	45,006	0.32	1028	3363	841

In 1985, there were only 11 countries reporting an installed capacity of over 100 MWt. By 1990 this number had increased to 14, and by 1995 to 15. At present there are 18 countries reporting over 100 MWt of installed capacity.

CATEGORIES OF UTILIZATION

The 1995 and 2000 data is divided in Table 2 among the following individual uses in terms of capacity and energy utilization for comparison:

Table 2. Categories of Utilization of Geothermal Energy World-Wide

Category	Capacity MWt		Utilization TJ/yr	
	2000	1995	2000	1995
Geothermal				
Heat Pumps:	6,849	1,854	23,214	14,617
Space Heating	4,954	2,579	59,696	38,230
Greenhouse Heating	1,371	1,085	19,035	15,742
Aquaculture pond heating	525	1,097	10,757	13,493
Agricultural Drying	69	67	954	1,124
Industrial Uses	494	544	10,536	10,120
Bathing and Swimming	1,796	1,085	35,892	15,742
Cooling and Snow Melting	108	115	968	1,124
Others	43	238	957	2,249
TOTAL	16,209	8,664	162,009	112,441

Figure 1 presents the 2000 data in a pie-chart form in percentages. We attempted to separate individual space heating and district heating, but this was often difficult as reporters did not make this distinction. An approximate separation was made based on the authors' personal knowledge of the situation in the particular country. A preliminary estimate place 75 % (27.6 % of the total) of the space heating use in district heating. Snow melting is the majority of the Cooling and Snow Melting Figure (0.52 vs. 0.08% of the total). Other, include mainly earthquake monitoring and recuperation in China, tourism in Japan, and animal husbandry in Tunisia.

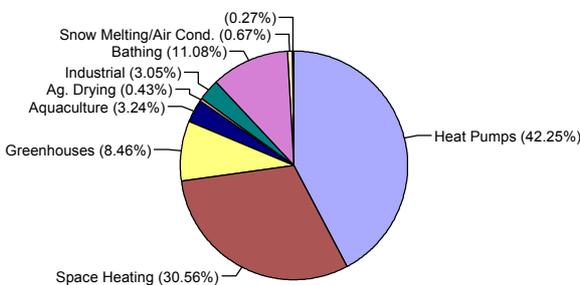


Figure 1a. Categories of Capacity in % for 2000.

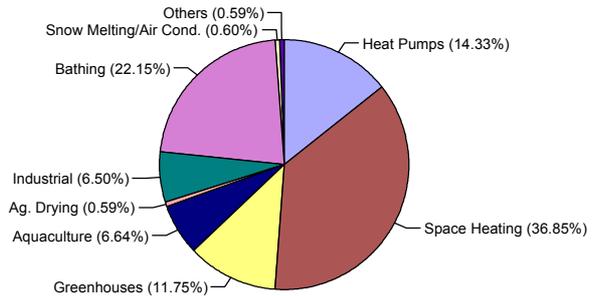


Figure 1b. Categories of Energy Use in % for 2000.

In comparing with the 1995 data (Freeston, 1995, 1996), it is necessary to note that there is a difference in quality of the numbers and the number of countries submitting information. In fact, if one only adds the MWt for 2000 for the countries that submitted data in 1995, we get 15,450 MWt, thus the new countries have only contributed 759 MWt or about 5% to the total. Comparing the energy, the 2000 total of the countries listed in 1995 is 150,107 TJ/yr, thus the new countries add only 11,902 TJ/yr or about 7% to the 2000 total.

Geothermal Heat Pumps

Geothermal (ground source) heat pumps has had the largest growth since 1995, almost 59% or 9.7% annually, of which almost all occurred in the United States and Europe. The installed capacity is 6,850 MWt and the annual energy use is 23,214 TJ/yr in 26 countries. The actual number of installed units is around 500,000, however, data is incomplete for this figure. The equivalent number of 12 kW units installed is slightly over 570,000. The 12kW equivalent is used as typical of homes in the United States and some western European countries. However, the size of individual units range from 5.5 kW (Poland and Sweden) for residential use to large units of over 150 kW (Germany and the United States) for commercial and institutional installations. In the United states most units are sized for the peak cooling load and are oversized for heating (except in the northern states) and thus, are estimated to average only 1,000 full-load hours per year (capacity factor of 0.11). In Europe, most units are sized for the heating load and are often designed to provide just the base load with peaking by fossil fuel. As a result, these units may operate from 2,000 to 6,000 full-load hours per year (capacity factor of 0.23 to 0.68). Unless, the actual number of full load hours were known, a value of 2,200 hours were used for energy output (TJ/yr) calculations for several of the European countries based on reporting by Rybach and Sanner (1999). The energy reported for heat pumps was also reduced from the installed capacity based on a COP (coefficient of performance) of 3.0, which allowed for one unit of energy input (usually electricity) to three units of energy output. Thus the geothermal component is 67% of the energy output.

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Space Heating

Space heating had the second largest growth since 1995 at slightly over 56% or 9.4% annually, reported by 28 countries. As stated earlier, about 75% of the 59,696 TJ/yr utilization is estimated for district heating, and the remainder for individual space heating. The majority of the district heating systems are in Europe where the leaders are France and Iceland, whereas the United States dominated the individual home heating systems use; typical of Klamath Falls, Oregon and Reno, Nevada. Other countries which have extensive district heating systems are China, Japan and Turkey.

Greenhouse and Covered Ground Heating

Greenhouse heating increased by 21% or 3.9% annually. The countries which have made maximum use of geothermal energy for heating greenhouses and covered ground include China, Georgia, Hungary, Iceland, Italy, Russia and the United States. The energy use ranged from 3 to 102 TJ/yr/ha (Greece to Russia), with most between 13 to 27 TJ/yr/ha (Slovakia to Iceland). Only 11 of 28 countries reported their heated area which totaled 322 ha. Using an average energy requirement (which is also typical of the United States) of 20 TJ/yr/ha for greenhouse heating, the 19,035 TJ/yr gives about 950 equivalent ha of greenhouses being heated worldwide, since not every country gave area heated in their country report.

Aquaculture Pond and Raceway Heating

Aquaculture use of geothermal energy dropped by 20% over the five year period, however, no explanation can be given for this reduction. A total of 16 countries reported installations, with the largest use is in China, Iceland, Georgia, Israel and Turkey. Unfortunately, very little information on pond sizes, the use of raceways, or kg of fish produced were presented in the country reports. Thus, based on work in the United States, it was calculated that it requires 0.242 TJ/yr/tonne of fish (bass and Tilapia) using geothermal water in ponds and 0.675 TJ/yr/tonne of fish in raceways. Using these approximate numbers, the 10,757 TJ/yr of energy reported for aquaculture, should be equivalent to producing between 15,699 to 44,800 tonnes of fish per year.

Agricultural Crop Drying

Only ten countries use geothermal energy for drying various grain, vegetable and fruit crops. Examples are seaweed (Iceland), onions and garlic (United States), wheat and other cereals (Serbia), rice (Macedonia), fruit (Guatemala and Mexico), lucern or alfalfa (New Zealand), coconut meat (Philippines), and timber (New Zealand, Romania, and Mexico). However, there is a large potential and interest in using geothermal energy for drying crops in tropical regions where field spoilage occurs rapidly. A total of 954 TJ/yr are utilized in these processes, with a 15% decrease since 1995.

Industrial Process Heat

This is also a category that has applications in 19 countries where the installations tend to be large and energy consumption

high. Examples include concrete curing (Guatemala and Slovenia), bottling of water and carbonated drinks (Bulgaria, Serbia and the United States), paper and vehicle parts production (Macedonia), oil recovery (Russia), milk pasteurization (Romania), leather industry (Slovenia and Serbia), chemical extraction (Bulgaria, Russia, and Poland), CO₂ extraction (Iceland and Turkey), mushroom growing and laundry use (United States), salt extraction and diatomaceous earth drying (Iceland), pulp and paper processing (New Zealand), and borate and boric acid production (Italy). This use has grown approximately 4.1% over the past five years and would have been higher, except that the gold heap leaching operations in the United States were halted due to the expense of paying federal government royalties for use of water from government land.

Snow Melting and Space Cooling

There are very limited applications in this area with pavement snow melting projects in Argentina, Iceland, Japan, Switzerland and the United States. Approximately 500,000 m² of pavements are heated, the majority in Iceland. A project in Argentina uses steam for highway snow melting in the Andes to keep a resort community open during winter. The power required varies from 130 to 180 W/m² (United States and Iceland). The only space cooling reported was in Bulgaria, Switzerland and Japan. The chiller on the Oregon Institute of Technology campus in the US has been replaced with an electric chiller due to the poor efficiency of the geothermal unit using 90°C water. Heat pump cooling is not included, as this process returns heat to the earth.

Bathing and Swimming

Figures for this use were the most difficult to collect and quantify. Forty-five countries have spas and resorts that have swimming pools, however, many allow the water to flow continuously, regardless of use. As a result, the actual use and capacity figures may be high. In other cases, where use was reported, but no flows and temperature drops known, a figure of 0.35 MWt and 7.0 TJ/yr, typical of many installations, were used to estimate the capacity and energy used. Use of natural hot springs that were undeveloped were not included in this report. In addition to the 45 countries that reported bathing and swimming use, the authors are also aware of developments in Armenia, Ethiopia, Malaysia, Mozambique, Yemen and Zambia, but no figures were reported from these countries since details and location were lacking. This use increased by 128% or about 18% annually, however, some of the increase is due to better reporting and including countries with long established facilities not previously reported.

Other Uses

China, Japan and Tunisia reported other uses such as earthquake monitoring, tourism, and animal husbandry.

Capacity Factors

Average capacity or load factors were determined for each country as shown in Table 1. They vary from 0.12 to 1.00 with an average of 0.32. The lower values are for countries dominated by geothermal heat pump use; whereas, the higher

numbers are for countries with high industrial use or continuous operations of pools for swimming and bathing. Similar factors were also calculated for each use category and are listed in Table 3. These are then compared with the 1995 data.

