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GEOTHERMAL DEVELOPMENT IN ICELAND 1995-1999

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ABSTRACT

Geothermal energy plays an important role in the energy supply of Iceland. It provides about 50% of the total primary energy supply while the share of hydropower is 18%, oil 30% and coal 2%. The principle use of geothermal energy in Iceland is for space heating; about 86% of all energy used for house heating comes from geothermal resources. The share of geothermal heating is still slowly growing. A recent development is a 7 MWt district heating scheme for the village Stykkisholmur which started operation in 1999.

An expansion in the energy intensive industry in Iceland the last years has increased the electricity demand considerably. This has been met partly by increased geothermally produced electricity. A second turbine unit, 30MWe, was installed at Krafla power plant in 1997, bringing the capacity of the plant up to 60 MWe. At Nesjavellir high temperature field, Reykjavik District Heating (now Reykjavik Energy) has been operating a plant producing hot water since 1990. In 1998 the plant was expanded by installation of two turbine units for electricity generation with a total capacity of 60 MWe. The Svartsengi co-generation power plant has been expanded and partly reconstructed. After the installation of a new 30 MWe unit for electricity generation in late 1999 the installed capacity of the plant is 200 MWt for hot water production and 45 MWe for electricity generation. Thus the total capacity of geothermal power plants in the country has increased from 50 MWe to 170 MWe in about two years time. In 1999 15.8% of the total electricity generation in the country was based on geothermal energy.

The paper gives a summary of the main utilization sectors for geothermal energy which besides space heating and electricity generation are: swimming pools, snow melting, industrial uses, greenhouses and fish farming. Figure 1 showes how the uses are devided on the different utilization sectors.

1. INTRODUCTION

The geothermal resources in Iceland are closely associated with the country's volcanism and its location on the Mid-Atlantic Ridge. The high-temperature resources are located within the active volcanic zone running through the country from southwest to northeast, while the low-temperature resources are mostly in the areas flanking the active zone. About two thirds of the population live in the southwestern part of the country, where geothermal resources are abundant.

To date about 250 separate low-temperature areas with over 600 hot springs (temperature over 20°C) have been located. There exist moreover at least 26 high-temperature areas with steam fields. The high-temperature areas are directly linked to the active volcanic systems.

The annual primary energy supply in Iceland, which has a population of 279,000, is 121 PJ or 434 GJ per capita, which is higher than in any other country. Geothermal energy provides about 50% of the total, hydropower 18%, oil 30% and coal 2%. Thus about two thirds of the energy supply of the country come from indigenous renewable energy sources. It is estimated that the total direct heat uses of geothermal energy in Iceland in 1999 was 20,170 TJ and the corresponding installed capacity 1,469 MWt.

The availability of geothermal energy has influenced strongly the standard of living in Iceland. The economic benefits of using geothermal energy for space heating instead of fossil fuels are significant, as it saves annually about 100 million US$ in imported oil. Besides financial savings the environmental benefits are of great importance. It has been estimated that house heating by fossil fuels would cause release of CO_2 to the atmosphere of the same order of magnitude as the total release of CO_2 by human activity in Iceland today (Palmason, 1997).

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, high priority was given to replacing imported oil with the indigenous energy sources hydro and geothermal. Today about 86% of the space heating is by geothermal energy, the rest is by electricity (12%) and oil (2%). The total geothermal energy used for space heating in Iceland is about 15,600 TJ per year.

In 1998 the Ministry of Industry started a two year project to encourage geothermal exploration for domestic heating in areas where geothermal resources have not been identified, so-called "cold areas" (Torfason, 2000). A total amount of 800,000 US$ have been granted for this purpose and used mainly for drilling 50-100 m deep thermal gradient exploration wells. This method has proved to be a successful exploration technique in Iceland. Positive results of the project are recorded and the new district heating scheme in Stykkisholmur is the result of applying this exploration method. The increased use of geothermal resources will reduce the public subsidies for house heating with electricity, which at present is about 9 million US$ per year.

2.1 Reykjavik

Reykjavik District Heating (Hitaveita Reykjavikur), which is by far the largest of the 26 municipally owned geothermal district heating system in Iceland, was formally established in 1943. However, the history of district heating in Reykjavik dates back to 1930. Reykjavik District Heating utilizes low-temperature areas within and in the vicinity of Reykjavik as well as the high-temperature field at Nesjavellir, about 27 km away. Today it serves about 160,000 people or practically the whole population in Reykjavik and four neighboring communities, see table 1.

Over the past decade Reykjavik District Heating has experienced almost constant total water consumption per year. In the same period the number of people served and total volume of houses has increased by 15-20%. Thus the specific energy use, measured as annual water consumption per house volume, has decreased considerably. The main reason for this is better controlled heating systems, better insulation of houses and increased energy awareness. Similar reductions in water consumption have been observed in other district heating systems as results of changes in tariff systems from a system based on maximum flow restriction to a system based on metering the quantity of water used.

On the 1st of January 1999 a new energy company was established by the merger of Reykjavik District Heating and Reykjavik Electricity. The new company is called Reykjavik Energy (Orkuveita Reykjavikur) and is responsible for distribution and sale of both hot water and electricity in the city. The total number of employees is 490 and the annual turnover 125 million US$.

