ICELAND *COUNTRY* UPDATE

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ABSTRACT: The principal use of geothermal energy in Iceland is for space heating, which started on a large scale over sixty years ago. Today *85%* of all houses are heated with geothermal water. Production of electricity accounts for 20% of the gross production of geothermal energy, but contributes only 5% to the electricity generated. The paper gives a summary of other utilization sectors: swimming pools, snow melting, industrial uses. greenhouses and fish farming. A recent development is the Nesjavellir geothermal power plant owned by Reykjavik Municipal Healing, that produces 150 MW_{th}. At the Svartsengi power plant four additional Ormat units (binary systems) were installed in 1992. 1.3 MW_e each. Increased attention is being paid to the influence of production on geothermal reservoirs and their potential, and on the environmental impacts of geothermal utilization.

1. INTRODUCTION

The annual primary energy supply in Iceland, which has a population of 265,000, is 98 PJ or 370 GJ per capita. which is among the highest in the world. Geothermal energy provides about 44% of the total, hydropower 16%, oil 38% and coal 2%. The main use of geothermal energy is for space heating. About 85% of all houses are heated with geothermal energy. the rest are heated mainly by electricity. *So* far geothermal resources have only to a limited extent been used for electric power generation, because of the availability of relatively cheap hydropower resources. Of the total electricity production of **4.800** GWh in 1994, only 265 GWh or 5,5% came from geothermal energy, 94,4% from hydro and 0,1% from fuels

Fig. 1 shows the annual primary energy supply in the period 1940-1994, classified by energy sources. In fig. 2 the primary energy supply and used energy in 1994 are shown. The primary energy for direct uses is calculated on the basis of the referance temperature 5°C, which is the average annual tempeature in Reykjavik. For electricity prcduction the primary energy is calculated on the basis of 10% thermal efficiency.

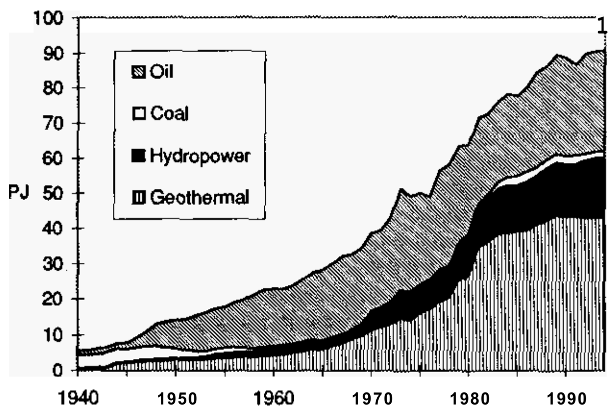

Fig. 1. Primary energy supply in Iceland 1940-1994, classified by energy *sources* (excluding aircraft and ship refueling outside Iceland).

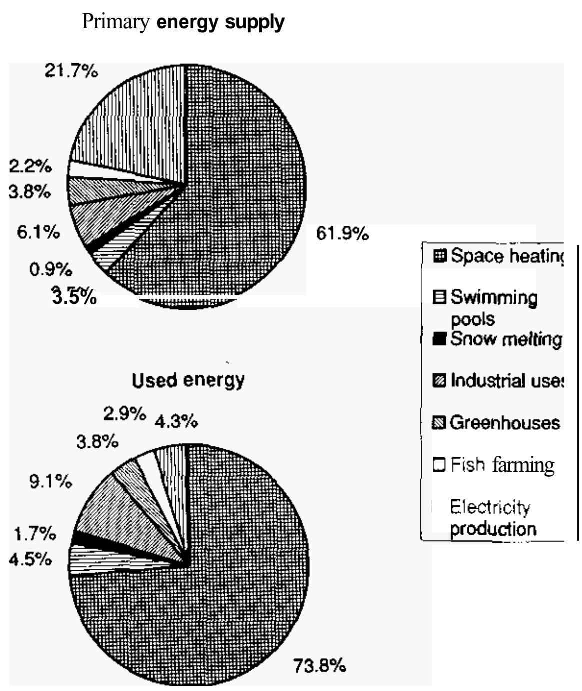

Fig. 2. Geothermal primary energy supply and used energy in Iceland in 1994. classified by sectors.

2. SPACE HEATING

The main use of geothermal energy in Iceland is for space heating. In 1970 about 50% of the population was served by geothermal district heating systems. After the oil crisis in the 1970s replacing *imported oil* with *indigenous* energy sources (geothermal and hydro) received high priority. Today about *85%* of the space heating is by geothermal energy. the rest is by electricity (12%) and oil (3%). Fig. 3 shows how geothermal energy has replaced imported oil for space heating over the period 1970-1994. The benefits of geothermal heating are of great imponance in a country where heating is required practically throughout the year, as it saves annually about 100 million US$ in imported oil. The total geothermal energy used for space heating in Iceland is about 16300 TI per year.

There are now 27 municipally owned geothermal district heating services in Iceland. By far the largest one is the Reykjavik Municipal District Heating (Hitaveita Reykjavíkur), which had it's beginning in 1930. Today it serves about 145,000 people, or 99.7%

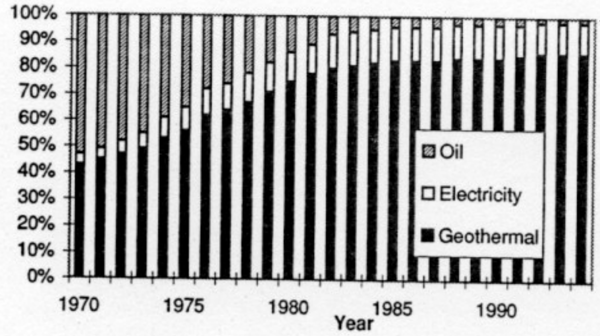

Fig. 3. Space heating market by sources 1970-1994.

of the population in Reykjavík and five neighboring communities, see table 1.

Table 1. Reykjavík Municipal District Heating Service 1993

Number of people served	144,549
Volume of houses served	37,568,000 m^3
Water temperature at user end	75°C
Number of wells in use	56
Installed capacity	640 MW$_{th}$
Total pipe length	1121 km
Water delivered	56,789,000 m^3/year

The only Icelandic district heating system using heat pumps is in Akureyri. Two heat pumps, 1.3 MWth each, were installed in 1984. They extract heat from part of the return water from the district heating system at 35°C and boost another part of the return water to 80°C. They provide about 5% of the total energy production. The ten year experience with the heat pump units has shown them to be satisfactory, both from technical and economical points of view.