Table 3. Capacity factors

Category	Capacity Factors	
	1995	2000
Space Heating	0.47	0.38
Greenhouse Heating	0.46	0.44
Aquaculture Ponds	0.39	0.65
Agriculture Drying	0.53	0.44
Industrial	0.59	0.68
Snow Melting	0.25	0.29
Bathing/Swimming	0.46	0.63
Heat Pumps	0.25	0.11
Total	0.41	0.32

Most of the values for 2000 are about the same as in 1995, except for the following: the lower space heating number is due to the dominance of values from Iceland and China; the higher aquaculture number is due to the dominance of higher values for the United States; and the higher number for bathing and swimming is due to more accurate reported values and the almost full-time flow through operation of many resorts; and the lower heat pump number is due to the low equivalent number of full load days used by the United States as discussed earlier. The reduction in the total factor is also due to the increased influence of geothermal heat pumps which have a low value.

Wells Drilled, Person-years, and Funds Invested in Geothermal Projects

Table 1 also shows data submitted for wells drilled, person-years of work and funds expended on direct-use project during 1995 -1999. Not all countries reported data for these tables, and it was often difficult to separate Electrical from Direct-Use values. However, for those countries that did submit data, the following observations are made. During this period over 1,028 wells were drilled with 306 in Russia and 241 in Iceland being the most active countries. Geothermal heat pump wells are not included in these data.

The person-year column numbers refer to the total employed on geothermal projects, and as was reported in Freeston (1995, 1996), it is assumed that in many countries one work force caters to both disciplines. The total number is 3,363 professional person-years of effort, submitted by 29 countries for the five-year period. Relating this to developed capacity is difficult because both electrical and direct-uses, with the assumption above, have benefitted from this work force. However, a percentage of the 3,363 person-years of effort enabled the capacity to increase since 1995 by 87% to 16, 211 MWt. The increase of 7,547 MWt results in almost 0.5 person-years per MW of increase or about 0.2 person-year of total capacity. However, since the person-years is under reported, a better example would be data from eleven Central and Eastern European countries where almost all of the development has been in direct-use and the numbers are more complete. Here 967 person years for 1,139 MWt (180 MWt new) calculates that approximately five person-years per new MWt developed or one person-year is necessary to develop and maintain one MWt of total capacity - probably a better indication.

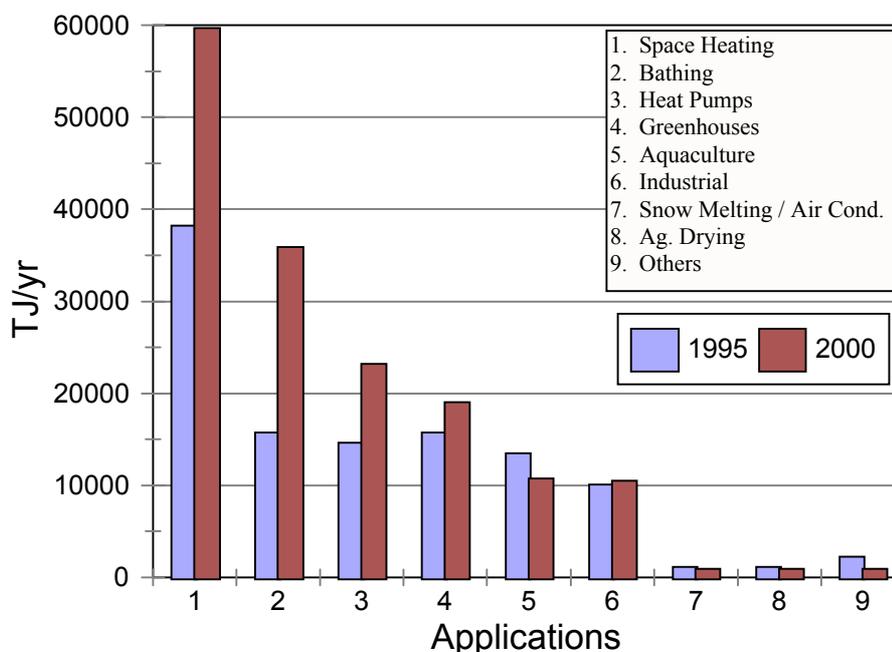


Figure 2. Comparison of Energy Use in TJ/yr for 1995 and 2000.

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Twenty-three countries replied with data on investments. For the five-year period a total of at least US\$ 841 million was invested in direct-use development, about a 40% decrease from the 1985-1994 number. However, we are comparing a five year period to a 10 year period in this case. However, this number should not be taken too literally since only 23 countries reported data and these were not necessarily the same countries that reported in 1995. Two countries invested more than half the total: Switzerland at US\$ 230 million and Korea at US\$276 million. Again, to obtain a ball-park figure, if the assumptions for Central and Eastern Europe are used as above, then US\$ 105.6 million from ten countries were used to develop 180 new MWt and maintain 1,139 MWt total, thus approximately US\$ 0.6 million was used to develop one new MWt or US\$ 0.1 million to develop and maintain one MWt of total capacity.

Summary

Figure 2, presents a comparison between the various uses in 1995 and present based on Freeston (1995, 1996).

COUNTRY REVIEWS

The reports submitted for each country and published in the WGC2000 Proceedings of the Congress are briefly summarized below and any additional information from the recent literature added to gave an overview of the a country's development, program and prospect. Over ninety papers and personal contacts were made to gather the information as cited in the Reference section.

Africa

Algeria: Bathing and balneotherapy are the principal uses of geothermal waters in Algeria. The sites consist of modern thermal resorts, ancient roman pools and primitive shelters. Unfortunately there has been no update since 1995. At that time it was estimated by Freeston, (1995) that for a total of eleven localities used for bathing that the total flow was about 516 kg/s and an energy annual utilization of 1586 TJ and with an assumed load factor of 0.5 gives a thermal power of 100 MWt .

Kenya: Information on the use of geothermal fluids for direct heat utilization in Kenya is scarce. However Mwangi, (2000) reports a horticultural farm using well OW-101 on the Olkaria field, with an output capacity of 1.28 MW for use in a greenhouse for flower growing on an experimental basis which later will be converted to a commercially viable operation. This development was first mentioned at the 1995 Congress by Melaku et al., (1995) where a study had been made to utilize heat from the well to pass through a heat exchanger to produce clean fluid to be sprayed onto the soil to sterilize it.

Tunisia: The geothermal resources of Tunisia were described in Ben Dhia and Bouri, (1995). No update report was received, however some data is available from Mohamed, (1997). This is confined to the Kebili region in the southern part of the country where geothermal fluid is used for irrigation of oases and heating and irrigation of greenhouses. The irrigation practiced is by submersion of all the area resulting in significant water wastage. In general geothermal resources are rare and non-renewable due

to the absence of recharge in aquifers which are over exploited. When the water temperature is less than 40°C it is used directly for irrigation but when it exceeds 45°C it is cooled by atmospheric towers before use, since vegetation and plants are sensitive to relatively hot water.

Other Countries: **Eritrea:** Lowenstern, (1996) reports of a USGS and Eritrean team assessing the geothermal potential of the Alid Volcanic center 30km south of the Gulf of Zula in the Danakil (Afar) Rift. Fumaroles and thermal pools were found in at least 11 small sites over about 10 km². A variety of gas thermometers also yielded high parent reservoir temperatures up to and over 250°C. **Ethiopia** has considerable both high and low enthalpy resources in the Ethiopian Rift Valley and Afar depression. However the only new development is utilizing wells drilled in the middle 80's at Aluto-Langano (Lakes District) where a small pilot power plant for a 5-7 MWe has been operating. There is a history however of low enthalpy use for resort and therapeutic purposes Teklemariam et al., (2000), although no details have been published. For the first time **Morocco** submitted a Country update report, Rimi, (2000) which gives an evaluation of its geothermal resources, which are mainly low enthalpy. Maps of heat flow density and temperature distributions down to 3000m depth are drawn and potential regions identified by estimation of heat in place. The promising regions for development are northeastern Morocco and the sedimentary basins in the Sahara. **Tanzania:** Hochstein et al., (2000) reports an evaluation of the countries resources. There are at least 15 thermal areas with hot (T>40°C) spring activity however there appears to be little evidence to encourage or support any of these areas for development of direct use schemes. Isabirye, (2000) reports on the status of geothermal developments in **Uganda**. However there is no mention of direct heat applications, the studies to date appear to have focused on power generation.

The Americas

Central America and the Caribbean Islands

A number of countries in Central American and the Caribbean Islands have developed geothermal electric power. These include Costa Rica (115 MWe), El Salvador (161 MWe), Guatemala (33.4 MWe), Nicaragua (70 MWe), and Guadeloupe (5 MWe). However, as detailed below, only two countries and several Caribbean Islands report any geothermal direct-uses.

Guatemala: The first two successful direct-use of geothermal energy in Guatemala has been at the Amatitlan geothermal field (Merida, 1999). The first one is Bloteca, a construction block factory established about 20 years ago and that recently started using geothermal steam in the curing process for concrete products. The other one is Agroindustrias La Laguna, a fruit dehydration plant, that was setup as an experimental and demonstration project. While developing this second project the owners decided to bring a product, Eco-Fruit, to the local market using the plant. The product was so successful that it has been in all supermarket chains for the past two-and-a-half years. At Bloteca a 185°C well is used saving \$24,000 per month as compared to diesel fuel. The installed capacity is 0.88 MWt and the annual utilization is 27.65 TJ. A downhole heat exchanger

is used at the Eco-Fruit plant, with an estimated installed capacity of 0.5 MWt and an annual utilization of 15 TJ.

Honduras: The development of geothermal resources in the electrical generating field is being changed from a state owned company to open private participation, thus new developments are on hold (Castillo and Salgado, 2000). There is direct heat utilization in the form of bathing and swimming. A total of three locations have been developed in the country with an installed capacity of 0.71 MWt and an annual utilization of 17.02 TJ.

Nicaragua: No direct utilization exists at this time, but the government with support from the European Community and the U.N. Economic Commission for Latin America and The Caribbean (ECLAC) will carry out a geothermal rural electrification and direct application pilot project in two areas: Cosiguina and Ometepe Island (Zuniga and Medina, 2000). Low-enthalpy geothermal fluids will be investigated for use in grain drying, fish farming and heating greenhouses.

Caribbean Islands: Low temperature waters are informally used for bathing on several islands and bath houses have been built on St. Lucia and Nevis (Huttrer, 2000). Installed capacity is 0.05 MWt and annual use is 0.97 TJ. Otherwise, geothermal fluids are not being used in this region except for the power plant on Guadeloupe.