2.2 Stykkisholmur

A new geothermal district heating system for the village Stykkisholmur in W-Iceland started in 1999 (Thermie project information brochure, 2000). Stykkisholmur is a trading centre and fishing village with 1,300 inhabitants. It is located in an area where no manifestations of geothermal energy are seen on the surface. The method used to locate the geothermal field consisted of drilling a grid of shallow thermal gradient wells in an 3 km long and 1 km wide area. A geothermal resource was located and the reservoir fluid is a geothermal brine at 87°C. Because of the mineral content the geothermal water can not be used in a direct throughflow heating system as commonly used in Iceland.

The production well is located about 5 km outside the village. By a variable speed submersible well pump, the water is pumped through a pre-insulated steel pipe to a central heat exchange building situated in the centre of the village (see Figure 2). This building houses the required distribution pumps, a bank of heat exchangers and the control equipment for the primary and secondary systems. The installed capacity of the system is 7 MWt. The geothermal water exiting from the heat exchangers will be used in part for therapeutic bathing in the municipal swimming pool before disposal to the ocean.

The secondary system is a closed loop. The water in the loop is carefully de-aerated to avoid pit corrosion in piping and radiators. Domestic hot water is provided by heating potable cold water from the village's mains via a small heat exchanger installed in each house.

The total cost of the Stykkisholmur project is about 6 million Euros (5.9 million US$). The European Union contributes 40% of the innovative portion of the project, or 470,000 Euros, through the Thermie Fourth Framework Programme.

At the end of 1999, the construction of the district heating system was almost completed and it is expected to be fully operational in the autumn 2000.

2.3 Husavik

A geothermal district heating system has been in operation in Husavik since 1970. Husavik is a small town in N-Iceland with about 2,500 inhabitants. The water comes from the Hveravellir geothermal area, partly from artesian wells with 125°C hot water and partly from hot springs that discharge about 100°C hot water. The Hveravellir fluid has been flashed to 100°C on site and the hot water gravity fed through a 18 km long asbestos pipe to the town. The pipe is only insulated by soil. In Husavik, it is used for space heating, drying and also to heat greenhouses and farmhouses in the district. Some 15°C are lost on the way to town and significant thermal energy is lost in the flashing. The geothermal fluid contained within the reservoir is suited to direct use.

A steady growth in the demand for 80°C hot water for space heating, industry and health use in Husavik, as well as the need for overhauling the old transmission pipeline led to the decision of a major renewal of the geothermal hot water supply (Thermie project information brochure, 2000). The renewal project started in 1999 and is planned to be completed in the middle of the year 2000. An important part of the highly innovative project is to combine in one system the generation of electricity and the provision of hot water for industrial applications, agricultural and heating purposes. The integrated system will vastly improve the efficiency in the utilization of the thermal energy.

The 125°C geothermal fluid from the production wells will be transported under pressure to the Energy Centre located in the town. The pipeline will constitute a buried thermally insulated steel pipe laid along the old pipe for most of the way. The temperature loss on the 20 km way will be some 2°C.

The Energy Centre building houses a Kalina Binary Electric Power Plant. It also houses banks of heat exchangers and control equipment. The calculated output of the electrical plant is 2 MWe, which is sufficient to meet 75-80% of the town's electric power demand. From the Energy Centre water of the appropriate temperature and quantity will be piped to the different industrial users and to the Husavik District Heating. Figure 3 shows in a simplified diagram the new supply system and the highly diversified utilization planned.

The total investment for the Husavik project is estimated at 10.4 million Euros (10.2 million US$). The Husavik Municipality finances 91.6%, other project partners 1.9% and the remainder comes from the European Union, which contributes 40% of the innovative portion of the project, or 663,000 Euros, through the Thermie Fourth Framework Programme.

2.4 Arskogsstrond

In December 1998 a new geothermal district heating system started operation at Arskogsstrond in N-Iceland. It is operated by the district heating system in the neighbour community Dalvik. After several years of exploration, which included drilling of about 30 shallow thermal gradient wells, a succcessful drilling of a production well was performed in October 1997. The well is situated midway between two small villages with a total population of 270 people. The well is 443 m deep and gives at least 20 l/s of 75°C hot water. The estimated annual hot water demand is 120,000 m^3 which correspnds to a mean flow rate of 3.8 l/s. The replacemant of electrical heating by geothermal heating has lowered the heating cost in Arskogsstrond by approximately 40%.

2.5 Akureyri

A two-year reinjection experiment was completed in late 1999 in the Laugaland geothermal system in N-Iceland (Axelsson et al., in press). This is a low-temperature field utilized for district heating in the town of Akureyri, which has about15,000 inhabitants. Because of a low overall permeability and limited recharge, a great pressure drawdown has been observed in the reservoir since the production started in 1977. However, more than sufficient thermal energy is stored in the 90-100°C hot rocks of the system. The purpose of the reinjection was to demonstrate that energy production from fractured low-temperature geothermal systems might be increased by reinjection.