Over the last decade, many district heating systems have been built in rural areas with low population densities. These single pipe systems typically serve ten to twenty farms that can be one to three kilometers apart. These systems serve about 4,000 inhabitants and the total pipe length is about 900 km, or 225 m per person, compared to 12 m in towns. In most cases plastic pipes are used. They are made in Iceland of polypropylene or polybutylene and have diameters ranging from 25 to 110 mm. The insulation consists of 4 m long sections of polyurethane "sandwiches", which are strapped to the pipe in the field after unrolling the pipe. The installation of these pipelines is simple and is often performed by the farmers themselves. Each farmer receives a certain maximum flow, typically 15 liters per minute, that he can freely use throughout the year.

Experience in Iceland to date shows that plastic pipes can be used for moderate pressure water at temperatures up to at least 85°C. At higher temperatures the risk of pipe damage increases considerably. It is important to keep the water pressure low, due to temperature and pressure limitations of the plastic, and to keep the pipe wall, and thereby material costs, as thin as possible. Compared to the traditional pre-insulated steel pipes, the main advantages of plastic pipes are the relatively low piping costs, easy installations and no corrosion effects on plastic pipes. The main disadvantages are the low limits on water pressure and temperature, rapid increase in pipe cost with increased pressure and pipe diameter, corrosion of radiators because of oxygen diffusing through the plastic pipe walls and high heat loss, especially during wet weather.

Two systems for selling the geothermal water are in general use, by water meter or by subscription. Most commonly, the user pays a fixed annual charge and a price for each cubic meter of water used as measured by a water meter. The other system is based on maximum flow restriction, where the user pays a fixed annual charge and a price related to the maximum flow rate that is equal to the expected demand during the coldest winter period. As most of the systems are direct throughflow systems, conventional energy metering is not suitable, because it would not encourage the users to maximize the heat extracted from the water before it goes to waste (the sewer system). Over the past few years most of the systems which earlier used maximum flow restriction have changed their tariff systems to water meters. The main reason for this is that the old system did not encourage the users to cut back the flow outside the coldest winter months. Where this change of tariff system has been completed, it has resulted in 20%-35% reduction in annual water consumption. As a result, the draw-down in the geothermal reservoir exploited has been reduced and money has been saved by delaying the need for additional drilling or development of new geothermal fields.

Increased attention has been paid to the influence of large-scale production of hot water or steam on the geothermal systems. In several geothermal systems the water level continues to drop and in other instances cold water is starting to invade the systems. The latter may cause changes in both the temperature and the chemical content of the of the water produced. Lowering of the water level and temperature are factors that limit the potential of a geothermal system. Table 2 gives a few examples of these effects on geothermal reservoirs being exploited.

Table 2. Effects of exploitation on six geothermal reservoirs in Iceland.

Geothermal system	Prod. starts	Average prod. kg/s	Water temp. °C	Draw-down m	Cooling °C
Laugarnes	1930	160	127	130	0
Reykir	1944	920	64-100	100	0/13
Hamar	1970	24	64	35	0
Svartsengi	1976	260	240	210	0
S-Laugaland	1976	42	95	350	0
Urridavatn	1980	19	75	35	2/15

As the effects of hot water production on the reservoirs have become clearer, the district heating services have paid more attention to monitoring of the geothermal fields. During the past five years the National Energy Authority (NEA) has developed and installed data logging systems at 12 sites for field monitoring. The parameters logged are: water temperature, draw-down and flow rate from each well. The data is automatically transferred to NEA where it is used for monitoring and for reservoir engineering studies.

Another area receiving increased attention in recent years is the environmental impact of geothermal projects. According to a new Icelandic environmental law, all geothermal developments exceeding 25 MW$_{th}$ gross production, or 10 MW$_e$ net production, have to submit a detailed appraisal of the environmental impacts. The National Energy Authority has, since 1991, been working on a research project in this field in cooperation with some of the largest geothermal companies. A study of all the high-temperature geothermal areas under utilization has been initiated. Several unexploited areas are being studied for comparison. Pollution of air by hydrogen sulphide (H_2S) emission and of ground water by power plant effluents are among the influences considered, as well as thermal pollution and land subsidence.

3. SWIMMING POOLS

From the time of settlement of Iceland some 1100 years ago until early in this century the utilization of geothermal resources in Iceland was limited to bathing, washing and cooking. Today these uses are still important and heating of swimming pools is among the largest segments, after district heating. There are 120 public swimming pools heated by geothermal energy with a combined surface area of 23,000 m². Most of them are out-doors and in use throughout the year. They are both far recreational use and far swimming instruction, which is compulsory in the primary schools. In general, swimming is a very popular pastime in Iceland and in the Reykjavik area alone there arc five outdoor and three indoor public swimming pools. The largest pool is Laugardalslaug in Reykjavik. with a surface area of 1500 m² and five hot tubs with a water temperature ranging from 35 to 42°C. The annual water consumption of Laugardalslaug is 460,000 m³. The total geothermal energy used in swimming pools in Iceland is estimated to be 1000 TJ per year.

4. SNOW MELTING

The use of geothermal energy for snow melting has been widespread for the past 10-15 years. This kind of utilization gained popularity when plastic pipes for hot water were introduced in the market. Spent water from the houses, at about 35°C, is commonly used for deicing of sidewalks and parking spaces. During the last few years the extension of snow melting systems has expanded considerably. The total area now covered by snow melting systems is estimated to be 350,000 m², of which about 250.000 m² are in Reykjavík. Extensive rehabilitation of the streets in down-town Reykjavík has been undertaken during the past five years. One improvement was to install snow melting systems, covering an area of 50,000 m², in the sidewalks and streets. This system is designed for a heat output of 180 W perm' surface area. The annual energy consumption is of course strongly dependent on the weather conditions. Measurements from Reykjavik's center has shown the energy consumption to be *250* kWh/m²-375 kWh/m² (Jónsson, 1994). The total energy use for snow melting is estimated to be 380 TJ per year.