North America

Canada: Geothermal direct utilization consists of four categories in Canada: geothermal heat pumps, aquifer thermal energy storage, energy from mine waters, and use at resorts (Allen, et al., 2000). The use of low-grade geothermal energy for heating and cooling using heat pumps, has increased steadily in recent years. Today, there is an estimated 30,000 units of 12 kW installed, giving a capacity of 360 MWt and an annual use of 864 TJ. (Kane, 2000). Canada's cold winters coupled with growing concerns over greenhouse gas emissions suggests that this technology will be an important component of the country's geothermal industry in the future. The development is usually in small units, providing heat and/or cooling to commercial buildings and larger private homes. However, there are several showcase projects situated throughout the country that have proven to be economically attractive. Some of these applications have combined heat exchangers and aquifer thermal storage technologies (ATES), whereby the geothermal energy is recycled in the ground to provide both seasonal heating and cooling. ATES has been or is currently being implemented in a number of large-scale buildings projects in Canada, including in Ottawa, New Brunswick, British Columbia, and Toronto. A low-temperature geothermal resource associated with abandoned coal mines at Springhill, Nova Scotia continues to provide direct-use geothermal energy for space heating in an industrial development in that community (Jessop, 1995). This project provides 26 TJ/yr and an estimated 11 MWt of installed capacity. A similar project has been proposed for Nanaimo, British Columbia where there is an abundance of warm water in extensive underground mine workings beneath the city. There are also 11 commercial hot pools and eight resorts in British Columbia and Alberta using geothermal energy for heating with average temperatures of 40° and 50°C respectively (Sadler

Brown, 2000). This would add an estimated 6.6 MWt and 133 TJ/yr. The total is then 377.6 MWt and 1023 TJ/yr.

Mexico: In addition to having 755 MWe of geothermal electric power on-line, Mexico has several smaller space heating, greenhouse heating, agricultural drying, timber drying, and mushroom breeding projects, along with 20 bathing and swimming pool heating sites (Quijano-Leon and Gutierrez-Ne grin, 2000). The agricultural drying (fruit drying), greenhouse heating, space heating and timber drying projects are demonstration facilities at the Los Azufres geothermal field (Casimiro and Pastrana, 1996). The mushroom growing facility is located at the Los Humeros geothermal field, which produces approximately 1.5 tonnes annually of *Pleurotus ostreatus* (Rangel, 1998). An experimental timber drying facility, not reported, is located at Los Azufres, and adds additional 0.04 MWt and 0.63 TJ/yr. The total capacity of these projects is 0.23 MWt and the annual energy use is 6.04 TJ. There are many places where warm waters are used for recreation and therapeutic purposes, but there are no coordinated efforts to promote balneology. These places use from 7 kg/s to 1,000 kg/s in the pools, most of which are located outside. They are found throughout the Mexican volcanic zone and some were even used by the early Aztecs. The total installed capacity is 164.23 MWt and the estimated annual energy use is 3,919.48 TJ.

United States: Since 1995, 27 new and 10 expanded direct-use projects have been developed representing 136 MWt in thermal capacity and 2,600 TJ of annual energy utilization (Lund and Boyd, 2000). Geothermal heat pumps represent the largest growth sector during this period, adding an estimated 2,956 MWt and 3,812 TJ annually. The total capacity of the U.S. is now at 5,366 MWt with an annual utilization of 20,302 TJ. The largest increase in geothermal direct-use was in the heating of aquaculture pond and raceways. Ten new fish pond heating projects were recently identified in the Imperial Valley of California along with the expansion of two existing projects (Rafferty, 1999). Approximately 3.65 million kg of Tilapia, catfish and hybrid striped bass are raised annually. A second area identified as having a significant increase in aquaculture projects is along the Snake River Plain of southern Idaho. Seven new projects were identified in this area, adding an additional one million kg of Tilapia and catfish in annual production. These installations use cascaded water from artesian wells in raceways for raising their fish. Two district heating projects were expanded: the City of Klamath Falls and Oregon Institute of Technology. Both have also added snow melting. A total of 8,250 m² of sidewalk and highway pavement snow melting have been added to these systems. Six greenhouse projects have also been expanded, two in California, three in Idaho and one in New Mexico for a total of 46.5 ha. Geothermal heat pumps have steadily increased over the past five years with an estimated 45,000 units installed annually of 12 kW size capacity. Of these, 46% are vertical closed loop, 38% horizontal closed loop and 15% open loop systems. Projections for the future are that the installation rate will increase about 10% annually, so that by 2010 an estimated 120,000 new units would be installed in that year. It is estimated that 400,000 units are presently installed in the U.S., thus, this rate would add an additional 1.1 million units for a total of about 1.5 million units by 2010. The majority of the installations are in the mid-west and southern states (from North

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Dakota to Florida). Data from individual space heating and pool heating were updated with missing information added. This increase, in most cases, is not due to new installations, but reflects the gathering of better data.

South America

Argentina: This southern country leads South America in geothermal utilization. The emphasis on geothermal development has been in the area of direct-utilization, as the small geothermal binary power plant (670 kW) at Copahue went off line in 1996 (Pesce, 2000). A National Geothermal Plan has been instituted to raise interest in geothermal development. New direct-use developments have taken place in northeastern Argentina where six new thermal areas have been exploited for recreational and therapeutic purposes, which has produced new economic activity in that region. In the western part of the county, on the flanks of the Andes at Copahue-Caviahue, projects using thermal fluids to heat streets and access roads for a ski resort area has been completed. This area is an international thermal center with capacity to supply 2,500 thermal baths a day. Until the installation of the snow melting system, the village was only open in summer from December to April, as winter storms could cumulate up to four meters of snow on the streets. South of Buenos Aires, greenhouse heating, shrimp farming and a thermal therapeutic center were developed. Further south, in Chubut Province, a project using thermal fluids for trout farming is under development. At present there are 134 direct use projects with an installed capacity of 25.71 MWt and an annual energy use of 449.24 TJ.

Bolivia: The main effort in this country is a study of the geothermal Sol de Mañana of Laguna Colorado in southern Bolivia near the Chilean border (Terceros, 2000). Engineering services for field studies were contracted to the Federal Commission of Electricity (CFE) of Mexico. As a result, the field has been certified to generate at least 120 MWe over 25 years. The generated electricity will be distributed in the local market for mining, processing of minerals and use by the local populations. A 5 MWe pilot plant will be installed initially. No direct utilization is planned.

Columbia: After more than 30 years of trying to develop the geothermal potential of Colombia, there is no concerted effort to explore and assess the geothermal resources of the entire country (Alfaro, et al., 2000). Until recently, the availability of other sources of conventional energy prevented geothermal from being exploited. However, the 1992-93 energy crisis, alerted the authorities and the community about the necessity for exploring alternative energy sources. There are, however, current geothermal direct utilization in the form of approximately 38 bathing and swimming sites with an estimated installed capacity of 13.3 MWt and annual energy use of 266 TJ.

Others: There are many potential geothermal sites in **Chile, Ecuador** and **Peru** along the front range of the Andes, but no papers were prepared from these countries for the Congress. Based on the authors' personal knowledge there is direct utilization of geothermal waters at spas in Chile and Peru, however, the size is unknown. In Peru there are at least two spas at Arequipa, three in the Colca River Valley and two in the Cotahuasi River Valley (Huttrer, 2000). Plans are also being

made to develop the geothermal resources in southern Peru and at El Tatio in Chile. In southern Chile at Puyehue a resort hotel, Termas Puyehue, uses five different springs from 41 to 54° C for bathing. **Venezuela** has several small spas and is investigating a geothermal resource in the El Pilar area that has the potential for electricity generation but also for greenhouse heating, drying of agricultural and forestry products, spas and tourism (Urbani, 1999). These spas are estimated to have a capacity of 3.5 MWt and use of 70 TJ/yr.

Asia

China: Zhang et al., (2000) discusses geothermal developments within the country over the last 10 years. They report on studies that have identified more than 3,200 anomalies in China of which some 50 geothermal fields have been investigated and explored. An annual increase of 12% for the past 10 years is reported. Non-electrical use has developed rapidly, particularly in the last 5 years, especially in the areas of space heating, sanatorium use and tourism. By the end of 1998 low temperature use was 8,000,000 m² of space heating, 700,000 m² of greenhouses, 3,000,000 m² of aquaculture ponds, and over 1600 sites of spa and sanatorium use of geothermal energy. The total capacity originally reported for non-electrical use was 4,310,000 t standard coal (approx 118,569 TJ), however, this figure has been modified to 31,403 TJ/yr based on an 8% annual growth rate. The future of geothermal exploitation in China is discussed; R & D and setting up of standards for materials and equipment are prominent in the plans. A paper by Cai, (2000) discusses the technical progress of space heating in Tianjin. The application of four types of space heating in use in Tianjin are presented. Axelsson et al., (1998) have studied the Tanggu (Tianjin) geothermal reservoir as there are indications that the field is over exploited. They recommend a comprehensive management program be put in place and in particular an improvement in the energy efficiency of space heating in the district should be attempted where a 50% reduction in hot water use should be possible. Huang, (2000) presents a historical review of developments in China and includes a discussion on the transport of geothermal fluids over long distances for direct use. Wang et al., (2000a) discusses utilization in Hebei province, where 80 hectares of aquaculture plant, 183,200 m² of district heating, 13 medical treatment facilities and 63 bathing units are part of the 119 sites that have been developed in the past 20 years utilizing geothermal fluids. The same authors Wang et al. (2000b), discusses the geological and development strategy in Xiong County geothermal field. Zhu, (1999) presents an overview of developments of low temperature use (< 150°C) China with 2,410 MWt installed and this is also reported by Liao (1997). Using this value, it was then extrapolated to 2000 at 2,814 MWt installed. The emphasis is on the replacement of coal fired projects with geothermal. It is projected to replace 13.4 million tonnes of coal by geothermal over the period 2001 – 2010. Although no heat pumps are currently operating in China it is recorded in this paper that the absorption heat pump is being researched.