The Laugaland reinjection experiment was a co-operative project involving a few companies and institutions in Iceland, Sweden and Denmark, partly supported by the European Union. Between 6 and 21 kg/s was injected into two reinjection wells. A comprehensive monitoring program, including seismic monitoring, was implemented as part of the reinjection project. In addition several other tests and well logging were performed. Results of the experiment indicate that reinjection will be a highly economical mode of increasing the production potential of the Laugaland system and reinjection is expected to be an important part of the management of the Laugaland reservoir for decades to come.

In 1984, Akureyri District Heating installed two heat pumps, 1.3 MWt each. They used return water from the district heating system, partly as a heat source and partly as new supply water. The heat pumps had been running about 5,500 hours every year and contributed about 3% to the annual hot water production when they were replaced by two new heat pumps in 1998. Because of considerable lowering of the aveage return water temperature from the district heating system since the old heat pumps were installed, they were no longer running at the design conditions and thus not so efficient as desirable. The new heat pumps are 1.9 MWt each and designed for a COP-factor of 4.75. They use ammonia as refrigerant. The old heat pumps used freon (F-12) as refrigerant. It is now prohibited to use freon as refrigerant in Iceland.

3. SWIMMING POOLS

From the time of settlement of Iceland some 1,100 years ago until early in this century, the use of geothermal energy was limited to bathing, washing of clothing and cooking. These uses are today still significant and heating of swimming pools is the third most important type of use after space heating. 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 m^2. Most of the public pools are open-air pools in constant use throughout the year. The pools both serve for recreational use and for swimming instruction, which is compulsory in schools. Swimming is very popular in Iceland and in the greater Reykjavik area alone there are ten public outdoor pools and three indoor ones. The largest of these is the Laugardalslaug, having a surface area of 1,500 m^2 and five hot tubs in which the water temperature ranges from 35 to 42°C. Other health uses, such as the Blue Lagoon, the Health Facility in Hveragerdi comprising geothermal clay baths and water treatments, are gaining popularity.

In the last five years, about ten new geothermally heated public swimming pools have been built in Iceland. Most of them have replaced older and smaller pools. The annual water consumption varies a lot from one pool to another, but typically about 220 m^3 of water or 40,000 MJ of energy is needed annually for heating one m^2 pool surface area. The total annual water consumption in geothermally heated swimming pools in Iceland is estimated to be 6,000,000 m^3 which corresponds to an energy use of 1,100 TJ per year.

4. SNOW MELTING

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 the houses, at about 35°C, is commonly used for deicing of sidewalks and parking spaces. Most systems have the possibility to mix the spent water with hot water (80°C) in periods when the load is high. Under an extensive rehabilitation of the streets in downtown Reykjavik few years ago, a snow-melting system was installed in the sidewalks and streets, covering an area of 40,000 m^2. This system is designed for a heat output of 180 W per m^2 surface area.

The total area now covered by snow melting systems in Iceland is estimated to be 350,000 m^2, of which about 250,000 m^2 are in Reykjavik. The annual energy consumption is strongly dependent on the weather conditions, but in the average it is estimated to be 325 kWh/m^2. Of that about two third come from spent water from the houses and one third from 80°C hot water (Johannesson, 2000). The total geothermal energy used for snow melting is estimated to be 410 TJ per year.

5. INDUSTRIAL USES

Industrial uses of geothermal steam on a large scale started in Iceland in 1967 by the establishment of Kisilidjan, the diatomite plant at Myvatn near the Namafjall high-temperature field. The plant is one of the world's largest industrial users of geothermal steam and produces annually some 20-30 thousand tonnes of diatomite filter aids for export. The raw material is diatomaceous earth found on the bottom of Lake Myvatn. Access to a stable and inexpensive supply of geothermal steam has made it possible for this unique process to compete successfully with conventional processes based upon surface mining of dry diatomite deposits. The geothermal steam is mainly used for drying, but also for other purposes such as pre-heating of fuel oil and diatomite slurry, space heating, deicing of holding pond and loading area and for dust elimination.

The average diatomite production for the last 5 years has been about 27 thousand tonnes per year and the annual steam consumption about 270 thousand tonnes or 10 tonnes of steam at 10 bar absolute (180°C) per tonne of diatomite. This corresponds to an energy use of 521 TJ per year. The steam drying system has been operated problem free and with minimal maintenance for over thirty years. The plant, which employs about 50 people, has been rationalized during the past few years in order to reduce the production cost. The future of the plant is uncertain because the current mining license in Lake Myvatn will run out in a few years time and expansion of the mining activity meets opposition from nature conservationists.

At Reykholar, a seaweed processing plant uses geothermal water for drying. About 28 l/s of 107°C hot water are used and cooled down to 50°C. The annual use of geothermal energy in the plant is about 150 TJ. The annual production of seaweed and kelp has been 2,000-4,000 tonnes per year since the start of the production in 1976.

On the Reykjanes Peninsula, a salt plant was in operation for more than twenty years, but was closed down in 1994. From geothermal brine and seawater the plant produced salt for the domestic fishing industry as well as low-sodium health salt for export. In 1999 a part of the plant was restarted for salt production on a small scale and full operation of the plant is now under preparation.