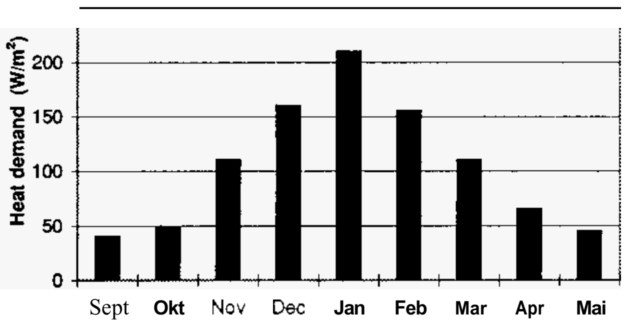

Fig. 4. Heat demand for snow melting in Reykjavík (Jónsson, 1994).

5. INDUSTRIAL USES

Kísilidjan, the diatomite plant at Mývatn, near the Námafjall high-temperature ficld, is among the largest industrial users of geothermal steam in the world. The plant has been in operation since 1967, and the annual production has been between 20,000-30,000 tons of diatomite filter aid which is exported. The raw material is diatomaceous earth taken from deposits on the bottom of lake Mývatn. In the last few years the production has slightly decreased. the average for the last 5 years being about 22,000 tons of diatomite per year. The process requires about 220,000 tons annually of geothermal steam at 10 bar absolute (180°C). This corresponds to an energy use of 515 TJ per year.

At Reykhólar, a seaweed processing plant uses geothermal water for drying. About 28 l/s of 107°C hot water are used and cooled down to 55°C. The annual use of geothermal energy in the plant is about 150 TJ.

On the Reykjanes Peninsula, a salt pilot plant was in operation far more than twenty years, but was closed down in 1994 due to bankruptcy. From geothermal brine and sea water the plant produced salt for the domestic fishing industry as well as low-sodium health salt for export. The annual use of steam was about 400,000 tons at 10 bar absolute (180°C). which corresponds to an energy use of 813 TJ per year.

Several small companies use geothermal water for industrial purposes, most of them buying their water from the district heating services around the country. A new survey indicates that 10% of the total geothermal energy delivered by the district heating services is used for industrial purposes, including space heating in the industry (Líndal, in press). Over the past 5 years there have been no notable changes in the utilization of geothermal energy for industrial purposes in Iceland and no new plants have been built.

6. GREENHOUSES

Heating of greenhouses with geothermal water began in 1920. Before that time, naturally warm soil had been used for growing of potatoes and other vegetables. Over the past few years the use of artificial lighting has gained popularity and has extended the growing season to nine months. The total area under glass has increased over the years to 175,000 m², and 105,000 m² of soil is heated by pipes buried in the ground. Tomatoes, cucumbers, paprika etc. are the most popular crops and greenhouses also supply most of the flowers far the domestic market. The total geothermal energy used in the greenhouse sector in Iceland is estimated to be 830 TJ per year.

7. FISH FARMING

In the middle of the 1980s an explosive growth in fish-farming took place and over 120 land based aquaculture complexes were built. Salmon is the main species but arctic char and trout has also been raised. This industry has had fmancial difficulties and many of the farms have gone into bankruptcy, mainly the large installations. Because of this the anticipated increase in geothermal utilization in the fish-farming sector did not materialize. At present there are 75 farms in operation. Many of them use geothermal hat water to heat 4-6°C freshwater to approximately 12°C. the ideal temperature for rapid development of fish smolt. The total geothermal energy used in the fish-farming sector in Iceland is estimated to be 630 TJ per year.

8. GEOTHERMAL ELECTRIC POWER GENERATION

Geothermal resources have only to a limited extent been used for electric power generation in Iceland, because of the availability of relatively cheap hydropower. At present the total capacity of existing power plants exceeds the actual demand. This of course does not encourage further geothermal utilization for power production. Geothermal power is produced far the national grid at three high-temperature areas: Bjarnarflag, Krafla and Svartsengi.

The first geothermal power plant was built in 1969 when a 3 MW, back-pressure turbine was installed in Bjarnarflag (Námafjall field). This field also supplies steam to the Kisilidjan diatomite plant. The power plant has been operated successfully ever since the beginning 25 years ago. The reservoir temperature is about 280°C. Steam is separated from the water at 9.5 bar absolute to provide a steam flow rate of 12.5 kg/s to a single flash turbine. The total electrical production of the Bjarnarflag power plant in 1993 was 8.9 GWh.

The Krafla power plant, located about 10 km north of the Nhafjall field, has been in operation since 1977. Two units, 30 MW_e each, were purchased but only one of them was installed because of inadequate steam supply. The shortfall of steam was in part due to volcanic activity in the area. At the end of 1975, while the plant was under consttuction. a volcanic eruption started only 1-2 km from the drilling area. The immediate effect of the emption was a contamination of the geothermal fluids by the volcanic gases. This caused operational problems in some of rhe production wells. mostly in the form of rapid scaling of complex iron silicates and also corrosion in the wells. Recent exploration drilling has shown that the concentration of magmatic gases in the steam has decreased drastically. Surface lava flows and earthquakes did not harm the installations. The plant has operated successfully with one unit in spite of nine etuptions, the last one in September 1984. Initially the power production was 8 MW_e, but reached the present 30 MW_e in 1982. The plant is shut down for four months every summer as there is abundant hydropower due to high riverflows from snow melt. The production reservoir zone has a temperature of about 210°C. Steam is separated from the water in two stages, at 7.7 and 2.2 bar absolute, to provide 60 kg/s high pressure steam and 15 kg/s of low pressure steam. The installed unit has a double flash condensing turbine, which in 1993 had a total electrical production of 145 GWh.

The Svartsengi power plant is a co-generation plant. which produces both hot water for district heating and electricity. It is located on the Reykjanes peninsula, about 40 km from Reykjavik. The system was commissioned 1976 and has the main purpose of providing the neighboring communities of about 14,500 inhabitants and the airport at Keflavik with disuict heating. The geothermal reservoir fluid is a brine at 240°C and with a salinity of about two thirds of sea water. The geothermal heat is transferred to freshwater in several heat exchangers. The effluent brine is disposed of into a surface pond called the Blue Lagoon, that is popular by tourists and people suffering from psoriasis and other forms of eczema, who seek therapeutic effects from the silica rich brine

Three single flash back-pressure turbines were originally installed at Svartsengi, one 6 MW_e and two 1 MW_e. In 1989, three Ormat units were installed. each of 1.3 MW_e. They are binary systems using low-pressure excess steam from the back-pressure units to produce electricity in a closed organic Rankine cycle. In 1992 four additional Ormat units were installed bringing the total installed capacity to 17.1 MW_e. The electrical production of Svartsengi power plant in 1993 was 100 GWh.