India: The seven major geothermal provinces of India enclose nearly 400 springs, Chandrasekharam, (2000). Exploration and pre-feasibility studies on promising geothermal provinces have demonstrated that commercial exploitation of these reserves has to be initiated. All of the current direct use recorded is used for

bathing however the paper does discuss a project involving the use of geothermal fluids for drying onions in Andhra Pradesh province and a project for removing Cesium from the Puga waters is described. The Tattapani geothermal field is reported by Sarolkar and Pitale, (2000) to have possibilities of using the effluent from a 300 kW binary plant for further use in direct heat plant. 1800 liters/minute of 100°C water is produced from 5 wells. A number of schemes for utilization of the effluent are discussed. The water, which is fairly benign, is finally used for irrigation.

Indonesia: The developments in Indonesia have been centered on producing electricity. About 3.4% of the total mixed electrical energy can be attributed to geothermal by the year 2000, as reported by Sudarman et al. (2000). The only recorded direct use is for 5 sites where a total capacity of 7.3 MWt with an annual energy use of 42.6 TJ is used for bathing. The severe economic crises that started in late 1997 has adversely affected power sector demand and growth in Indonesia, Fauzi et al., (2000).

Israel: Some 430 deep oil and structural wells have been drilled in Israel, Greitzer and Levitte (2000). Most of these wells have been abandoned or are not in use. Thermal gradients and isotherm maps were estimated from the accumulated data. About 100 of these wells have been studied for possible geothermal use. A number of them were selected for spas and others, particularly in the Dead Sea Rift, are used for greenhouses. Thermal waters used for health and recreation utilize waters from both springs (26-62°C) and deep drillholes (42°C). Greenhouses use brackish water from the Mash'abbe Sade well field in the northern Negev. In the south, 80km from the Dead Sea, 60°C water is available and in the Paran area 30-33°C is used for heating greenhouses. Fish farming in the north close to the Jordan Valley and south along the Mediterranean coast, 70 km north of Tel-Aviv, utilizes warm brackish water at 26°C. In all 1787 kg/s of fluid are used with a capacity of 63.3 MWt and an annual energy use of 1654 TJ.

Japan: Sekioka and Yoshii, (2000) presents detailed analysis of the use of geothermal fluids throughout Japan using a new version of a database developed by the New Energy Foundation. Installed thermal power is 253 MWt with the maximum in Hokkaido Prefecture (81.8 MWt). The major use is for space heating at 152 MWt. Annual energy use is 5772 TJ with maximums in Hokkaido Prefecture and for space heating. Hokkaido uses 2050 TJ and space heating is attributed with 3862 TJ. Space heating has a capacity factor of 0.81 with the highest factor being 0.92 for fish and animal heating. A small use of heat pumps is indicated which are concentrated in the cold and snowy Prefecture of Okayama. Hot spring water above 15°C is available all over the country so there is little demand for heat pumps.

Jordan: Investigations across the country in the last 30 years have revealed good prospects for low enthalpy use of geothermal fluids, Swarieh (2000). The geothermal gradient map of Jordan reveals two distinct regions of high geothermal gradients up to 50°C/km. These are in the vicinity of the east side of the Dead Sea and near the border with Syria and Iraq. In this region several thermal wells discharge water from the Upper Cretaceous Limestone. The thermal water from the springs and

wells range in temperature from 30 to 63°C. These springs and wells are currently used for spas and recreation. The estimated capacity for bathing and swimming is 153.3 MWt with an annual utilization of 1540 TJ. Giving an average capacity factor of 0.42. The medicinal uses of the thermal waters of the springs has long been recognized and the paper discusses briefly the application of the fluids to greenhouse heating, fish farming and refrigeration by absorption.

Korea: Geothermal resources are primarily and traditionally centered on public bathing facilities (Yum, 2000). Current plans do not envisage utilizing geothermal for electric power generation. Over the period 1992 – 1998 the Korean Institute of Geology, Mining, & Materials (KIGAM) has conducted geological surveys for more than 200 outcrops and made temperature logs from 350 bores nationwide with depths from 150 – 1500 metres. Fifteen of the older geothermal areas, which have 233 wells and 452 hot springs with temperatures ranging from 25 to 75°C, were visited by more than 24 million users in 1994. There are about 100 newer areas with temperatures in the range 25 to 50°C where 42 spa facilities have been constructed up to 1997. Geothermal waters are also used in district heating and industrial use but no statistics are available.

Nepal: Geothermal manifestations occur in more than twenty eight localities in Nepal mainly scattered along the Main Central Thrust and the Main Boundary Fault, Ranjit (2000). The surface temperatures of thermal water varies between 23°C and 73°C. The popularizing of the use of low temperature water through the media has drawn the energy planners. As a result the Ninth Plan of Nepal (1997-2002) has undertaken to prepare and/or update the inventory of geothermal localities and also to conduct a few pilot projects. Hot springs throughout the country used for tourist and religious purposes have long been popular but recent media coverage has increased their popularity. The Singha hot spring in western Nepal is one that people from distant places visit. Preliminary analysis of waters and isotopic studies indicate that there exists a large reservoir in western Nepal. Drilling activities for large-scale utilization of geothermal water has been limited by road access. The government is now placing emphasis on road construction which will open up areas for development. Currently all the logged data are for bathing at spas etc. A total capacity of 1.06 MWt is estimated with an annual energy use of 22.2 TJ

Philippines: Karunungan and Requejo (2000) presents the update for geothermal development in the Philippines and mainly discusses the power industry. However, they make the point that the Asian crisis although not cutting off expansion, has curtailed plans and restricted growth of the industry. Two papers, Chua et al. (1996) and Adajar (1999), discuss the details of pilot plants for multi crop drying plant, one attached to the Southern Negros power project of PNOC and the other at Manito in the province of Albay about 20 km north east of the Bacon-Manito power project. The Southern Negros pilot 1 MWt plant, which was referred to in Freeston (1995, 1996) is described in detail by Chua et al. (1996). At that time it was anticipated that other plants of similar design would be in use in other areas and would seem to be moving in that direction.

Thailand: The paper by Ramingwong et al. (2000) details the studies that have been ongoing since the 1995 report, however

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it appears that little progress has been made in developing operational projects. The 0.3 MWe Ormat plant at Fang has continued to operate at high load factors and the air conditioning, cold storage and crop dryer using the 80°C exhaust from the power plant has continued. Recently a new larger crop dryer has been constructed and the Mae Fang National Park has built a public bathing pond and sauna room to serve visitors. The San Kampaeng, Pai and nine other geothermal systems are reported to be under further investigation but to date no other above ground developments have taken place. Charusiri et al. (2000) discusses hot spring and heat flow data collected in SE Asia and their application to Tectonic settings.

Turkey: Turkey has been in the forefront of direct use application and development in recent years. Freeston (1995, 1996) reported an installed capacity of 140 MWt, Batik et al. (2000) at this conference, has a figure of 820 MWt installed with an annual energy use of 15,756 TJ. Most of the development has occurred in space heating where 51,600 residences have geothermal heating (493 MWt) with 45.4 ha of geothermal greenhouse heating and 194 spas used for balneological purposes (327 MWt). Engineering design to supply a further 150,000 houses with geothermal heat is complete. The projections for 2010 is 3,500 MWt (500,000 residences equivalent which is about 30% of the total residences in the country), of heating and 895 MWt for spas and by 2020, 8300 MWt (1.25million residences equivalent) of heating and 2300 MWt of spas will be complete. Construction costs for heating are 850-1250 US\$/kW and the cost per residence around 2000 US\$ for investments that are paid back in 5-10 years. At Kizildere geothermal field where 12-15 MWe is produced, a liquid CO₂ and dry ice production factory utilizes geothermal fluid to produce 120,000 tonnes annually. Kocak (2000) discusses the setting of the geothermal fields in Turkey and gives details of both the high and low enthalpy geothermal areas.

Other countries: **Iran** has continued exploration activities since that reported in 1995, Fotouhi and Noorollahi (2000). Sarein area in the Sablan region where there are hot springs, is targeted for direct use utilization. Bakht (2000) provides a good overview of the geology and related geothermal resources of **Pakistan**, however there is no use of fluids reported.

Europe

Europe has only geothermal electric power generation in Iceland (170 MWe), Italy (785 MWe) and Portugal (Azores) (16 MWe), however, most countries have some form of direct utilization, mainly in the form of heating swimming pools and spas, or using geothermal heat pumps for space heating.

Albania: Studies have been carried out oriented toward the distribution of geothermal fields and the natural thermal water springs and wells (Frasheri, 2000). This includes temperature measurements, and the calculation of geothermal gradient and heat flow density. Approximately 145 wells have been logged along with the chemical analysis of eight springs. Artesian wells have fluid temperatures as high as 65.5°C and the springs reach 60°C. Two directions of exploiting these resources are proposed: first to use the thermal water springs and wells of low enthalpy, and secondly, the use of deep doublet in abandoned oil

and gas wells and single well using a "Vertical Earth Heat Probe." No direct-use is listed for Albania.

Austria: The period since 1995 has seen a lot of activities on exploitation of geothermal energy in Austria (Goldbrunner, 1999). In this time 17 wells have been drilled for a total of 31,875 m. Three of these were injection wells which were drilled in the Upper Austrian Molasse Basin. At present Austria has four geothermal plants (all in Upper Austria) which inject the water. At one site (Geinberg) cascaded geothermal use is now performed which includes district heating, spa heating, use of thermal water for bathing, swimming and balneology and greenhouse heating. The temperature use at 12 sites vary from 33 to 95°C. The drilling of deviated injection wells were supported by the European Union via the Thermie A program. The installed capacity of the direct-use projects is 27.3 MWt and the annual utilization is 515.1 TJ. There is also an estimated 19,000 geothermal heat pump installation in the country with an annual increase of 1,600 (Rybach and Sanner, 1999). Based on typical values of 12 kW per installation, COP of 3.0 and 2,000 equivalent full time operating hours in the heating mode, would give 228 MW installed capacity and 1094 TJ/yr utilization.