The most recent industrial application is drying of hardwood in Husavik. This plant has been in operation since 1996. Hardwood logs are transported from North America to Husavik where they are sawn and kiln dried with geothermal hot water. In the beginning the products were mainly exported to Europe without further processing. After financial difficulties the plant was reorganized in 1999 with emphasis on further processing of the hardwood as floor parquet, until now mainly for the domestic market.

In addition to the above mentioned industrial uses of geothermal energy one could mention drying of fish at several locations, retreading of car tires and wool washing in Hveragerdi, curing of cement blocks at Myvatn and steam baking of bread at several locations. Also several small companies use geothermal water for industrial purposes, most of them buying their water from the district heating services around the country. The total geothermal energy used as process heat in industry in Iceland is estimated to be 1,600 TJ per year. This is a reduction of 400 TJ compared to 1994, caused by the reduced production in the salt plant at Reykjanes.

5.1 Haedarendi

A plant for the commercial production of liquid carbon dioxide (CO_2) has been in operation at Haedarendi in the Grimsnes district of southern Iceland since 1986. The geothermal field has an intermedium temperature (160°C) and very high gas content (1.4% by weight). The gas discharged by the well is nearly pure carbon dioxide with hydrogen sulfide concentration of only about 300 ppm (Bjarnason, 1999).

Upon flashing, the fluid from the Haedarendi well produces large amounts of calcium carbonate scaling. Scaling in the well is avoided by a 250 long downhole heat exchanger, made of two coaxial steel pipes. Cold water is pumped down through the inner pipe and back up on the outside. By this the geothermal fluid is cooled down and the solubility of calcium carbonate raised sufficiently to prevent scaling.

At the end of 1997 the production of CO_2 was increased from 40 kg per hour to 250 kg per hour, which is sufficient to meet current industrial demand in Iceland (about 2,000 tonnes per year). The production process is basically composed of four stages, cleaning, compression, dehumidification and storage. The carbon dioxide from Haedarendi is used in greenhouses, soft drink production and other food industries.

6. GREENHOUSES

Geothermal heating of greenhouses started in Iceland in 1924. Before that time, naturally warm soil had been used for growing of potatoes and other vegetables. The greenhouse production is divided between different types of vegetables (tomatoes, cucumbers, paprika etc.) and flowers for the domestic market (roses and other flowers, potted plants etc.). The total area under glass has increased slowly the last years and is now about 183,000 m^2. Of this area 55% are used for growing vegetables and 45% for growing flowers. In addition it is estimated that about 105,000 m^2 are used for soil heating. The majority of the greenhouses are in the southern part of Iceland. Most greenhouses are glass covered, but plastic film does not stand up well in the windy climate (Thorhallsson, 1999). The heating installations are by unfinned steel pipes hung on the walls and over the plants. Undertable or floor heating is also common. Many greenhouse farmers have lately changed from direct throughflow heating systems to closed loop systems with heat exchangers. By this significant energy savings have been obtained as well as improved control of the greenhouse climate.

Over the last few years artificial lighting and CO_2 enrichment has gained popularity along with growing the plants in inert growing media (volcanic scoria, rhyolite) on concrete floors with individual plant watering. The artificial lighting has practically doubled the crop yield and allowed year-around production, but at considerable extra expense in electricity, gas and labor. The CO_2 gas used in greenhouses originates mainly from the geothermal plant at Haedarendi.

Soil heating has the main benefit of early thawing of the soil and the vegetables can be brought to market sooner. Similar results are commonly obtained at a lower cost by covering the plants by plastic sheets. Therefore there has not been an increase in soil heating the last years.

The total geothermal energy used in the greenhouse sector in Iceland is estimated to be 790 TJ per year.

7. FISH FARMING

In the middle of the 1980s, an explosive growth in fish farming took place in Iceland and for a period there were over 100 fish farms in operation, many of them quite small. The industry encountered early problems and many of the farms suffered financial difficulties. At present there are about 50 fish farms in operation in the country. Salmon is the main species with about 70% of the production but arctic char and trout are also raised. Geothermal water is used mainly in the hatchery stage.

Three different types of salmon farms exist in Iceland, namely ocean ranching, shore based fish ponds and floating fish cages (Eliasson, 1999). Ocean ranching is based upon raising the salmon for a year or so in tanks on land and then release it to the open sea and wait for it to return to the same source when it has reached maturity in 2-3 years time. Ocean ranching did, however, not prove successful over the long run as the number of returning fish dropped to 2-3% (Thorhallsson, 1999). In shore based fish farming geothermal water is used for the hatchery and growing out stage. Then the water is gradually changed from freshwater to seawater in which the salmon is raised to market size. Geothermal water, commonly 20-50°C, is used to heat fresh water in heat exchangers, typically from 5 to 12°C. Farming fish in cages floating along the shore can only be carried out in a few sheltered places and only for a limited period in the year. Therefore the fish is often raised for a few months in summer in the floating cages and for the rest of the year in shore based fish ponds.

Shore based fish farming requires large consumption of both freshwater and seawater and this adds considerably to the operating cost. Recent advances have been made in reducing the electricity consumption by cutting down on the waterchanges by injecting pure oxygen into the water.