At the salt plant on the Reykjanes peninsula a small back-pressure turbine of 0.5 MW_e is installed and provides electricity far local needs only.

At the Nesjavellir high temperature field, Reykjavik Municipal District Heating has built a co-generation power plant, which was commissioned in 1990. The primary purpose of the plant is to provide hot water for the Reykjavik area 27 km away. It supplements the water from the low-temperature fields in the vicinity of Reykjavik which are fully exploited. Freshwater is heated by geothermal steam in heat exchangers in a similar way as in the Svartsengi power plant. The fust phase of the plant was a hot water production of the capacity 100 MW_{th}. The second phase, which was for another 50 MW_{th}, went into operation in 1992. The production of electricity has ken postponed because of the current overabundance of electricity in the counuy. The ultimate goal is to produce 400 MW_{th} for space heating and 80 MW_e far electric generation.

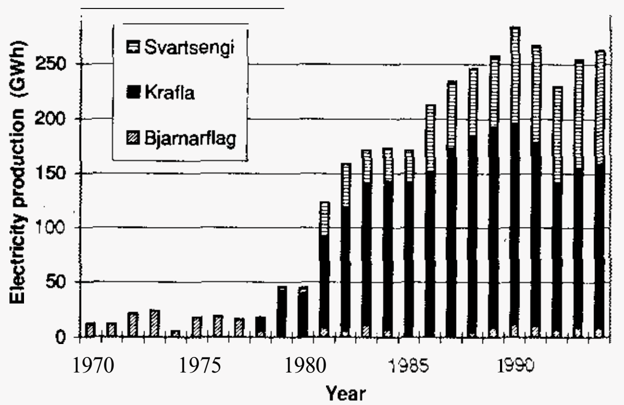

Fig. 5. Geothermal production of electricity in Iceland 1970-1994.

9. EXPLORATION ACTIVITIES

The National Energy Authority, in cooperation with the National Power Company, Reykjavik Municipal Heating and Sudurnes District Heating, has since 1991 been working on a project, which involves exploration of high-temperature geothermal area with respect to their potential for electricity generation. The project is based on the principle of conducting investigations simultaneously in more than one geothermal area and hamessing the areas in relatively small steps. As a part of this project surface explorations have been carried out in several geothermal fields. Many smaller studies have also been carried out in a number of low-temperature fields for district heating services.

10. DRILLING ACTIVITIES

Drilling activity has been slow in Iceland for the past 5 years. with only two wells drilled in high-temperature areas. A good number of low-temperature wells have been drilled in this period, mainly for new projects in rural areas and for fish-farms. Drilling of shallow temperature gradient wells for exploration has also increased in recent years. Fig. 6 gives an overview of the drilling activity over the past 25 years.

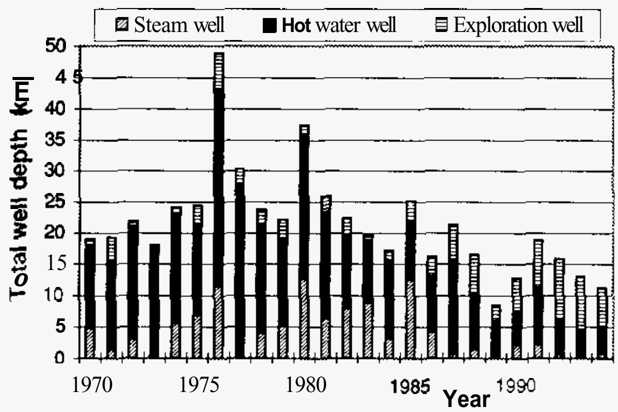

Fig. 6. Total depth of geothermal wells drilled annually in Iceland in the period 1970-1994.

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TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Total	
	capacity MWₑ	Gross Prod. GWh/yr	Capacity MWₑ	Gross Prod. GWh/yr	Capacity MWₑ	Gross Prod. GWh/yr	Capacity MWₑ	Gross Prod. GWh/yr	Capacity MWₑ	Gross Prod. GWh/yr
In operation in January 1995	50	265	119	3	875	4532	0	0	1044	4800
Under construction in January 1995	0		0		0		0		0	
Funds committed, but not yet under construction in January 1995	0		0		0		0		0	
Total projected use by 2000	50	280	119	3	875	4817	0	0	1044	5100

TABLE 2. IJTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRICAL GENERATION IN DECEMBER 1994

[1] Data for 1994 if available, otherwise for 1993. Please specify which.

Locality	Power Plant Name	Year Commissioned	No of Units	Status	Type of Unit	Unit Rating MWₑ	Total Installed Cap. MWₑ	Annual Energy Prod. [1] 1994 GWh/yr	Total under Constr. or Planned MWₑ
Krafla	Krafla	1917	1	In operation	2-Flash	30	30	150	
Námafjall	Námafjall	1969	1	In operation	1-Flash	3	3	10	
Svartsengi	Svartsengi	1978	2	In operation	1-Flash	1	2	16	
Svartsengi	Svartsengi	1981	1	In operation	1-Flash	6	6	56	
Svartsengi	Svartsengi	1989/92	7	In operation	Binary	1.2	8.4	33	
Total			12				49.4	265	

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT IN DECEMBER 1994

[1] I = Industrial process heat
C = Air conditioning
A = Agricultural drying
F = Fish and other animal fanning
S = Snow melting
D = Space heating
B = Bathing and swimming
G = Greenhouses
O = Other (please specify by footnote)

[2] Enthalpy information is given only if there is steam or two-phase flow

[3] Energy use (TJ/yr) = Annual average water flow rate (kg/s) x [Inlet temp.(°C) - Outlet temp.(°C)] x 0.1319