Belgium: There has been no new geothermal development in the country since the 1995 country update (Vandenberghe, 1999). Production is mainly concentrated in the Mons area, in southwest Belgium (Berckmans and Vandenberghe, 1998). The government is aware that in the future the geothermal issue will be raised again if energy prices start to rise. The Flemish government has a technology research facility (VITO), which emphasizes the use of <25°C aquifers for cold/heat storage purposes for large buildings. In addition a study is commissioned to evaluate what the governments position should be regarding HDR (Vandenberghe, 2000). In north Belgium, swimming pools are heated at Herentals and Turnhout. There is also a fish farm at Turnhout. In south Belgium water is used to heat schools, swimming pools, sport facilities and residential buildings. The water is then cooled from 50° to 40°C to heat a greenhouse of 4,000 m², and further cooled to 30°C to heat waste muds at Wasmuel. The well water at Bouvain is used to heat a local hospital (Berckmans and Vandenberghe, 1998). The total installed capacity is 3.89 MWt and the annual energy use is 107.1 TJ.

Bulgaria: Geothermal research and development has progressed at a slow pace in the last five years (Bojadgieva, et al., 2000). The government has withdrawn their support and the private industry has been generally involved only in bottling of potable water and soft drinks. Only two small demonstration projects for space heating and hot tap water, entirely financed by PHARE program have been completed at two geothermal cities. A small geothermal installation for school heating was partially funded by the state. The major applications of thermal water in the country is in balneology, for space heating and air conditioning, for domestic hot water, for greenhouses and aquaculture, swimming pools and bottling. There is some processing of flax and hemp fibers, and a small enterprise for the extraction of iodine, bromine, boron, strontium, etc., from the thermal water is in operation near Varna on the northern Black Sea coast. The total installed capacity is now 107.2 MWt of which 13.3 is due to geothermal heat pumps. Compared to 1995 about 2.5 MWt of direct utilization was removed due to maintenance problems

and 0.85 MWt were added. The annual utilization is 1637.2 TJ of which 162.0 is due to geothermal heat pumps. The direct utilization is distributed between eight sites in the country.

Croatia: Low temperature thermal water is widely used for bathing, swimming and medical purposes in traditional spas, some of which are also equipped with geothermal space heating systems (Jelic et al., 2000). Only two out of ten geothermal fields discovered during the hydrocarbon exploration activities are currently in use. According to the Program of Geothermal Energy Utilization GEOEN, in the near future the energy from the majority of the geothermal fields should be directly used for space heating and in the agricultural sector for greenhouse heating and industrial processing of fruits and vegetables. Beside the direct heat applications, the construction of a geothermal electric power plant is planned for 2005. There are 18 sites in the country using geothermal energy with an installed capacity of 113.9 MWt and annual energy use of 544.8 TJ.

Czech Republic: The geothermal resources are available either directly in the tectonic structures of the crystalline Bohemian Massif or in sedimentary basins covering the Massif which represent secondary accumulations of geothermal heat (Stibitz, 1999). Geothermal heat of low-enthalpy is used for domestic and swimming pool water heating, and for some small industry. The most famous spa use are at Karlovy Vary (Karlsbad) and Mariánské Lázně (Marienbad) along with five others (28 to 72°C water) in the western part of the country with an estimated 4.5 MWt capacity and 90 TJ/yr (Lund, 1990). About 390 geothermal heat pumps have been installed with a total of 7.95 MWt capacity and an estimated 38.2 TJ/year (350 vertical and 10 horizontal ground coupled, and 30 water source installations). The small scale private installations are typically used for heating of family houses (output less than 20 kW), hotels, accommodation facilities, swimming pools and small businesses (20 to 100 kW) as well as three water treatment plants using heat pumps with output more than 100 kW each. A heat pump with 1 MW output has been installed at the Prokop Mine of the Příbram ore mining district. The warm water is pumped from the mine shaft at 28°C, run through the heat pump where the water is then used for heating the mine facilities as well as the adjacent administrative buildings. Future project possibilities included a 15 MW heat pump in the town of Breclav for district heating, direct-use in a soap factory and swimming pool in Trávek, two projects in Mušov and Písek for thermal spas, swimming pool and greenhouses heating, and a power plant in the region close to the Czech-German border (Doupovské vrchy and Boží Dar).

Denmark: The country has widespread geothermal aquifers, which can be used for district heating (Mahler, 2000). However, combined heat and power (CHP) plants cover the heat demand on the Danish district heating networks. The Danish geothermal development has thus been concentrated on a single geothermal plant in Thisted (northern Jutland). This plant uses an absorption heat pump driven by an incineration CHP plant. The plant was recently expanded and now uses 150 m³/hr of a 15% saline 45°C geothermal water. The capacity of the system is 4 MWt and produces 53.9 TJ of annual heat energy. Approximately 250 ground water based heat pump units were installed in the early eighties and an additional 37,500 ground and air-

based heat pumps are also installed; however, it is unknown how many of these are ground coupled. The 250 groundwater units have an approximate capacity of 3.0 MWt and annual energy use of 20.8 TJ.

Finland: The most promising forms of geothermal energy in Finland are restricted to the utilization of ground heat with heat pumps (Kukkonen, 2000). This is due to the geological conditions as Finland is a part of the Fennoscandian (or Baltic) Shield. The bedrock is Precambrian covered with a thin (<5 m) cover of Quaternary sediments. Topography is subdued and does not easily produce advective re-distribution of geothermal heat by groundwater circulation systems. Due to the crystalline character of the bedrock, rock porosity and its water content are low. This practically excludes geothermal systems utilizing hot wet rock. Nevertheless, promising applications can be found for small-scale use of ground-stored heat in all parts of the country. About 10,000 heat pumps have been installed in boreholes, lakes or Quaternary deposits since the early 1980's. About 70% are horizontal and 10% vertical ground coupled systems and 20% use lake water. Typical vertical installations are in small family houses using a shallow 100-200 m deep borehole, extracting about 50 W/m. The total installed capacity is 80.5 MWt and the annual energy use is 484 TJ/yr (based on 4000 full load hours per year and average capacity of 8 kW). The use of ground heat with geothermal heat pumps is currently increasing in Finland.

France: The development of geothermal energy began as the result of the two energy crises in the 1970s, with an important development of activity from 1978 to 1987, when energy prices fell. During this nine-year period more than 70 geothermal district heating operations were constructed providing heat and hot water for around 200,000 housing units. During the early 1990s, with cheap energy, financial support for renewable energy was reduced. In 1997, with the Greens being elected to the French Parliament and with the necessity of controlling CO₂ emissions, the French authorities expressed renewed interest in renewable energies and energy management, and thus, in 1998 increased their financial support for these activities. The following priorities were planned for geothermal energy: (1) continuation of the HDR program, (2) dissemination of ground-source heat pump technologies, (3) development in the use of high-enthalpy resources in the French Overseas Departments, and (4) development in the use of metropolitan low-enthalpy resources with an extension of the existing geothermal district heating plants to new consumers, and an extension of the duration of the Long Term Guarantee System by 10 years. Out of the 74 plants operating at the end of 1986, only 61 are still in operation today: 41 in the Paris region, 15 in the Aquitaine Basin, and five in other regions (LaPlaigne, et al., 2000). They heat and produce hot water for around 200,000 housing units. About one third of the plants in the Paris Region are profitable, one third break even and one third show a deficit. The installed capacity in the Paris Basin is 295 MWt with an annual energy use of 4,434 TJ, and elsewhere in the country such as at Bordeaux and including two greenhouse locations (8 MWt and 124 TJ/yr), the installed capacity is 31 MWt and the annual energy use 461 TJ. Assumed within the district heat system are an estimated 2,750 heat pump units installed from 1993-1996 (Rybach and Sanner, 1999). Extrapolating this to 1999 gives 4,000 units with a

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installed capacity of 48 MWt and utilization of 255 TJ/yr. This gives a total for the country of 326 MWt and 4895 TJ/yr (Des plan, 2000).

Germany: By the end of 1999 direct thermal use of geothermal energy in Germany amounted to an installed thermal power of approximately 397 MWt (Schellschmidt, et al., 2000). Of this sum, approximately 53.2 MWt are generated in 27 major centralized installations. Small, decentralized earth-coupled heat pumps and groundwater heat pumps are estimated to contribute an additional 344 MWt from at least 18,000 installations. By the year 2002 an increase in total installed power of about 120 MWt is expected: 82 MWt from major central and 40 MWt from small, decentralized installations. This would boost direct thermal use in Germany close to an installed thermal power of 517 MWt. At present no electric power is produced from geothermal resources. The large centralized installations comprise heating plants, thermal spas sometimes combined with space heating, and in some cases, greenhouses and clusters of ground heat exchangers used for space heating and cooling. Most are located in the north German sedimentary basin, the Molasse Basin in southern Germany, or along the Rhine Graben. Direct-use of geothermal heat for space heating in small decentralized units is widespread in Germany. Depending on the local conditions these units consist of earth coupled heat pumps (horizontal heat collectors, vertical heat exchangers), or groundwater heat pumps. The estimated annual energy use is 419 TJ from direct use and 1149 TJ from individual heat pumps.

Greece: During the period 1995-99, geothermal research and applications were mainly related to low enthalpy fields (Fytikas, et al., 2000). The areas of research included northern Greece (Thrace, Macedonia), NW Greece (Epirus), Chios and Lesbos islands (Aegean Sea). In Thrace, near the village Arisino, a new geothermal field was discovered with temperature approaching 92°C. In NW Greece, exploration wells discovered temperatures of 48°C, and on Chios a recently discovered field produced 90°C water. Many new developments have occurred in the last five years, including heating of greenhouses, subsurface soil heating for early asparagus cultivation, production of spirulina, heating a hotel in the neighborhood of Nea Appollonia hot springs (Macedonia), and a spa complex in Thrace and applications that use heat pumps near Athens and on the island of Rhodes. Heat pumps have been installed for both heating and cooling. The first one was in a private house near Athens (35 kW) and the second in the Municipal building in Rhodes (140 kW). In addition, a heat pump coupled with ground heat storage is used for heating and cooling a 6000 m² office building using 36°C water with a rating of 220 kW. The geothermal power plant on Milos has remained shut down since 1989. The direct-use installed capacity is 56.7 MWt and annual energy use is 382.3 TJ. In addition, for heat pumps the installed capacity at five sites is 0.40 MWt and the annual use is 3.1 TJ.