The total production in fish farms in Iceland has been slowly increasing the last years to about 4,000 tonne per year. In the same period the number of farms in operation has reduced from about 70 to 50. The total geothermal energy used in the fish farming sector in Iceland is estimated to be 650 TJ per year.

8. GEOTHERMAL ELECTRIC POWER GENERATION

An expansion in the energy intensive industry in Iceland in recent years has increased the electricity demand considerably. This has been met partly by increased geothermally produced electricity. The total capacity of geothermal power plants in the country has increased from 50 MWe to 170 MWe in about two years time. Of the total electricity generation of 7,185 GWh in 1999, 1,138 GWh or 15.8% came from geothermal energy, 84.1% from hydro and 0.05% from fuels. Figure 4 shows the geothermal generation of electricity in Iceland in the period 1970-1999.

8.1 Bjarnarflag

A geothermal power plant with one 3 MWe back pressure unit started operation in Bjarnarflag (Namafjall field) in 1969. This field also supplies steam to the Kisilidjan diatomite plant. The power plant has been operated successfully ever since the beginning 30 years ago except for three years in 1985-1987 when the plant was closed, partly due to volcanic activity in the area. 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 electricity generation of the Bjarnarflag power plant in 1999 was 18 GWh.

8.2 Krafla

The Krafla power plant in N-Iceland has been in operation since 1977. Two 30 MWe double flash condensing turbine units were purchased in the beginning, but because of inadequate steam supply the plant was run with only one of them installed for 20 years. The shortfall of steam was in part due to volcanic activity in the area which caused contamination of the geothermal fluids by the volcanic gases. This again caused operational problems in some of the production wells, mostly in the form of rapid scaling of complex iron silicates and also corrosion in the wells. Exploration drilling in the area has shown that the concentration of magmatic gases in the steam has decreased drastically.

The plant operated successfully with one unit installed for 20 years in spite of nine volcanic eruptions, the last one in September 1984. Initially the power generation was 8 MWe, but reached 30 MWe in 1982. In 1996 it was decided to install the second unit and drilling of 4 new production wells started. In late 1997 the plant started production at the designed 60 MWe capacity.

Several production zones have been identified within the geothermal system in Krafla with large variation in temperature ranging from 210 to 350°C. Steam is separated from the water in two stages, at 7.7 and 2.2 bar absolute, to provide 120 kg/s high pressure steam and 30 kg/s of low pressure steam. The total electricity generation of the Krafla power plant in 1999 was 484 GWh.

8.3 Nesjavellir

At Nesjavellir high temperature field Reykjavik District Heating (now Reykjavik Energy) has been operating a co-generation power plant since 1990. The primary purpose of the plant is to provide hot water for the Reykjavik area 27 km away. Freshwater is heated by geothermal steam and water in heat exchangers. In October 1998 the power plant started electricity generation when a 30 MWe steam turbine was put into operation and a second one of the same size a month later. The working pressure of the turbines is 12 bars (190°C). Five additional wells will be put online, increasing the total hot water production to 200 MWt with the water production (82°C) reaching more than 1,100 l/s. In the condenser the steam is used to preheat cold water from 4°C to 60-70°C. The investment cost of these power plant expansions was about 56 million US$. This increased the efficiency of the plant significantly. Based on the results of reservoir modelling calculations a further expansion of the electricity generation capacity from the present 60 MWe to 76 MWe has now been decided. The total electricity generation of the Nesjavellir power plant in 1999 was 486 GWh.

8.4 Svartsengi

The Svartsengi co-generation power plant has been producing both hot water and electricity since it started operation in 1977. It is located on the Reykjanes peninsula, about 40 km from Reykjavik, and serves about 15,000 people. 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 last few years several improvements and expansions have been done in Svartsengi power plant.

The oldest part of the plant has been totally reconstructed. The main emphasis has been put on increased electricity generation by installing a new 30 MWe unit, thus improving the overall efficiency of the plant considearably. Also the hot water production was increased by some 75 MWt. In connection with this four new wells were drilled in the Svartsengi geothermal field, of that one for reinjection. The total cost of the build-up was about 37 million US$ for the power plant and additional 7.5 million US$ for drilling the new wells.

After the completion of the expansion in late 1999 the total installed capacity of the Svartsengi power plant is 200 MWt for hot water production and and 45 MWe for electricity generation. Of that 8.4 MWe come from Ormat binary units using low-pressure waste steam. The total electricity generation of the Svartsengi power plant in 1999 was 147 GWh.

The effluent brine from Svartsengi is disposed of into a surface pond called the Blue Lagoon. It has for a long time been used by people suffering from psoriasis and other forms of eczema, who seek therapeutic effects from the silica rich brine. Also it is getting increasing popularity by tourists with an annual number of visitors about 170,000, making it one of Iceland's most popular tourist attractions. In July 1999 the Blue Lagoon opened new facilities at a location 800 m from the previous site. They include indoor and outdoor bathing facilities, steam caves, mud pool and restaurants. The new facilities have gained much attraction and are expected to contribute to further increase in the annual number of visitors.

Sudurnes Regional Heating, the owner of the Svartsengi power plant, is operating a 0.5 MWe back-pressure turbine at the salt plant on the Reykjanes peninsula. The electricity generation of the plant in 1999 was 2.3 GWh.