Locality	Type[1]	Maximum Utilization					Annual Utilization		
		Flow Rate	Temperature (°C)		Enthalpy[2] (kJ/kg)		Average Flow Rate	Energy Use[3]	Load Factor
		kg/s	Inlet	Outlet	Inlet	Outlet	kg/s	TJ/yr	
Reykjavik	DBGSF	3314	80	35			1800	10684	0.54
Seltjarnarnes	DBIS	96	82	35			43.7	271	0.45
Mosfellsbær	DBG	85	78	35			46.1	261	0.54
Suðurnes	DBIF	433	82	35			312	1934	0.72
Akranes og Borg.	DBGIS	149	78	35			73	414	0.49
Reykhólar	3BG	6	90	35			3.3	24	0.55
Suðureyri	DBG	4.5	74	35			2.7	14	0.60
Laugarbakki	DBG	3	78	35			1.6	9	0.53
Hvammstangi	DB	19	95	35			12.7	92	0.67
Blönduós	DB	32	62	35			20.9	74	0.65
Sauðárkrókur	DBGIS	98	70	35			73.8	341	0.75
Varmahlíð	DB	9	89	35			5.5	39	0.61
Siglufjörður	DB	34	70	35			19	88	0.56
Ólafsfjörður	DBIF	57	60	35			35	157	0.61
Dalvík	DBISF	51	64	35			25.7	98	0.50
Hrísey	DB	11	78	35			7	40	0.64
Akureyri	IBIS	240	78	35			133	754	0.55
Húsavík	DBF	93	80	35			45	267	0.48
Reykjahlíð	DB	14	90	35			7.5	54	0.53
Egilsstaðir	DBGF	38	74	35			22.5	116	0.59
Rangæinga	JB	29	77	35			16.7	92	0.57
Brautarholt	JBG	2	73	35			1	5	0.50
Flúðir	JBGI	62	96	35			48	386	0.77
Laugarás	DGI	67	96	35			46.6	375	0.70
Selfoss	DBI	166	72	35			100	488	0.60
Hveragerði	DBG	98	85	35			44.4	293	0.45
Þorlákshöfn	JBI	27	94	35			20.5	[illegible]	0.76
Reykhólar		33	107	50			20		0.61
Kísiliðjan, Mývatn		8	180		2778		7		0.87
Reykjanes		16	180		2778		12.8		0.80
Other **uses**	DBGIF	500					326	2151	0.65
Total		5794					3333	21158	0.57

TABLE 4. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES

[1] Inst. thermal power (MW_t) = Max. water flow rate (kgls) x [Inlet temp.(°C) - Outlet temp.(°C)] x 0.004184

[2] Energy use (TJ/yr) = Annual average water flow rate (kg/s) x [Inlet temp.(°C) - Outlet temp.(°C)] x 0.1319

	Installed Thermal Power[1] MW_t	Energy Use[2] TJ/yr
Space heating	1150	16300
Bathing and swimming	60	1000
Agricultural drying		
Greenhouses	45	830
Fish and other animal farming	25	630
Industrial process heat	105	2000
Snow melting	55	380
Air conditioning		
Other uses (specify)		
Subtotal	1440	21140
Heat Pumps	3	18
Total	1443	21158

TABLE 5. GEOTHERMAL HEAT PUMPS

[1] Thermal energy used (TJ/yr)
= Annual average geothermal water flow rate (kg/s) x [Inlet temp.(°C) - Outlet temp.(°C)] x 0.1319·

Locality	Heat Source °C	COP - Factor	Heat Pump Rating MW_t (Output)	Thermal Energy Used in Heating Mode[1] TJ/yr
Akureyri	35	3	2 x 1.3	14
Grenivík	19			2
Other				2
Total				18

TABLE 6. INFORMATION ABOUT GEOTHERMAL LOCALITIES

1) Main type of reservoir rock

2) Total dissolved solids (TDS) in water before flashing. Put v for vapor dominated

3) N = Identified geothermal locality, but no assessment information available
R = Regional assessment
P = he-feasability studies
F = Feasability studies (Reservoir evaluation and Engineering studies)
U = Commercial utilization

Locality	Location To Nearest 0.5 Degree		Reservoir		Status3) in January 1995	Reservoir Temp. (°C)	
	Latitude	Longitude	Rock”	Dissolved Solids2) mg/kg		Estimated	Measured
Reykjanes	64.0N	22.5 W	Basaltic: lavas, breccias. hyaloclastites & intrusions	33000	U		295
Eldvörp	64.0	22.5	Basaltic: lavas, breccias. hyalo-clastites & intrusions	23000	F		
Svartsengi	64.0	22.5	Basaltic: breccias. lavas. hyaloclastites & intrusions	22000	U		240
Krísuvík	64.0	22.0	Basaltic: lavas, breccias & hyaloclastites	2000	R		220
Brennisteinsfjöll	64.0	22.0	Basaltic		R		
Hengill	64.0	21.0	Basaltic: lavas. breccias, hyalo-clasties & intrusions intermediate & rhyolitic:lavas & intrusions	loa,	U		300 (boiling)
Geysir	64.5	20.5	Basaltic & rhyolitic	1000	R	260	
Kerlingarfjöll	64.5	19.0	Basaltic & rhyolitic: breccias & lavas	loa,	R	280	
Hveravellir	65.0	19.5		loa,	R	280	
Mýrdalsjökull (:subglacial)	63.5	19.0			N	>200	
Torfajökull	64.0	19.0		1000	R	265	
Grímsvötn (subglacial)	64.5	17.5			R	>300	

TABLE 6. (co nued)

Locality	Location To Nearest 0.5 Degre		Reservoir		Status[3)] in January 1995	Reservoir Temp. (°C	
	Latitude	Longitud	Rock[1)]	Dissolved Solids[2)] mg/kg		Estimated	Measured
Köldukvíslarbotnar	64.5 N	18.0 W			N	250	
Vonarskarð	64.5	18.0			N	>200	
Kverkfjöll (subglacial)	64.5	16.5			R	270	
Askja	65.0	16.5	Basaltic & rhyolitic		R	>300	
Fremrinámar	65.5	16.5			N	270	
Námafjall	65.5	17.0	Basaltic: lavas & breccias. Basalt & intermediate ntrusions	700	U		300 (boiling)
Krafla	65.0	16.5	Basaltic & rhyolitic: avas. breccias & ntrusions Basaltic & hyolitic	000-1500	U		300 (boiling)
Theistareykir	66.0	17.0			R	*300*	
Öxarfjördur	66.0	16.5			N		
(Prestahnúkur)	64.5	20.5					
(Hofsjökull subglacial)	64.5	19.0					
(Tindfjallajökull)	63.5	19.5					
(Thórdarhyrna subglacial)	64.0	17.5					
(Hrúthálsar)	65.0	16.5					
(Kolbeinsey suboceanic)	67.0	18.5			N		