Hungary: During the years since WGC'95 there have been six new geothermal developments in Hungary (Arpasi, et al., 2000). Geothermal is used directly by 94 different organizations at 42 locations. The majority of the geothermal capacity and annual use is in greenhouse heating at 48 different locations (63.7%), followed by space heating (22.5%). There are two industrial users and four spas. Three pilot projects are under study by the

Hungarian Oil and Gas Company (MOL) to develop geothermal electric power plants and then cascaded direct use projects (mainly for the heating of greenhouses). The installed capacity is 324.6 MWt, supplying 2804.3 TJ annually. This does not include use for swimming and bathing at spas which adds another 14.2 MWt and 358 TJ/yr. Geothermal heat pumps represent an additional 3.8 MWt of installed capacity, which is estimated to provide 20.2 TJ/yr. This gives a total of 342.6 MWt and 3,182.5 TJ/yr.

Iceland: Geothermal energy plays an important role in the energy supply of the country. It provides about 50% of the total primary energy supply (Ragnarsson, 2000). The principle use of geothermal energy is for space heating where about 86% of all houses are heated with geothermal water. The benefits of geothermal heating are of great importance since heating is required almost all year and it saves about 100 million US\$ in imported oil. A total of 26 municipally owned geothermal district heating systems are located in Iceland, the largest of which is in Reykjavik serving 160,000 people. On the 1st of January, 1999, a new company was established by the merger of Reykjavik District Heating and Reykjavik Electricity: Reykjavik Energy (Orkuveita Reykjavíkur), which is responsible for the distribution and sale of both hot water and electricity in the city. In December, 1998, a new geothermal district heating system started operation in northern Iceland at Arskogsstrond (population 270). Another new geothermal district heating system for the village of Stykkisholmur in the western part of Iceland is now under construction (population 1,300) and expected to be fully operational in the fall of 2000. There are about 100 public swimming pools and about 30 pools in schools and other institutions heated by geothermal energy with a combined surface area of 27,000 m² - most of which are open-air and in constant use throughout the year. The use of geothermal energy for snow melting has been wide-spread for the past 15-20 years. This kind of utilization gained popularity when plastic pipes for hot water were introduced in the market. Spent water from houses, at about 35°C, is commonly used for deicing of sidewalks and parking spaces. The total area now covered by snow melting systems is estimated to be 350,000 m², of which about 250,000 m² are in Reykjavik. The main industrial uses of geothermal steam are for the diatomite drying plant at Mývatn in northern Iceland where about 27,000 tonnes per year are produced. At Reyhólar, a seaweed processing plant uses geothermal energy for drying with an annual production of 2,000 to 4,000 tonnes. The pilot salt plant on the Reykjanes Peninsula was closed down in 1994; however, a small part of the plant was restarted in 1999 and full operation is now under preparation. The most recent industrial application is drying of hardwoods from North America. A plant for the commercial production of liquid carbon dioxide has been in operation at Haedarendi in southern Iceland since 1986. At the end of 1997 the production of CO₂ was increased from 40 kg per hour to 250 kg per hour, which is sufficient to meet current industrial demand in Iceland. Some 183,000 m² of greenhouses and 105,000 m² of soil heating are primarily located in southern Iceland. The greenhouse production is divided between different types of vegetables (55%) and flowers (45%). Most of the greenhouses are constructed of glass, as plastic film does not stand up well in the windy climate. At present there are about 50 fish farms in operation, with many of them using geothermal hot water to heat freshwater from 5 to 12°C mainly for raising

salmon (70%), but arctic char and trout are also raised. The total fish production is about 4,000 tonnes per year. Today the installed capacity is 1,469 MWt and 20,170 TJ annual energy use. This includes 4 MWt and 20 TJ/yr for a few heat pump installations, mainly of large capacity.

Italy: The lack of economic incentives for direct use of geothermal heat prevented the research and development of low-temperature resources and made it difficult to develop new projects using fluids already available (Cappetti, et al., 2000). In Italy, the vast majority of geothermal development is based on steam-dominated reservoirs, so waste steam with high enough temperatures are generally not available. Under these circumstances, heat has to be supplied by means of geothermal steam subtracted from the electricity generation; the subsequent loss of generation has to be charged to the heat user, resulting in increased costs, especially when the electricity produced with that steam benefits from the state subsidies. Despite this, some progress has been made over the last five-year period. The district heating of many villages in the Larderello area (Monte Cerboli, Serrazzano, Lustignano, San Dalmazio and Sasso Pisano) accounts for the largest amount among the new applications, even though the unit capacities are small. These plants are fed by steam supplied by ERGA (the new energy company owned by ENEL) and operated by local municipalities. In Larderello, the local swimming pool has re-opened after many years of closure and features a brand-new geothermal heating system. New greenhouses have been built in the Radicondoli area, and finally an industrial plant for the transformation of dairy by-products has been built in Carboli, in the southernmost part of the Larderello field. Existing greenhouses in Castelnuovo V.C. have been dismantled; and most importantly, the Vicenza district heating system has been converted from geothermal to natural gas. The recent start-ups of geothermal power plants in the water-dominated fields of Bagnore and Latera will make available large quantities of waste heat in the sites for district heating and greenhouses. Elsewhere, direct-use of geothermal energy are mainly connected to the spa business, but a large share is also related with greenhouses and fish farming (Carella and Sommaruga, 2000). Geothermal space heating include hotel facilities in the Abano area and district heating at Ferrara, the use of heat pumps at Acqui Terme in NW Italy, and a district heating system in Bagno di Romana in the NE Appennines. Carella and Sommaruga (2000) estimate that there are 52 ha of greenhouses and four major fish farms in Italy using geothermal waters. Only about 100 individual heat pumps are estimated to be used. The installed capacity for direct-use is 324.6 MWt and the annual energy use 3767.4 TJ (Cappetti, et al., 2000), with space heating accounting for 41%, bathing and swimming for 28%, greenhouse heating for 22%, industrial process heat for 9%, and fish farming for less than 1% of the annual energy use. The 100 individual heat pumps are estimated to account for 1.2 MWt and 6.4 TJ/yr.

Lithuania: The country has no volcanic activities and no hot springs, but has many reservoirs with warm geothermal water which can be used for district heating, and in health resorts and swimming pool (Suveizdis, et al., 2000). The geothermal potential in Lithuania was investigated through seismic exploration, investigation of oil and gas wells, and the drilling of geothermal exploration wells. Two wells were drilled in 1989 and 1993 with flow rates up to 50 m³/h and at a tempera-

ture of 72°C. A geothermal demonstration district heating plant is being constructed at Klaipeda in cooperation with a Danish firm (Mahler, 2000). Two production and two injection wells have already been drilled. The plant will produce 49.7 MWt (20.9 MWt from geothermal) from 500 to 700 m³/h of 38°C water and should be completed by the end of 1999. A second district heating plant is being proposed by a German firm which will extract 6.1 MWt from up to 150 m³/h of 49°C water. Geothermal heat pumps are also being used in several locations. The installed capacity is 21.0 MWt and the annual energy use is 598.8 TJ.

Macedonia: The country has over a 30-year tradition in geothermal energy utilization (Dimitrov et al., 2000). Today, about 15 geothermal projects are in operation or under development. Four of these are of major importance and have a general influence on the development of direct application of geothermal energy in the country. The most important are the Kocani project, the agricultural project at Gevgelija and Vinica, and the integrated project at Bansko. The Kocani project consists of 18 ha of glasshouses, a rice-drying plant, and due to a successful new borehole, use of the energy is made in the paper industry, a factory for vehicle parts production, and the heating of dwellings. At Gevgelija 22.5 ha of glass houses are heated at one location, and a balneological project supplying a hotel complex with sanitary and spa water from a second location. The project at Vinica of supplying heat to 6 ha of glasshouses is not finished due to problems with corrosion of the pipes. At Bansko, a 2.2 ha greenhouse is heated, and the building, sanitary water and pool at the Car Samoil Hotel are heated with spring water. Future use include the continued injection of used thermal water, modernization and rehabilitation of old fashioned greenhouses and increasing the number of dwellings heated by geothermal energy. The installed capacity is 107.4 MWt and the annual energy use is 509.6 TJ.

Netherlands: No new report was presented; however, a geothermal heat pumps program was initiated in 1995, which was intended to achieve a saving of conventional energy of 5-10 PJ in 2000 and 50 PJ in 2010 (Walter, 1995). In 1997 it was estimated that 900 heat pumps were installed (Rybach and Sanner, 1999). This estimate gives an installed capacity of 10.8 MWt and an annual energy use of 57.4 TJ.

Norway: No country update report was available from Norway; however, an estimate of the number of geothermal heat pump installations from 1993 to 1996 is made in Rybach and Sanner (1999). They estimate 4,000 total units of all kinds installed of which 8% or 320 are ground-source units. Extrapolating to the end of 1999, this gives an estimated 500 units with 6.0 MWt capacity and 31.9 TJ/yr.

Poland: The country is characterized by large low-enthalpy resources connected with three extensive sedimentary geothermal provinces covering about 80% of the country (Kempinska, et al., 2000). Geothermal energy use has been concentrated in space heating and balneology/bathing, while other uses such as greenhouse heating, fish farming, and timber drying are on an experimental scale. In 1999 two heating plants went on line in the Podhale Region and Pyrzyce town. A third plant in Mszczonow town went on line in 1999. At Podhale the

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plant serves 220 houses and the water is then cascaded for timber drying, greenhouse heating, fish farming, plant growing in heated soil and for space and domestic hot water heating at the PAS MEERI Geothermal Laboratory. By 2001-2002 geothermal heat will be delivered to about 4,400 customers in Zakopane. The Pyrzyce plant, opened in 1996, serves 12,000 customers. This system replaces a 20,000-tonne/yr coal fired plant. Geothermal is also planned to be used from recreation and agriculture. The Mszczonow plant is the most advanced of all the geothermal plants, supplying heat and drinking water for about 6,000 people. In 1999, eight spas used 20-60°C waters from springs or wells for balneology and bathing. In addition, CO₂, iodine-bromine for medical purposes and cosmetic salts are also extracted from geothermal waters. During the last several years, there has been increased interest in geothermal heat pumps. Two large sized units (20.4 MWt) are used in the Pyrzyce plant and a small unit uses ventilation air from an underground coal mine in Upper Silesia. In 1999 over 4000 ground-source and groundwater heat pumps were on line. The installed capacity is 68.5 MWt of which 26.2 MWt is from heat pumps, and the annual energy use is 274.7 TJ of which 108.3 TJ is from heat pumps.