9. OTHER GEOTHERMAL ACTIVITIES

In the period 1991 to 1997 Orkustofnun, in cooperation with some of the largest energy companies, worked on a research project about environmental impacts of geothermal utilization. The study included all high-temperature areas in Iceland. This has stimulated further activity in this field which is now considered as an important part of geothermal projects.

Another research project carried out in cooperation between Orkustofnun and the largest energy companies involves exploration of high-temperature geothermal areas with respect to their potential for electricity generation. The project has been running for several years and includes for example surface explorations in various geothermal fields, TEM resistivity surveys and establishment of a comprehensive data bank of geothermal reservoir coefficients for Icelandic rock types. The project includes also a study of the effects of the location of boreholes for reinjection on the operation of geothermal power plants.

A survey carried out on research and development in the geothermal sector in Iceland showed that in 1996 about 4.2 million US$ were used for that purpose (Idnadar- og vidskiptaraduneyti, 1998). This includes exploration and regular monitoring of geothermal fields. Of the total cost 54% came from the geothermal utilities, 31% from the government and 15% from others. More than half of the geothermal utilitie's share came from Reykjavik District Heating, or 31% of the total. The share of the geothermal utilities corresponds in the average to 2.7% of their annual turnover. Of the total cost 41% was used for what is defined as basic research, 25% for preparation of new plants and 16% for monitoring of geothermal fields. Since 1996 the annual investment cost in geothermal research and development has been a similar amount.

In the period 1995-1999 there has been a high drilling activity in Iceland, especially compared to the previous five-year period. In this period there have been drilled 19 wells in high-temperature areas, most of them for the purpose of increased steam supply for the three main geothermal power plants. About 40 low-temperature wells have been drilled in this period and almost 200 shallow temperature gradient wells for exploration. Figure 5 gives an overview of the drilling activity over the last 30 years.

The Geothermal Training Programme of the United Nations University (UNU) has operated in Iceland since 1979 with six months annual courses for professionals from developing countries. Candidates must have a minimum of one year practical experience in geothermal work in their home countries prior to the training. Specialized training is offered in different geothermal disciplines. The aim of the programme is to assist developing countries with significant geothermal potential to build up groups of specialists that cover most aspects of geothermal exploration and development. Most of the candidates receive scholarships financed by the Government of Iceland and the UNU. From the beginning a total number of 227 scientists and engineers from 35 countries have completed the six month courses. (Fridleifsson, in press).

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Table 1. Reykjavik District Heating 1998

Number of people served	157,430
Volume of houses served	42,607,000 m^3
Water temperature at user end	75°C
Number of wells in use	62
Installed capacity	830 MWt
Peak load 1998	593 MWt
Total pipe length	1,293 km
Water delivered	53,140 m^3/year

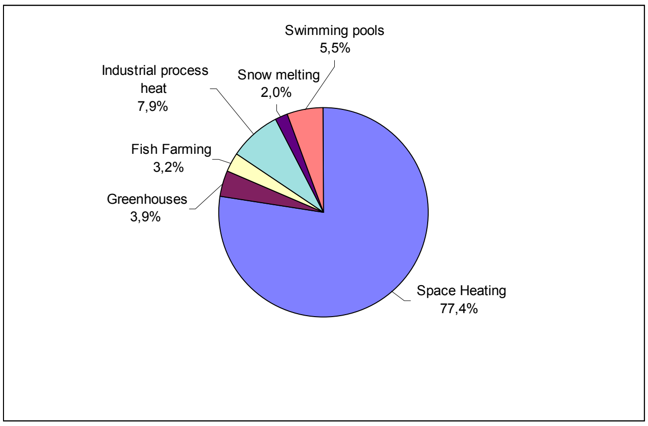

Figure 1. Geothermal direct heat uses in Iceland, classified by sectors.

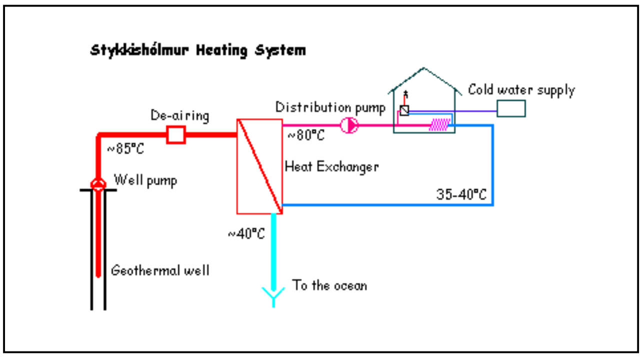

Figure 2. Schematic diagram of the Stykkisholmur heating system.