TABLE 6. (continued)

Locality	Location To Nearest 0.5 Degree		Reservoir		Status[3)] in January 1995	Reservoir Temp. (°C)	
	Latitude	Longitude	Rock[1)]	Dissolved Solids[2)] mg/kg		Estimated	Measured
Árnessýsla	64.0 N	21.0 W	Tectonically active flood basalts interbedded with hyaloclastite formation	200-1500	U		50-150
Gullbringu- og Kjósarsýsla	64.0	21.5	Tectonically active flood basalts interbedded with hyaloclastite formation	150-36000	U		100
Borgarfj. og Mýrar	64.5	21.5	Tectonically active flood basalts region	200-1000	U		50-120
Snæfellsnes og Dalir	65.0	22.0	Tectonically active flood basalts region	200-1500	U		50-80
Vestfirðir	66.0	23.0	Tectonically active flwd basalts region	100-1000	U		20-90
Húnaþing	65.5	21.0	Tectonically active flood basalts region	300-1000	U		100
Skagafjörður	65.5	19.5	Tectonically active flood basalts region	200-400	U		20-90
Eyjafjörður	66.0	18.0	Tectonically active flood basalts region	200-900	U		40-90
Þingeyjarsýslur	66.0	17.5	Tectonically active flood basalts interbedded with hyaloclastite formation	200-12000	U		50-140
Múlasýslur	65.5	14.5	Tectonically active flood basalts region	100-500	U		55-75
Skaftafellssýslur	64.0	18.0	Tectonically active flood basalts interbedded with hyaloclastite formation	200-400	N	20-70	
Rangárvallasýsla	64.0	20.0	Tectonically active flwd basalt region	200-4500	U		40-90

TABLE 7. WELLS DRILLED FOR ELECTRICAL AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1,1990 TO DECEMBER 31,1994

(Do not include thermal gradient wells less than 100 m deep)

1) Type or purpose of well

T = Thermal gradient or other scientific purpose
E = Exploration
P = Production
I = Injection
C = Combined electrical and direct use

2) Total flow rate at given wellhead pressure (WHP)

Locality	Year Drilled	Well Number	Type of Well[1]	Total Depth m	Max. Temp. °C	Fluid Enthalpy kJ/kg	Well Output[2] Flow Rate kg/s	WHP bar
KRAFLA	1990	K-25*	E	2105	332	1600	40	20
	1991	K-26	P	2065	341	2500	8	20
	1991	KH-1	T	204	174			
	1991	KH-2	T	166	40			
SVARTSENGI	1992-93	14	P	612	230	2750	6.5	11.5
	1992	15	T	141	195	2780	1	1
HENGILL								
Ölkelduháls	1994-95	1	E	782	250			
Total				2705				

* Deposits of iron sulphides and silicates block the well

TABLE 8. WELLS DRILLED FOR DIRECT HEAT UTILIZATION OF GEOTHERMAL RESOURCES FROM JANUARY 1,1990 TO DECEMBER 31,1994

(Do not **include** thermal **gradient wells** less than **100** m **deep)**

1) Type or purpose of well and manner of production
Use one symbol from colomn (a) and one from column (b)

(a)	(b)
T = Thermal gradient or other scientific purpose	A = Artesian
E = Exploration	P = Pumped
P = Production	F = Flashing
I = Injection	

2) Total flow rate at given wellhead pressure (WHP)

Locality	Year Drilled	Well Number	Type of Well[1]	Total Depth m	Max. Temp. °C	Fluid Enthalpy kJ/kg	Well Output[2] Flow Rate kg/s	Draw-down m
GULLBRINGUSÝSLA								
Seltjarnarnes								
Ráðagerði	1993	SN-7	E	153	41.5			
Nes	1993	SN-8	E	153	19.8			
Bakki	1994	SN-9	E	132	34.4			
Bakki	1994	SN-10	E	132	33.9			
Ráðagerði	1994	SN-11	E	145	56.7			
Ráðagerði	1994	SN-12	P P	2714	138.5		35	90
Reykjavik								
Bústaðaháls	1992	HS-23	E	316	80.5			
Gufunes	1992	HS-25	E	104	21.3			
Kleppur	1993	HS-31	E	380	63.9			
Gufunes	1993	HS-33	E	346	98.3			
Nauthólsvík	1993	HS-36	E	990	87.9			
Örfirisey	1994	HS-40	E	348	43.4			
KJÓSARSÝSLA								
Mosfellsbær								
Skammidalur	1992	HS-24	E	231	84.7			
Þormóðsdalur	1992	HS-26	E	378	6.3			
Þormóðsdalur	1992	HS-27	E	451	19.1			
Þormóðsdalur	1993	HS-32	E	408	13.2			
Reykjahvoll	1993	HS-34	E	200	62.2			
Lágafell	1993	HS-35	E	220	40.3			
Helgafell	1993	HS-37	E	446	77.8			
Sólvellir	1994	HS-39	E	251	50.2			
Reykjahvoll	1994	HS-41	E	370	9.9			
Lágafell	1994	HS-35	E	447	40.3			
Varmá	1994	HS-43	E	200	32.6			
Kjalarneshreppur								
Álfsnes	1992	HS-28	E	255	62.7			
Norður-Gröf	1992	HS-29	E	104	31.9			
Álfsnes	1992	HS-30	E	153	23.8			
Kjósarhreppur								
Fremri-Háls	1992	FH-5	P P	873	120		20	100
Fremri-Háls	1993	FH-6	P P	404	96.9		2	100
Hvammsvík	1992	HV-10	P P	1466	117.1		25	100

* Exploration wells are mainly thermal gradient wells

TABLE 8. (continued)