Portugal: On the mainland in the northern part of the country, Chaves and S. Pedro do Sul springs have the highest temperature of 76° and 69°C respectively (Aires-Barros and Marques, 2000). They are used for space heating, greenhouse heat, bathing and swimming. The municipal swimming pool at Chaves has been in operation since 1982 and uses water from a 150-m deep well. The water is also used for space heating and domestic hot water. At S. Pedro do Sul the spring water is used at the local spas for bathing and swimming, with 20,000 visitors in 1998, for heating a 2 ha greenhouse, and for heating local hotels. Near Lisbon, a 1,500-m deep well with water temperature of 53°C is used to heat the Air Force Hospital since 1992. At São Miguel Island in the Azores, six small greenhouses covering about 200 m² have been constructed. Experimental crops such as cape gooseberry, melon and pineapples are grown here. The greenhouses use waste water from a nearby geothermal power plant. The installed capacity is 5.47 MWt and the estimated annual energy use is 35.1 TJ.

Romania: There are over 200 wells drilled with depths between 800 and 3,500 m, that encountered geothermal resources at temperatures from 40 to 120°C (Cohut and Bendea, 2000). These wells have a total thermal capacity of about 480 MWt, of which 96 wells are used (of which 35 wells are used for balneology and bathing), producing water with temperatures from 45 to 115°C. The main geothermal resources are in the northwest around Oradea (including Bors and the Western Plains) accounting for the majority of the use, in the Olt Valley in central Romania and just north of Bucharest. The main direct uses of geothermal energy are: space and district heating 35%, bathing 30%, greenhouse heating 23%, industrial process heat 7%, and fish farming and animal husbandry 2%. During the past five years 14 wells were drilled. Due to the problems with the local economy, only three new geothermal projects were completed, one for direct use and two for bathing and swimming. Today there are 38 “geothermal localities” using the 96 wells. The total capacity is 152.4 MWt with an annual energy use of 2870.7 TJ.

Serbia: There are four geothermal provinces in the country with more than eighty low enthalpy systems, the most important of which is located at the south edge of the Pannonian Basin in the north (Milivojevic and Martinovic, 2000). Geothermal energy is being utilized for balneological purposes, in agriculture and for space heating with heat exchangers and heat pumps. There are 59 thermal water spas used for balneology, sports and recreations and as tourist centers. Certain archeological evidence indicates similar uses by the ancient Romans in some of the same localities. These waters are also bottled by nine mineral water bottling companies. In the Pannonian Basin, thermal water is used from 23 wells, two for greenhouse heating, three for heating pig farms, two for industrial process in leather and textile factories, three for space heating, and 13 for spas and for sport and recreation facilities. Outside of the Basin geothermal energy is used to heat greenhouses, a poultry farm, a textile workshop, in the carpet industry, for drying wheat and other cereals, and for spas and a hotels. The installed capacity is 80.0 MWt of which 6.0 MWt is for heat pumps, and the annual energy use is 2375 TJ of which 40 TJ is for heat pumps.

Slovak Republic: The distribution of geothermal aquifers occur in 26 prospective areas and structures with the potential for exploitation (Fendek and Franko, 2000). These aquifers lie at depths of 200 to 5000 m and the waters have temperatures between 20 and 240°C with a potential of 5,538 MWt. Prospecting and exploration have been carried out in 14 of these areas. Geothermal water is used in 13 agricultural farms (greenhouse heating and soil heating), in four localities for heating of service buildings, in one locality for sport hall heating, in two localities for fish farming, in one locality for restaurant heating and on 30 localities for recreational purposes (bathing and swimming). The total areas covered by greenhouses is about 27.4 ha. The first geothermal heating plant with a capacity of 8 MWt was put on line in Galanta in 1996. This system provides heat and hot water to 1236 flats and a hospital. Another large use is at Podhajska where the first geothermal doublet was drilled in the country. The geothermal water is used to heat a hotel, administrative buildings, greenhouses and swimming pools. A third large energy use is at Besenova in the Liptov Basin where a hotel, greenhouses and swimming pools are heated. Future geothermal energy utilization projects and being undertaken in Kosice, Poprad, Liptov, Skorusina and Ziar basins. The total installed capacity is 132.3 MWt of which 1.4 MWt is for heat pumps, and the annual energy use is 2118.3 TJ of which 12.1 TJ is for heat pumps.

Slovenia: The main use of geothermal energy is for space heating and for bathing and swimming (including balneology), the latter began on a large scale over 40 years ago (Kralj and Rajver, 2000). Other uses include greenhouse heating, industrial applications and the use of heat pumps. Space heating including domestic hot water, the largest geothermal use, is mostly implemented at spas. At Murska Sobota 300 dwellings are heated through heat exchangers. The second high use in Slovenia is for bathing and swimming. There are 24 thermal spas and recreation centers where swimming pools with a surface area of about 29,600 m² are heated directly or indirectly

through heat exchangers and heat pumps. Most are located outside. The total area of greenhouses is 4.5 ha which are located at Catez. Flowers are grown for the domestic market. The industrial applications include heat for the leather industry at Vrhnika, and for cooling at a cement works and heating a swimming pool at Trbovlje. Geothermal heat pumps are used at even thermal spas and/or recreation centers for swimming pools and space heating. Most are groundwater units (around 56) and less than 10 are ground-coupled units. The installed capacity is 42.0 MWt which includes 2.6 MWt for heat pumps, and the annual energy use is 704.6 TJ of which 46.8 is for heat pumps.

Sweden: No country update report was received from Sweden. However, based on their WGC'95 report (Alm and Bjelm, 1995) the only energy use is from geothermal heat pumps in the Scania area of southwestern Sweden. At that time a large plant near the city of Lund had been operating since 1986. The installed capacity was 47 MWt and the annual energy use 960.2 TJ. More recently (1998) an estimate of the number of individual heat pumps in operation is reported at about 55,000 with a thermal capacity of 330 MW (Rybach and Sanner, 1999). A particular success story can be told of Strömstad, a town of 6,000 about 200 km north of Gothenburg. The rocky subsoil is not suited for district heating, and thus 140 ground-source heat pumps with a total of 400 borehole heat exchangers have been installed for heating of houses and apartment for 3,000 people (Sanner and Hellström, 1998). The improvement of air quality in winter was reported to be significant. The estimated annual use of the 55,000 units is then 3,168 TJ (based on 4,000 full load hours per year and a COP = 3.0). This then gives a total of 377 MWt and 4,128 TJ/yr.

Switzerland: Geothermal direct-use developed rapidly over the last five years (Rybach, et al., 2000). The increase is due mainly to geothermal heat pumps, with about 21,000 borehole heat exchanger/heat pump systems installed in the country, mainly for single family dwellings and smaller building complexes. In addition, novel solutions like combined heat extraction/storage, energy piles and tunnel water are used and are supported by government aid. Thus, the Swiss mix of geothermal use has two main components: 1) shallow resource utilization through horizontal coils and borehole heat exchangers, foundation piles and groundwater wells, and 2) use of deep resources - deep borehole heat exchangers, aquifer use by single and doublet systems, and tunnel water. Heat pumps are the key components in practically all these utilization schemes. There are 17 locations where spas use geothermal well water for balneology, space heating and heating nearby hospitals. A successful drilling to tap deep aquifers is at Riehen where heat is used in a district heating network which has also been extended to the neighboring community of Lörzach in Germany, thus providing the first example of a trans-boundary geothermal use. Warm tunnel water, frequently encountered during construction, is used at four sites for space heating and domestic warm-water productions. Future work, supported by the Swiss Government, include research and promotion of pilot and demonstration facilities including experimental and theoretical work with borehole heat exchangers and deep heat mining. The later projects aims at producing electricity and/or heat by the hot dry rock technology between 2005 and 2010. The installed

capacity is about 550 MWt of which 500 MWt is from

geothermal heat pumps, and the annual energy production is about 2,400 TJ of which 1,980 is from heat pumps. Annual growth for heat pumps is estimated at 15%.

United Kingdom: There is a large scale district heating projects in the UK at Southampton and a greenhouse project at Penryn (Batchelor, 1995). At Southampton a direct-use low enthalpy project provides district heating from the Sherwood Sandstone aquifer at 76°C from a depth of approximately 1,800 m. The 1987 project provides heat to the new Western Esplanade district in the center of town including a shopping center, offices, hotel and central baths. Geothermal energy provides 87% of the heat requirements and covers daily fluctuations in demand by means of storage tanks. A coal fired boiler provides back-up. The single geothermal well produces 10 to 15 L/s at sustained rates, and 20 L/s peak. The spent water is discharged into a nearby estuary through a main storm water sewer. The annual savings are 1,500 to 2,000 TOE and corresponding payback in approximately 14 year. The estimated capacity is 2.18 MWt and the annual energy use 17.17 TJ. Using other sources of energy, a combined heat and power generator and absorption heat pumps have been added in recent years and the system extended to other customers (Smith, 2000). At Penryn a 5.5 ha greenhouse project by Gabbons Nursery uses 22°C water for the hydroponic cultivation of tomatoes. A well, 275 m deep produces 5 kg/s water from Paleozoic rocks. The project has run profitably for 13 years with an estimated installed capacity of 0.10 MWt and annual use of 0.82 TJ. Geothermal heat pumps are found in both Scotland and England (Curtis, 2000). Approximately 25 houses used ground-coupled systems with a capacity of 62.5 kWt and annual use of 0.27 TJ in Scotland. In England there are approximately 15 domestic installations totaling 120 kWt and annual use of 0.52 TJ. There are also about nine commercial installations totaling 450 kWt and annual use of 1.94 TJ. Closed loop systems are expected to grow in the UK. Direct use of open loop systems mainly for cooling is also expected to grow to counteract the rising water table in some cities such as London. The total installed capacity in the UK is then 2.91 MWt and annual use of 20.72 TJ of which 0.63 MWt and 2.73 TJ is due to geothermal heat pumps. The historic Roman spa at Bath is being renovated and will be open to the public in 2001 using the naturally occurring thermal springs for bathing.