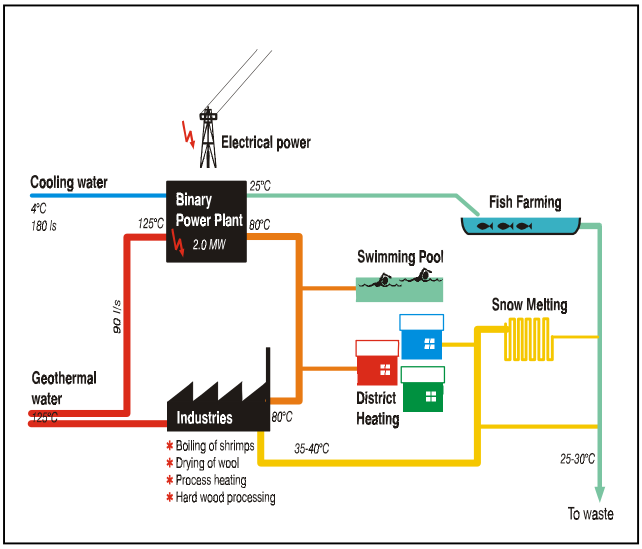

Figure 3. A simplified diagram of the new geothermal supply system and the utilization planned in Husavik.

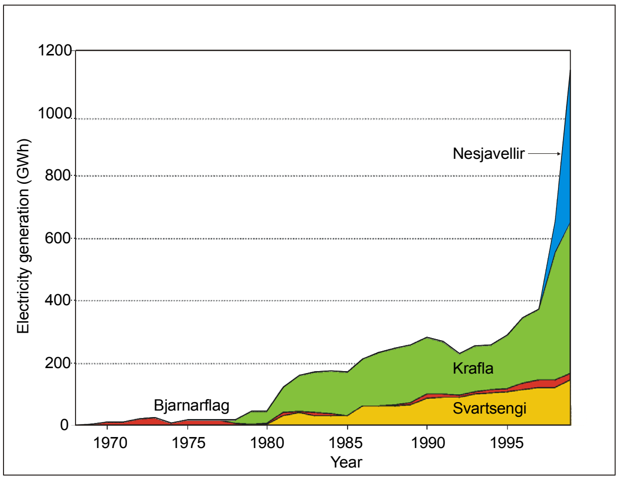

Figure 4. Geothermal generation of electricity in Iceland 1970-1999.

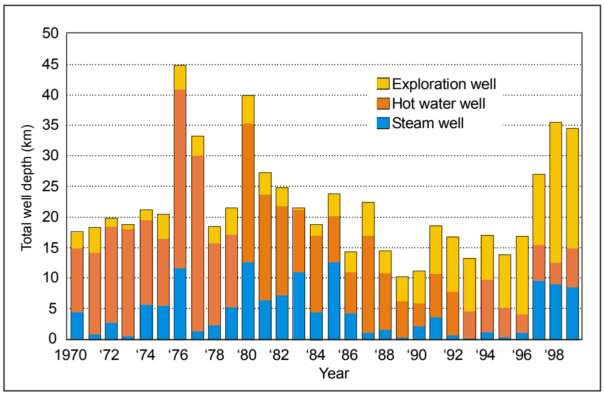

Figure 5. Total depth of geothermal wells drilled annually in Iceland 1970-1999.

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICTY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specifiy)		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	Capacity MWe	Gross Prod. GWh/yr
In operation in January 2000	170	1,320	120	4	1,014	6,400					1,304	7,724
Under construction in January 2000	16	125			120	850					136	975
Funds committed, but not yet under construction in January 2000												
Total projected use by 2005	186	1,445	120	4	1,134	7,250					1,440	8,699

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 1999

1) N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.

2) 1F = Single Flash B = Binary (Rankine Cycle)
2F = Double Flash H = Hybrid
3F = Triple Flash O = Other (please specify)
D = Dry Steam

3) Data for 1999 if available, otherwise for 1998. Please specify which.

Locality	Power Plant Name	Year Commissioned	No. of Units	Status[1]	Type of Unit[2]	Unit Rating MWe	Total Installed Capacity MWe	Annual Energy Produced 1999[3] GWh/yr	Total under Constr. or Planned MWe
Krafla	Krafla	1977/97	2		2F	30	60	484	
Námafjall	Námafjall	1969	1		1F	3.2	3.2	18	
Svartsengi	Svartsengi	1978	2		1F	1	2	13	
Svartsengi	Svartsengi	1981	1		1F	6	6	38	
Svartsengi	Svartsengi	1989/92	7		B	1.2	8.4	60	
Svartsengi	Svartsengi	1999	1		1F	30	30	37	
Reykjanes	Reykjanes	1983	1		1F	0.5	0.5	2	
Nesjavellir	Nesjavellir	1998	2		1F	30	60	486	16
Total			17				170.1	1,138	16

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 1999

1) I = Industrial process heat
C = Air conditioning (cooling)
A = Agricultural drying (grain, fruit, vegetables)
F = Fish and animal farming
S = Snow melting
H = Space heating & district heating (other than heat pumps)
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating
O = Other (please specify by footnote)

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

3) Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (°C) - outlet temp. (°C)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

4) Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

5) Capacity factor = [Annual energy use (TJ/yr) x 0.03171]/Capacity (MWt)
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% of capacity all year.