Locality	Year Drilled	Well Number	Type c Well"	Total Depth m	Max. Temp. °C	Fluid Enthalp kJ/kg	Well Output[2)] low Rat kg/s	Draw-down m
BORGARFJARÐARSÝSLA								
Leirár- og Melahreppur								
Eystri-Leirárgarðar	1990	EG-3	E	120	62.1			
Eystri-Leirárgarðar	1990	EG-6	E	143	87.3			
Skorradalshreppur								
Stóra-Drageyri	1994	SD-6	E	836	93.5			
Efri-Hreppur	1994	EH-1	E	142	64			
Lundarreykjadalshr								
Snartarstaðir	1991	SS-1	E	149	95.7			
Snartarstaðir	1991	SS-5	P A	309	100.9		8	0
Gilstreymi	1991	GS-1	E	104	25.9			
Hálsahreppur								
Úlfsstaðir	1993	US-3	P A	130	57		0.5	0
Rauðsgil	1993	RG-5	E	162	28.1			
MÝRASÝSLA								
Hvítársíðuhreppur								
Háafell	1992	HF-1	P A	63	102.6		1.5	0
Þórgautsstaðir	1992	w-4	P A	114	29.6		4	0
Síðumúli	1993	SM-1	P A	270	90.8		1.5	0
Norðurárdalshreppur								
Bifröst	1991	BI-2	E	210	42			
Bifröst	1991	BI-3	P P	408	62.3		11	40
Svartagil	1992	SG-3	P P	751	69.9		6	0
Stafholtstungnahreppur								
Munaðarnes	1992	MN-2	P A	969	86		2	0
SNÆFELLSNESSÝSLA								
Staðarsveit								
Bergsholt	1991	BH-3	E	120	30.3			
DALASÝSLA								
Hvammshreppur								
Gerði	1993	SG-4	E	137	15			
Gerði	1994	SG-5	P	440	41		0	0
Saurbæjarhreppur								
Kverngrjót	1990	KG-5	P	233	16.2		1	50
Suðurdalahreppur								
Gröf í Miðdölum	1990	GR-5	E	105	51.8			
Gröf í Miðdölum	1991	GR-8	P A	1018	88.8		5	0
Gröf í Miðdölum	1992	GR-9	P P	1280	86.1		15	100
A-BARÐASTRANDAS								
Reykhólahreppur								
Klettur	1991	KL7	E	110	27.4			
Klettur	1992	KL9	E	425	63.8			
Klettur	1993	KL-10	P P	599	71.3		20	40
Reykhólar	1993	RH-7	P A	550	112.7		10	0
V-BARÐASTRANDAS.								
Tálknafjarðarhreppur								
Eysteinscyri	1990	EE-7	P	148	14.6			
Eysteinscyri	1990	EE-8	P	127	14			
Eysteinseyri	1990	EE-9	P	144	14.7			

TABLE 8. (continued)

Locality	Year Drilled	Well Number	'ype c well':	Total m	Max. Temp. °C	Fluid Enthalp kJ/kg	Well Output"	
							'low Rat kg/s	Draw-down m
Eysteinseyri	1990	EE-10	P	168	14.5			
Sveinseyri	1992	SE-6	P	119	12.8			
Sveinseyri	1992	SE-7	P	210	8.3			
Sveinseyti	1992	SE-8	P	93	5			
Sveinseyri	1992	SE-9	P	77	6			
Sveinseyri	1992	SE-10	P	208	15			
Sveinseyri	1994	SE-11	P	117				
svcinseyri	1994	SE-12	P	70				
Sveinseyri	1994	SE-13	P	114				
Sveinseyri	1994	SE-14	P	226				
Sveinseyri	1994	SE-15	P	319	24.7			
svcinseyri	1994	SE-16	P	198				
svcinseyri	1994	SE-17	P	141	15.9			
Sveinseyri	1994	SE-18	P	119				
Sveinseyri	1994	SE-19	P	85				
svcinseyri	1994	SE-20	P	85				
V-HÚNAVATNSSÝSLA								
Staðarhreppur								
Reykir	1994	RS-10	P	440	125.5		0	0
Þingeyrar	1994	PE-13	E	132	21.6			
Þingeyrar	1994	PE-14	E	200	24			
SKAGAFJARÐARSÝSLA								
Rípurhreppur								
Keldudalur	1993	KD-2	E	104	15.8			
Fljótahreppur								
Lambanes-Reykir	1990	LN-14	P A	406	74.3		15	70
Siglufjörður								
Skarðdalur	1990	SF-12	E	200	34.5			
Skarðdalur	1990	SF-13	E	204	54.3			
Skarðdalur	1990	SF-14	E	125	29.2			
Skarðdalur	1990	SF-15	E	107	24.7			
Skarðdalur	1990	SF-16	E	360	70.3			
EYJAFJARÐARSÝSLA								
Árskógshreppur								
Ytri-Vík	1994	YV-1	E	153	51.6			
Glæsibæjarhreppur								
Laugaland	1990	LL-9	E	367	65.6			
Laugaland	1992	LL-10	E	914	87.4			
Laugaland	1992	LL-11	P P	454	90.2		15	200
Eyjafjarðarsveit								
Sigtún	1993	ST-1	E	108	28.8			
S-ÞINGEYJARSÝSLA								
Skútustaðahreppur								
Gautlönd	1991	GL-1	P A	945	65.5		25	0
N-ÞINGEYJARSÝSLA								
Öxarfjarðarhreppur								
Núpur	1990	NÚ-15	P	217	39		115	1
Núpur	1990	NÚ-16	P	145	21		115	1
Núpur	1990	NÚ-17	P	200	20		250	1
Ærlækjarsel	1991	ÆR-4	E	455	150.1		10	0