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Armenia: Since Armenia does not have any considerable fossil fuel resources and little hydro-electric potential it has become necessary to assess the geothermal resources of the country, Badalyan (2000) High heat flow values of 38 to 157 mW/m² have been estimated from 90 locations about the country. The highest numbers were measured in the central part of the country where thermal springs occur. It is found that a substantial part of the heat flow anomaly is caused by local heat sources at shallow depth. Silica geothermometer estimates of reservoir temperatures range from 40°C to 160°C. The eastern volcanic belt is thought to be the main area of geothermal potential where both dry and hydrothermal resources are expected.

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Belarus: Although there is no paper at this conference, it worth recording that there is geothermal energy potential, particular for low temperature use Zui and Levashkevich (1999). There are no known high enthalpy fields but temperatures up to 110°C at depths up to 5 km in the areas known as the Brest depression and the Pripyat Trough in the south east of the country have been measured. A number of shallow and deep boreholes have been drilled by drilling companies which has enabled temperature logs and heat flow measurements to be made.

Georgia: Buchachdize et al. (2000) reviews the status and future use of geothermal fluids in Georgia. In the South Caucasus and in particular Georgia, there is intensive use of geothermal energy. As of 1998 the confirmed total reserves are 90,000 m³/day which has a heat potential of 500,000 tonnes of equivalent fuel (TEF) annually. The field at Tbilisi, the capital of Georgia, is described as an example of the efficient use of energy and demonstrates that geothermal is cheaper and environmentally friendly for these conditions. The tables indicate that there is 350 MWt installed with an annual energy use of 9,986 TJ; however, this figure was reduced as the former numbers were based on a discharge temperature of 25°C for all installations giving the difference between inlet and outlet of as high as 83°C. Using instead a 40°C temperature change between inlet and outlet and a capacity factor of 0.8, a rounded figure of 250 MWt and 6,307 TJ/yr are used in this report summary. The maximum flow rate was also revised to 894 kg/s. In the period 1995-1999, 224 man years of effort and 1 million US\$ have been spent from mainly private funds.

Russia: Space heating (110 MWt) and greenhouse heating (160 MWt) dominate the direct-use scene in Russia, Kononov et al. (2000). Six towns and a number of settlements in the Northern Caucasus and Kamchatka, with a total population of about 220,000, use geothermal energy for space and district heating. Several greenhouses with a total area of 465,000 m² in the same area also geothermal fluids for heating. Besides Kamchatka and Northern Caucasus, the Western Siberian plate is a promising region for direct use applications. The aquifers located down to 3 km, in this region have a high hydrostatic pressure, temperatures of 35-75°C and capable of producing about 180 m³/s. These waters serve some small settlements for space heating and on a small scale are used to assist in the recovery of oil, extraction of iodine and bromide and for fish farming. The region is rich in natural gas which has limited the geothermal development. Heat pumps are at an early stage of development in Russia. An experimental facility in early 1999 was conducted in the Philippovo settlement of Yaroslavl district. The heat source is supplying 5-6°C to eight heat pumps which are heating the water up to 60°C supplying a 160-pupil school building. An aquatic park and water heating using heat pumps is planned in Moscow. Geothermal R& D is carried out in 14 cities of Russia where research centers unite the laboratories from 26 scientific institutes, 3 universities and 5 project bureaus. The Russian Academy of Sciences coordinates this research. The paper by Povarov (2000) adds information and detail of the country resources also mentions over a hundred heat pump applications in Siberia and Kamchatka is made but no details are given

Ukraine: Shuchkov, A. et al. (2000) discuss the possibility of utilizing the geothermal fluids discovered in a number of regions across the Ukraine. It is estimated that the commercially viable resources are about 20 to 30 million cu.m/day of waters with temperatures higher than 60°C. The major emphasis appears to be on co-generation plants and mention is made of the use of fluid for the supply of heat to residential, industrial and agricultural buildings on a small scale within the range 0.5 to 6 MWt. Some estimates of cost are included. A geothermal heating system in the range 1.2 to 6 MWt range, would cost installed from 270 USD to 700 USD for 1kW of installed power. The output cost for the same range is estimated at 16 USD to 26 USD for 1 MWh of energy, including all costs. Sensitivity of the numbers to fluid temperature and scale of project is demonstrated.

Oceania

Australia: Burns et al. (2000) report on Hydrothermal Power production centered in the great Artesian basin serving local communities. The basin in its lower part has permeable sediments, which are the intake beds for surface waters in a humid part of Queensland. The water moves slowly westward for 1500 to 1600 km and after about 2 million years emerges naturally in mound springs in the desert. About half of the natural recharge is tapped by 3,100 flowing artesian bores and over 35,000 non-flowing. In some regions the water at the surface reaches 100°C. For pastoral reasons the water is cooled and distributed by bore drains which are often tens of kilometers long, and may reach 90 km. Small homemade power plants used bore pressures to drive simple turbines to produce electricity for homesteads. They gradually became obsolete and only 20 or so survive.

Two small ORC power plants are currently in operation which were first reported in Burns et al. (1995). These are at Mulka (10 kWe) in South Australia and Birdsville Queensland. (39 kWe). They both use fluid from old wells which produce water from 1200-1300 m. Both plants have undergone major refurbishment since first reported.

Hydrothermal direct use continues in the Otway Basin of western Victoria, in a district heating system fully described in Burns et al. (1995). It uses 65 l/s of 58°C water from 1400 m and its current annual energy use is 271.2 TJ/yr. In addition, the system supports a 2000 m³ municipal pool giving a total energy use for the Portland system of 293.8 TJ/yr. There are numerous hot water pools around Australia developed for bathing by local government and tourist resorts or undeveloped, which draw water from natural hot springs but no information on heat production is available. A new development to build a hot water spa on the Mornington peninsular on the eastern part of the Otway Basin, was approved in 1999. It will use 50°C water from a depth of 534 m. The paper plant near Traralgon in the Gippsland Basin of Victoria, reported by Burns et al. (1995) which used 68°C water from two wells 600 m deep has ceased operation because of dewatering of the region due to the expansion of brown coal mining operations.

Ground and water source heat pumps have been widely adopted throughout Australia for air conditioning with at least 2000 installations in place and an estimated market expansion by more than 50% per annum including systems for heating commercial quantities of hot water and systems to dry fruits and vegetables. Several large systems are mentioned in Burns et al. (2000) but unfortunately no quantitative information is available. Research on raising the COP for heat pumps is underway at Melbourne and the Australian National Universities in collaboration with the Advanced Engineering Center for Manufacturing, by using paraffin wax as a phase change material on either side of the pump within the geothermal system.

New Zealand: Since the last update in Thain and Freeston (1995) there have been only minor changes in the New Zealand direct-use scene. The major direct user continues to be the Tasman Pulp and Paper Mill operation at Kawerau. With an installed capacity of 210 MWt and an annual energy use of 5,500 TJ/yr, (Thain and Dunstall, 2000) uses geothermal fluids to generate clean process steam for paper drying, a source of heat in evaporators, timber drying and electricity generation. Geothermal condensate previously discharged to the Tawarewa river is now collected, cleaned and used in power and liquor recovery boilers. Also on site is a timber drying plant and a green house of 5,250 m². Taupo Lucerne plant which used steam initially, has been converted to using reinjection hot water from the Ohaaki electric power system. The Wairakei prawn farm was also discussed in the 1995 paper but has since been converted for heating its 5.8 hectares of ponds with 130°C hot water from the Wairakei reinjection system. This farm has a capacity of 18.6 MWt and an annual utilization of 363 TJ/yr. Other uses of geothermal fluids are scattered about the central North Island but industrial use of geothermal heat is not extensive. The largest concentration of small direct heat users is in Rotorua where there is a long history of use. A management plan for the resource has been put in place which has proved to be a success. The bore users have some 150 small wells representing a capacity of >22 MWt and an annual utilization of 694 TJ/yr.

ENERGY SAVINGS

Using geothermal energy, obviously replaces the use of other forms of energy, especially fossil fuels. The benefits thus accrued are for many countries, less dependence on imported fuels, and for all, elimination of pollutants such as particulates and greenhouse gases. An attempt is made here to quantify these savings of fossil fuels using a 0.35 efficiency factor if the competing energy is used to produce electricity, and 0.70 if it is used directly to produce heat such as in a furnace.

Using the 162,009 TJ/yr of energy produced, estimating that a barrel of fuel oil contains 6.06×10^9 J, and that the fuel is used to produce replacement electricity, the savings would be 76.4 million barrels of oil or 11.4 million tonnes of oil annually. If the oil were used directly to produce energy by burning, then these values would be reduced by half. The actual saving is most likely somewhere in between these two values.

Using figures developed by Lawrence Livermore Laboratories for the U.S. Department of Energy, the following carbon savings

would be realized. If electricity were produced, then the carbon saving would be 14.65 tonnes/TJ from natural gas, 62.6 tonnes/TJ from oil or 72.7 tonnes/TJ from coal. This then produces a savings in carbon production of 2.37 million tonnes, 10.14 million tonnes or 11.78 million tonnes respectively. If the energy were produced by burning these fuels, the carbon saving would be half these values. Again the actual saving would be somewhere in between these sets of values and would include a mix of fossil fuels.

CONCLUDING REMARKS

As in 1995, some countries stand out as major users of geothermal fluids for direct-use, and in most countries the development has been slow. This is not surprising since the price of oil and natural gas during the past five years has been a major competitor to development of geothermal projects. However, many countries have been doing the necessary ground work by conducting an inventory and quantifying their resources in preparation for development when fossil fuel prices increase. We are also seeing many newcomers to the geothermal direct-use club - which we welcome - and hope to see more in the future. At the writing of these report, we are already seeing the cost of crude oil triple over the past year. In addition, the downturn in the economy of newly independent countries and in SE Asia have also stymied development in both the electric generation and direct-use fields. An important task for all of us, is to get the word out about the uses of geothermal energy and its many environmental benefits.

The country update reports used in this summary often had key data and explanation lacking, even though it was requested. In other cases, the data appeared to be in error or misreported. The authors hope to clarify these discrepancies at the World Geothermal Congress in Japan and then issue a final report later in the year, to be published in *Geothermics Journal*. We do not expect to see any set of numbers change significantly.

Even with these discrepancies, which we tried to correct in part, the preparation of this report has been useful if only to demonstrate that the use of low- to moderate-temperature geothermal resources for direct-use, given the right environment, is viable and economic. As oil and gas supplies dwindle and increase in price, the use of geothermal energy will become an even more economic viable alternative source of energy.

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