Locality	Type[1]	Maximum Utilization					Capacity[3]	Annual Utilization		
		Flow Rate	Temperature (°C)		Enthalpy[2] (kJ/kg)			Ave. Flow	Energy[4]	Capacity
		(kg/s)	Inlet	Outllet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5]
Reykjavík	HBGISF	3,897	80	35			734	1,768	10,494	0.45
Seltjarnarnes	HBIS	173	80	35			33	54.5	323	0.31
Mosfellsbær	HBGIS	143	80	35			27	44.4	264	0.31
Suðurnes	HBISF	584	86	35			125	236	1,588	0.40
Akranes og Borgarfj.	HBGF	18	78	35			3	5	28	0.28
Akranes	HBGIS	120	78	35			22	44.1	250	0.37
Borgarnes	HBGIS	48	82	35			9	20.7	128	0.43
Stykkishólmur	HB	40	80	35			8	16.9	100	0.42
Reykhólar	HBG	15	95	35			4	3.4	27	0.23
Suðureyri	HB	10	81	35			2	4.6	28	0.46
Laugarbakki	HBG	6	95	35			2	2.1	17	0.35
Hvammstangi	HB	31	77	35			5	11.5	64	0.37
Blönduós	HB	50	64	35			6	20.6	79	0.41
Skagafjörður	HBGIS	190	72	35			29	78.2	382	0.41
Siglufjörður	HBI	35	70	35			5	16.8	78	0.48
Ólafsfjörður	HBI	93	62	35			11	36.9	131	0.40
Dalvík	HBISF	88	62	35			10	30.9	110	0.35
Hrísey	HB	20	79	35			4	9.4	55	0.47
Akureyri	HBIS	306	78	35			55	133	754	0.43
Húsavík	HBIF	92	87	35			20	43.7	300	0.47
Reykjahlíð	HB	24	99	35			6	9.7	82	0.40
Egilsstaðir	HBGIS	64	73	35			10	24.1	121	0.38
Rangæinga	HBI	28	74	35			5	13.1	67	0.47
Brautarholt	HBG	7	70	35			1	2.2	10	0.31
Flúðir	HBGI	95	98	35			25	36.4	302	0.38
Laugarás	HGI	70	100	35			19	27.9	239	0.40
Laugarvatn	HBG	30	93	35			7	11.6	89	0.39
Selfoss	HBI	202	74	35			33	73.5	378	0.36
Hveragerði	HBGI	143	85	35			30	52.3	345	0.37
Þorlákshöfn	HBIF	46	94	35			11	23.6	184	0.51
Reykhólar	I	35	107	50			8	20	150	0.57
Húsavík	I	3	82	35			1	1.5	9	0.50
Kísiliðjan, Mývatn	I	9	180		2,778	419	21	7	521	0.78
Reykjanes	I	4	180		2,778	419	9	1.5	112	0.38
Other users	HBGISF	900	80	35			169	397.9	2,362	0.44
TOTAL		7,619					1,469	3,283	20,170	0.44

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF DECEMBER 1999

This table should report thermal energy used (i.e. energy removed from the ground or water) and not the heat rejected to the ground or water in the cooling mode.

1) Report the average ground temperature for ground-coupled units or average well water or lake water temperature for water-source heat pumps
2) Report type of installation as follows: V = vertical ground coupled
H = horizontal ground coupled
W = water source (well or lake water)
O = others (please describe)
3) Report the COP = (output thermal energy/input energy of compressor) for your climate
4) Report the equivalent full load operating hours per year, or = capacity factor x 8760
5) Thermal energy (TJ/yr) = flow rate in loop (kg/s) x [(inlet temp. (°C) - outlet temp. (°C)] x 0.1319
or = rated output energy (kJ/hr) x [(COP - 1)/COP] x equivalent full load hours/yr

Locality	Ground or water temp. (°C)[1]	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type[2]	COP[3]	Equivalent Full Load Hr/Year[4]	Thermal Energy Used (TJ/yr = 10^{12} J/yr)[5]
Akureyri	35	1,900	2	O	4.75		16
Grenivík	19		1	W			2
Other							2
TOTAL							20

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 1999

1) Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalphy (kJ/kg)] x 0.001

2) Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

3) Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^6 W)
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% capacity all year

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Space Heating[4]	1,200	15,600	0.41
Air Conditioning (Cooling)			
Greenhouse Heating	45	790	0.56
Fish and Animal Farming	25	650	0.82
Agricultural Drying[5]			
Industrial Process Heat[6]	65	1,600	0.78
Snow Melting	65	410	0.20
Bathing and Swimming[7]	65	1,100	0.54
Other Uses (specify)			
Subtotal	1,465	20,150	0.44
Geothermal Heat Pumps	4	20	0.16
TOTAL	1,469	20,170	0.44

4) Includes district heating (if individual space heating is significant, please report separately)
5) Includes drying or dehydration of grains, fruits and vegetables
6) Excludes agricultural drying and dehydration
7) Includes balneology

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 1995 TO DECEMBER 31, 1999

1) Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1)]	(all)		196			45.2
Production	>150° C	8	3	5	2	28.4
	150-100° C		11			12.5
	<100° C		31			11.7
Injection	(all)			1		
Total		8	241	6	2	97.8

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with a University degress)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributied Through Foreign Aid Programs
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
1995	33	32	6			34
1996	33	33	6			37
1997	33	34	5			40
1998	33	34	5			42
1999	33	34	5			42

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (1999) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1985-1989	20	22	105	0		100
1990-1994	13	15	89	7		100
1995-1999	21	50	63	90		100

15