TABLE 8. (continue

Locality	Year Drilled	Well Number	ſype o Well"	Total Depth m	Max. Temp. °C	Fluid Enthalp) kJ/kg	Well Output[2] low Rat kg/s	Draw-down m
N-MÚLASÝSLA								
Jökuldalshreppur								
Vaðbrekka	1990	VB-2	E	143	13			
Aðalból	1990	AB-2	P A	97	29.9		1	0
\-SKAFTAFELLSSÝSLA								
Nesjahreppur								
Miðfell	1992	ASK-29	E	137	25.4			
Miðfell	1993	ASK-33	E	179	25			
Mibfell	1993	ASK-57	E	246				
Krossbær	1992	KB-1	E	164	20.6			
Krossbær	1993	KB-4	E	179				
Krossbær	1994	KB-5	E	327				
/-SKAFTAFELLSSÝSLA								
Mýrdalshreppur								
Höfðabrekka	1990	HI-1	E	102	7.1			
Skaftárhreppur								
Heiðarsel	1993	HS-1	E	100	13.2			
ιANGÁRVALLASÝSLA								
A-Eyjafjallahreppur								
Raufarfell	1993	RF-1	E	106	17.5			
Raufarfell	1994	RF-2	P	681	75.9			
Skarðshlíð	1994	SK-2	E	450	42.1			
Fljótshlíðarhreppur								
Núpur	1992	Nu-1	E	304	28			
Holta- og Landssveit								
Kaldárholt	1990	KH-6	E	122	58			
Kaldárholt	1990	KH-7	E	128	55.6			
Kaldárholt	1990	KH-8	E	130	48.9			
Kaldirholt	1990	KH-9	E	116	64.7			
Kaldárholt	1990	KH-10	E	117	61.4			
Efri-Rauðalækur	1994	LA-3	E	145	14.8			
ιRNESSÝSLA								
Selfoss	1991	SE-14	E A	136	68.2		0.3	0
Selfoss	1992	SE-20	E A	128	67.8		0.8	0
Selfoss	1992	SE-22	E A	119	68		0.7	0
ſraungerðishreppur								
Sölvholt	1990	SH-2	P	275	56		0	0
Sölvholt	1990	SH-3	P	374	59.2		4	50
Þorleifskot	1994	HT-1	E	247	23.5			
Porleifskot	1994	H1-2	E	122	35.4			
Porleifskot	1994	H1-4	E	122	22.8			
Þorleifskot	1994	HT-7	E	122	16			
Porleifskot	1994	HT-10	E	166	33.1			
Villingaholtshreppur								
Flaga	1991	FL-3	E	105	18.4			
Kolsholt	1993	KH-10	E	105	35.4			
Kolsholtshellir	1993	HH-1	E	125	16.9			
Skeiðahreppur								
Hlemmiskeið	1990	HS-6	P	335	74.2		10	2

TABLE 8. (continue

Locality	Year Drilled	Well Number	'ype of Well')	Total Depth m	Max. Temp. °C	Fluid Enthalpy kJ/kg	Well Output[2)] low Rat kg/s	Well Output[2)] Draw-down m
Irunamannahreppur								
Galtafell	1990	GF-5	P	342	33.4		>20	10
Ásatún	1991	ÁT-1	P	354	70		10	10
Þórarinsstaðir	1993	PS-1	P	464	128.2		5	15
Flúðir	1994	FL-8	P A	274	105.1		35	2
Efra-Sel (Borgarás)	1994	BS-2	P P	1063	94.8		5	100
Sóleyjarbakki	1994	SB-1	P	582	31.7		80	5
iskupstungnahreppur								
Brautarhóll	1991	BR-3	E	114				
Stóra-Fljót	1991	RH-4	P A	1146	128.8		12	0
Miklholt	1992	MH-7	P	401	117.5		>5	10
Neðri-Dalur	1991	N1-3	E	600	106			
Neðri-Dalur	1993	ND-4	E	173				
Neðri-Dalur	1993	ND-5	P	302			4	0
Helludalur	1994	HD-2	P	360	117.8		2	0
augardalshreppur								
Böðmóðsstaðir	1991	BS-10	E	483	120.8			
Böðmóðsstaðir	1992	BS-11	P	1095	130		0	0
Böðmóðsstaðir	1992	BS-12	E	200	104.2			
Böðmóðsstaðir	1992	BS-14	E	122	55			
Böðmóðsstaðir	1992	BS-15	E	159	91.3			
Böðmóðsstaðir	1992	BS-16	E	225	110.1			
Böðmóðsstaðir	1992	BS-17	E	182	105			
Böðmóðsstaðir	1992	BS-18	E	158				
Böðmóðsstaðir	1992	BS-19	E	158	81.3			
Böðmóðsstaðir	1993	BS-20	P	900	126.7		0	0
rímsneshreppur								
Brjánsstaðir	1990	BS-3	E	61	9.5			
Brjánsstaðir	1990	BS-4	E	61				
Brjánsstaðir	1991	BS-5	P P	1156	120		3	70
Minni-Bær	1990	MB-1	E	61	12			
Hestur	1990	GS-5	E	210	6.2			
Öndverðarnes	1990	ON-12	P P	360	79.9		30	35
Öndverðarnes	1991	ON-18	P	110	81.1		10	20
Ormsstaðir	1993	os-2	P	548	105.7		3	0
Ormsstaðir	1993	OS-3	P	463	95.6		4	0
Eyvík	1993	EV-8	P	642	127.6		6	0
Bjarnastaðir	1993	BJ-1	E	856	69			
lfushreppur								
Hveradalir	1993	HD-5	P	98				
Laugarbakkar	1994	LB-16	E	294	80.3			
Laugarbakkar	1994	LB-17	E	219	47.8			
Laugarbakkar	1994	LB-18	E	303	70.4			
Laugarbakkar	1994	LB-19	E	320	81.5			
Laugarbakkar	1994	LB-20	E	291	79.9			

SUMMARY OF TABLE 8.

Type of Well	Number of Wells	Total Depth (m)
Production Wells	69	31043
Exploration Wells	100	22992
Total	169	54035

TABLE 9. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with a University degree)

(1) Government
(2) Public *Utilities*
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Programs
(6) Private Industriy

Year	Professional Man Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
1990	35	26	5			35
1991	34	27	5			35
1992	33	28	6			32
1993	33	29	6			30
1994	33	30	7			30

TABLE 10. TOTAL INVESTMENTS IN GEOTHERMAL IN (1994)US$

Period	Research & Development Incl. surf. Exp. & Exp. Drilling Million US$	Field Development Incl. Prod Drilling & Surf. Equipment Million US$	Utilization		Funding Type	
			Direct Million US$	Electrical Million US$	Private %	*Public* %
1975 - 1984	37	81				
1985 - 1994	30	34	178	7		100